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FINAL TECHNICAL REPORT

R7111

REVIEW OF POLLUTION OF COASTAL WATERS BY SEDIMENTS AND AGRO-CHEMICALS:-

Issues in watershed management, transfer of agro-pollutants and sediments and their impact in coastal zones

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Final Technical Report
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Review of pollution of coastal waters by sediments and agro-chemicals:-

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Contents

Review of currently available information on pollution of coastal waters by sediments and agro-chemicals: Identification of sources and transport mechanisms, and influence of land use management in the watershed

Executive Summary

1. The Land/Water Interface (LWI) of DFID's Natural Resources Systems Programme (NRSP) is a ten year programme of research, including as one of its geographical foci, the Caribbean region. The purpose of the research as it relates to the Caribbean is:

Livelihoods of communities dependent upon coastal zone production systems understood and incorporated into strategies for planning and management of resource utilisation.

Research Outputs that contribute to this Purpose relate to:

1. Service functions of the coastal zone,
2. Pollution of the coastal zone,
3. Coastal zone management options.

Following wide-ranging consultations in the region, a strategy for LWI research was published in a *Position Paper for Coastal Zone Research in the Caribbean'.*

2. On-going LWI projects are investigating issues related to ecosystem health and economic uses of coral reefs in marine park management in relation to Output 3: "Coastal zone management options understood and impacts on resource base and stakeholders quantified". Preparatory to commissioning new work in relation to Output 2, LWI has funded this comprehensive review of current knowledge in the field of wastal zone pollution. The term ‘pollution’ is used broadly to encompass nutrient enrichment from agricultural origin, agro-chemical pesticides from agriculture, agro-industrial pollution, as well as sediments resulting from soil erosion.

3. The review focuses on currently available information on the quantification of movement of sediments and pollutants of agricultural origin into the coastal zone, and of the impacts of these pollutants and sediments loads on coastal zone resources. It also addresses issues of watershed management as they relate to the generation of these potential pollutants. Furthermore, it identifies knowledge gaps that may be amenable to researchable solutions. The review centres on the Caribbean region, but is informed by research undertaken in other areas, particularly in the context of these process in Small Island Developing States (SIDS) and the priority coastal resources identified in Agenda 21: coral reefs, sea grass beds and mangroves.

4. The problem of agriculturally derived pollution and sediment impacting in the coastal zone is potentially very significant in the Caribbean. The region consists essentially of coastal zone, and many of the watersheds, such as in St Lucia, are hilly. The region experiences many storm events, which appear critical in transfer of sediment and pollutants to the coast. Furthermore, the prioritised living aquatic resources of the coastal zone - coral reefs, mangroves and seagrass beds - are of particular economic and ecological importance in the region. The nature of the oceanography of the Caribbean Basin also makes it prone to accumulation of persistent toxicants.

5. The problem can be viewed as a chain of three inter-linked sets of issues:

- Land use in watersheds, and its relationship to release of sediments and potential pollutants into water courses.
- Transfer of sediments and potential pollutants to the coastal zone.
- Impact of sediments and potential pollutants on living aquatic resources in the coastal zone.

6. There are studies of the damaging effects of eutrophication of coastal waters, coral reef sedimentation and fish kills due to pesticides, however the direct linkage between these downstream impacts and upstream watershed management has not been well demonstrated. 'The transfer pathways and processes lack research. Though acute pulses of pollution due to storm events have been recognised as important, mechanisms for chronic pollution and long-term fluxes are less well

understood. The function of vegetative buffer zones, such as mangroves and wetlands, in mitigating coastal zone pollution has been identified as a gap in the knowledge. Research is also needed into other remediating measures downstream as well as into policy and management options in upstream watersheds aimed at reducing release of potential pollutants.

7. Downstream impacts of potential pollutants and sediments on coral reefs, mangroves and seagrass beds have been in parts well documented. However degradation can have multifactorial causes, and directs effects are not always easy to disaggregate. Anthropogenic causes can also be confounded by natural events such as hurricanes and storms.

8. That eutrophication degrades coral reefs is known. There are several identified mechanisms. The particular sources of N and P loads is however uncertain. Nutrients may come from point or non-point land-based sources or from marine origins (such as cruise ships); land-based sources may be agricultural, industrial or domestic. Studies are required to ascertain that part of the elevated nutrient loads that derive from agricultural sources. Such source-sink studies are required for all the types of potential pollutant covered by this review. There is also a lack of baseline data on environmental quality in relation to levels of these potential pollutants in surface and ground water in watersheds and in the marine coastal zone. A particular aspect of this lack of baseline information is a reported paucity of data on types, sources and quantities of pesticides used in the region; and consequent to this a lack of data on eco-toxicology of some of the newer (non-organo-chlorine) pesticides in use.

9. In summary, particular knowledge gaps exist at the upstream (watershed) and downstream (coral reefs, mangroves and seagrass beds) parts of the land-water interface in the Caribbean region. This includes how different land use options affect the yield of sediments and potential pollutants, and how particular pollutants affect living aquatic resources. The substantive knowledge gaps, where integrative research is most needed appears to be in the relationships between pollution sources and sinks - the processes in the transfer, flux, residence and mitigation of pollutants and sediments as they move from agricultural land to coastal waters.

10. The findings of this review will provide a basis for commissioning research which will contribute to achieving Output 2:

"Pollution by sediments and agrochemicals quantified, sources identified and appropriate management strategies developed in recognition of impacts on stakeholders' livelihoods."

11. In order to provide maximum involvement of local stakeholders the review is being presented as a discussion paper to the OECS-NRMU Regional Watershed Management Workshop in November 1998.

British Geological Survey DFID

REVIEW OF CURRENTLY AVAILABLE INFORMATION ON POLLUTION OF COASTAL WATERS BY SEDIMENTS AND AGRO-CHEMICALS:- IDENTIFICATION OF SOURCES AND TRANSPORT MECHANISMS, AND INFLUENCE OF LAND USE MANAGEMENT IN THE WATERSHED

A report compiled by the British Geological Survey for the UK Department for International Development Land / Water Interface Programme.

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SUMMARY

The objective of this study was to review the currently available information on the movement of sediments and pollutants of agricultural origin into the coastal zone in the Caribbean, with particular emphasis on small island developing states. Information relating to four types of agricultural pollution is presented and assessed: soil erosion leading to siltation, nutrient enrichment, pesticide contamination and agro-industrial pollution. The review was based on scientific literature in the public domain, reports and studies conducted by research institutions and regional organisations. In addition, extensive use was made of searchable databases and information pages on the World-Wide Web. From the review, knowledge gaps have been identified which are amenable to researchable solutions.

The retention of marine pollutants, and thus their impacts on coastal living resources depends on coastal type which is varied throughout the region. There is a paucity of baseline data on turbidity and the concentration of nutrients and pesticides in the coastal zone. However, several published studies have attributed the degradation of coastal living resources to the effects of agricultural pollution (e.g. siltation of coral reefs, eutrophication of nearshore coastal waters and fish kills due to lethal concentrations of pesticides). The oceanographic features of the Caribbean make the region prone to the accumulation of persistent toxicants. Catastrophic events (such as storms and hurricanes) are considered to be critical in sediment dynamics of coastal systems and for pollutants adsorbed to these sediments. No published studies have been identified which assess the role of buffer zones, such as mangroves, coastal wetlands and sediments associated with seagrass beds, but these may act as important sinks for land-derived pollutants.

The increased use of marginal land and poor agronomic practices have led to increased rates of soil erosion in certain areas. However, few studies have linked the increased delivery of sediment into streams to their potential effects in reducing coastal water quality and degradation of coral reefs by siltation. The growth in the use of agricultural fertilisers and pesticides over the last 20 years suggests a concomitant rise in their loads to coastal waters. Only limited data are available to assess: i) the relative proportions of urban sewage and agricultural sources of nitrate and phosphorus in the nutrient loads entering nearshore coastal waters and, ii) pollutant loads derived from agro-industrial sources.

Insufficient research has been undertaken to link agricultural pollution with its potential effects. Without such studies, attempts to combat the potential negative impacts of agricultural activity may incur unnecessary effort and expense. Only by conducting integrated studies which quantify the flux of agricultural pollutants into coastal waters, *and* determine their long-term impacts on coastal living resources, can appropriate remediation strategies be identified. Two specific approaches which aim to achieve this have been suggested as researchable solutions. The first is an integrated catchment approach; the second (possibly as a sub-set of the first) is a more detailed study of the role of buffer zones (e.g. nearshore alluvial sediments, mangroves, coastal wetlands, seagrass beds and their host sediments) as long-term stores of pollutants. Such stores are prone to high contaminant loads which may lead to habitat change or degradation.

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1. INTRODUCTION.

1.1 Background

This study was instigated under the Department for International Development (DFID) Land/Water Interface (LWI) production systems programme for research in coastal zone ecosystems in the Caribbean region. There is concern over the degradation of coastal living resources in the Caribbean region. The causes of this degradation include the impacts of agricultural pollution (CLUWRR, 1996). Pollution from land-based sources is currently calculated to be the single most important threat to the marine environment of the Caribbean and impediment to the use and sustainable development of the coastal zone and its resources (UNEP, 1994). Land-based sources are considered to contribute approximately 77% of the pollution to the oceans: 44% through run-off and 33% via the atmosphere (UNEP, 1992).

Agriculture and tourism are central to the economy of the Caribbean, particularly for small island developing states (SIDS) where the agricultural sector is often one of the largest employers (CIA world factbook, 1996, Annex B). However, the effects of agricultural pollution, such as eutrophication of nearshore coastal waters can have negative impacts on the vital tourist industry if, for example, beaches and coral reefs are considered to be less than pristine. Agricultural pollution can lead to the degradation of coastal living resources, such as the priority coastal living resources identified in Agenda 21 (UNCED, 1992): coral reefs, mangroves and sea grass beds.

Four specific issues concerned with the effects of agricultural pollution in coastal waters will be addressed in this study:

- siltation caused by soil erosion (changing land-use)
- eutrophication caused by increased nutrient loads in agricultural runoff
- toxic effects of pesticides and their accumulation in coastal and marine biota
- agro-industrial pollution

Coastal living resources are particularly vulnerable to degradation in SIDS. This is probably because, in small islands, all activity occurs in the coastal zone, and partly because of their finite resources and their long distance from major markets which places them at an economic disadvantage. Hence, only limited funding is available for the monitoring and protection of coastal ecosystems. The Caribbean region was selected as being representative of the researchable constraints faced by SIDS (CLUWRR, 1996). The objective of this study is to review the currently available information on the movement of sediments and pollutants of agricultural origin into the coastal zone in the Caribbean, with particular emphasis on SIDS. The review is based on scientific literature in the public domain, reports and studies conducted by research institutions and regional organisations. Extensive use was made of searchable databases and information pages on the World-Wide Web; a list of the Web page addresses is provided in Annex B.

The impacts of sediments and agricultural pollutants on coastal living resources in the Caribbean is the subject of an associated study (MRAG, 1998). These two studies (the quantification of agro-pollutants and sediments; and their effects on coastal living resources) will be will be used as a basis for identifying knowledge gaps which are amenable to researchable solutions.

1.2 SIDS of the Caribbean - defining the region.

There are a number of definitions of the countries which constitute the Caribbean. However, this report focuses on SIDS of the CARIFORUM countries, including British Dependent Territories (see Table 1). These countries were considered to be most closely representative of the types of researchable constraints and potential uptake pathways of the LWI programme (CLUWRR, 1996).

1.3 History of marine pollution research and monitoring in the Caribbean.

The most recent regional overview of land-based sources of pollution (UNEP, 1994) indicates that there is a paucity of regional marine and coastal baseline environmental data, for example the concentrations of pollutants such as nutrients and pesticides in freshwater and nearshore coastal waters. This has been attributed not only to economic reasons (see section 1.1) but also to the absence of local staff and institutions to conduct the necessary research (Siung-Chang, 1997). For instance, apart from pioneering work conducted at the University of West Indies in Kingston Harbour (Wade, 1976), there is no history of long-term monitoring in the English-speaking islands. There is also a lack of integrated marine pollution monitoring and research programmes (Ross and DeLorenzo, 1997).

1.4 The degradation of coastal living resources.

Many papers published in the scientific literature have attributed the degradation of coastal living resources in the Caribbean to the effects of agricultural pollution (e. g. Corredor *et al.* 1977; Cortes and Risk, 1985; Tomascik and Sander, 1985, 1987; Lapointe, 1989; Nowlis *et al.*, 1997) or suggested that agricultural pollution may be implicated in such degradation (Rodriguez, 1981; Wells, 1988; Goenaga, 1991; Singh and Ward, 1992; Hallock *et al.* 1993).

Table 1 - Area, population (pop.), agricultural production as a percentage of GDP and percentage of population employed in agriculture in selected mainland and island states of the Caribbean (Source: CIA world factbook (1996, Annex B)).

Caribbean State	Area (km^2)	Pop. (000s)	Agriculture as % GDP	% Population Employed in Agriculture
Anguilla	91	10		<4.0
Antigua and Barbuda	440	66	3.5	11.0
Aruba	193	68		
Bahamas	13,940	259	3.0	5.0
Barbados	430	257	6.4	6.0
Belize	22,960	219	30.0	30.0
British Virgin Islands	150	13		
Cayman Islands	260	35	1.4	
Cuba	110,860	10,951	7.0	20.0
Dominica	750	83	26.0	40.0
Dominican Republic	49,730	8,089	13.0	50.0
Grenada	340	95	10.2	24.0
Guadeloupe	1,780	408	6.0	15.0
Guyana	214,970	712	26.5	33.8
Haiti	27,750	6,732	34.8	66.0
Jamaica	10,990	2,595	7.9	22.5
Martinique	1,100	399	6.0	10.0
Monserrat	100	13	4.8	<8.8
Netherlands Antilles	960	209		
Puerto Rico	9,104	3,819		
St. Kitts and Nevis	269	41	6.2	
St. Lucia	620	158	13.8	43.4
St. Vincent and the Grenadines	340	118	24.0	
Suriname	163,270	436	21.6	
Trinidad and Tobago	5,130	1,272	4.8	11.0
Turks and Caicos Islands	430	14		
U.S. Virgin Islands	352	97		

2. PHYSICAL SETTING

2.1 Geology and Hydrogeology

Broadly speaking, the SIDS of the Caribbean region can be divided into two geological types, volcanic and limestone (Table 2), which control their hydrological and hydrogeological conditions. The Lesser Antilles Island Arc forms two northward-diverging chains of islands formed of calc-alkaline volcanic rocks typical of an orogenic belt at a plate margin over a subduction zone. Such rocks build complex strato-volcanoes which contain poorly permeable lavas and also pyroclastic rocks with a range of permeabilities. Tuffs and reworked volcanics can be permeable and extensive and form potentially useful aquifers, as do the alluvial fans in coastal areas (Figure 1). Robins *et al.* (1990) further subdivided the smaller volcanic islands of the Lesser Antilles into three groups according to the occurrence of groundwater in different geological and topographic settings. Nevertheless, aquifers on the volcanic islands are generally small and surface water dominates in the provision of potable water supplies.

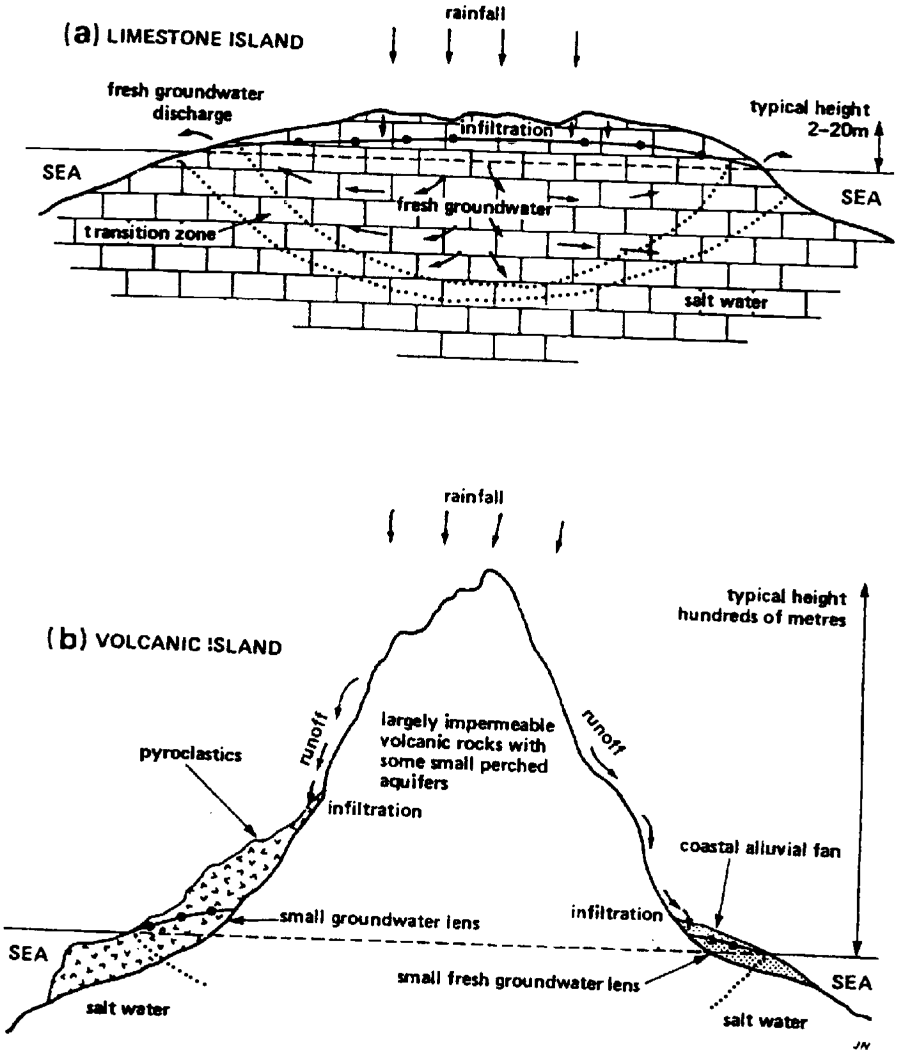

Figure 1- Generalized section through typical limestone (a) and volcanic (b) islands (after Foster and Chilton, 1993)

Many of the volcanic islands contain peaks of above 1000 m elevation (Table 2). They are characterised by high rainfall, which can reach 5000 to 8000 mm yr^{-1} on the upper windward slopes of some of the larger islands, and on lower, leeward slopes is approximately 2000 mm yr^{-1}. Rainfall is intense and often associated with tropical storms and hurricanes. The combination of steep gradients and intensive storm rainfall produces very high runoff, soil erosion and sediment loads in the short streams and rivers.

The limestone islands range from small atolls of very recent coral to much larger expanses of older, elevated limestone. They are characterised by the development of karst. The islands of Cuba, Puerto Rico and Jamaica exhibit large areas of classical and much-studied karstic geomorphology, and some of the smaller islands such as the Bahamas and Barbados have well-known karstic cave systems. In general, the limestone islands are lower in altitude (Table 2). They have lower but still intensive rainfall, much of which infiltrates into the limestone to form important, usually lens-shaped groundwater bodies (Figure 1) on which the populations depend for domestic water supply. Under natural conditions, recharge is adequate to maintain significant groundwater flow towards the coast, but such lenses have to be carefully developed and managed to prevent upconing and saline intrusion.

2.2 Coastal Typology

There is a wide range of coastal types within the region. The coasts vary in their geology and hydrogeology, their geomorphology, their climate and their oceanography (Uchupi, 1975). Each of these factors has an important bearing on the retentive capacity of the coastal zone and vulnerability of the coastal living resources to land-based sources of pollution.

The mode of discharge of pollutants from land-based sources to the coastal zone, the potential for their retention, and their dispersal from the coastal zone are key issues in the analysis of the problem at local to regional scales. Geology, geomorphology and climate are important factors in determining the mode of discharge. Where limestone has extensive outcrops in the coastal zone, as in western Barbados, much of the discharge may be from dispersed groundwater issues. Where relatively non-transmissive rocks, such as the volcanic rocks of St. Lucia, extend to the coast, discharge is confined to the outflow of surface streams and rivers. The amount of rainfall will determine the concentration of pollutants in both cases - an important factor is the occurrence of catastrophic events, for example, rainfall during hurricanes (Gentry, 1971) against normal day-to-day showers.

The nature of the coastal geomorphology controls the retentive capacity of the coastal zone as well as having a determining role in the distribution of habitats. Sheltered intertidal shores and creeks, including those with mangrove, favour the accumulation of sediments and provide sinks for pollutants.

Table 2- Generalised geology and maximum elevation of SIDS of the Caribbean. (Sources: Wilson, 1988; Dengo and Case, 1990; CIA world factbook, 1996, Annex B)

Caribbean State	**Generalised Geology**	**Maximum Elevation (m)**
Anguilla	limestone	65
Antigua and Barbuda	Barbuda - limestone, Antigua - volcanic	402
Aruba	limestone	188
Bahamas	limestone	63
Barbados	limestone	336
Belize	mainly limestone (some granite porphyry)	1,160
British Virgin Islands	limestone + volcanics (several islands)	521
Cayman Islands	limestone	43
Cuba	mostly flat with some volcanic hills and limestone	2,005
Dominica	volcanic	1,447
Dominican Republic	volcanic highlands with low lying limestone coastal zones	3,175
Grenada	volcanic	840
Guadeloupe	volcanic except for Grand-Terre - limestone	1,467
Guyana	Pre-Cambrian highlands, sedimentary along coast	2,835
Haiti	limestone, mountainous	2,680
Jamaica	limestone, mountainous	2,256
Martinique	volcanic	1,397
Monserrat	volcanic	914
Netherlands Antilles	volcanic	862
Puerto Rico	volcanic and limestone	1,338
St. Kitts and Nevis	volcanic	1,156
St. Lucia	volcanic	950
St. Vincent and the Grenadines	volcanic	1,234
Suriname	volcanic massif	1,286
Trinidad and Tobago	Tobago - volcanic, Trinidad - limestone	940
Turks and Caicos Islands	limestone	49
U.S. Virgin Islands	volcanic	474

Tidal range is an important factor in determining the residence time of polluted waters, and thus the potential for pollutant transfer in these environments (Kjerfve, 1971; 1986). Tidal range in many coastal situations is small - microtidal. Most islands of the region have little continental shelf, and deep ocean waters lie within a few kilometres of the shore. Where the shelves are narrow, mixing and dispersal of land-sourced pollutants from coastal waters is effective. Dispersal is enhanced on windward shores, subject to significant wave energy (e.g. along the eastern coast of Barbados. During typical weather conditions, rivers are blocked from the sea by sand bars, but these are breached every few years during storms, accompanied by a flushing of the river catchment. On lee shores, particularly those fringed with extensive intertidal or shallow subtidal platforms (with or without fringing coral reefs), mixing of pollutant-bearing waters with oceanic waters may be relatively ineffective and dispersal impeded. Narrow shelves limit this effect.

Thus knowledge of the coastal typology, particularly in respect of the physical attributes of the coast as described above, should be seen as an essential foundation for understanding the problems of flux and storage of pollutants from land-based sources as they affect the coastal zone.

2.3 Oceanography

Oceanographically the wider Caribbean region can be thought of as a semi-enclosed body of water consisting of several deep basins separated by major sills, the two main basins being the Caribbean Sea and the Gulf of Mexico. In general, the region lacks a shallow continental shelf, and 80% of waters in the region are deeper than 1800 m. The low seasonal temperature variation gives rise to a stable thermocline which minimises mixing of surface and deep waters (Rodriguez, 1981).

The oceanographic features of the Caribbean islands make this area particularly prone to the accumulation of persistent toxicants (Ross and DeLorenzo, 1997). Several deep basins in the Caribbean contain most of the region's water, and they receive very little renewal or flushing (Atwood, 1977). The general movement of the surface marine waters is stable all year round, although the velocities vary with season. Small-scale currents and eddies are known to develop seasonally. This led Rodriguez (1981) to postulate that, "a general estimate of the mass transport of material, including pollutants, by currents should only be made cautiously, because the large spatial and temporal variability which has been observed in the Caribbean may lead to serious errors if only prevailing current systems are accounted for".

2.4 Meteorology

Mean annual rainfall in the West Indies is between 1270 mm and >7600 mm with intensities between 25 mm and >127 mm per hour (Ahmad, 1977). Heavy rain is accompanied by strong winds and in some cases hurricanes. The associated heavy rains and strong winds, which have been measured for selected storm events, can have major effects on processes such as sediment transport and erosion which then exaggerate the effects of agricultural pollution. Significant differences in the magnitude of the effects of tropical storms between windward and leeward coastlines are observed (cf. section 2.1.3).

In September 1994, the island of St. Lucia was affected by tropical storm Debbie when up to 400 mm of rain fell on saturated ground (Nowlis *et al.*, 1997). Hurricane Hugo passed directly over St. Croix in the U.S. Virgin Islands in September 1989. Steady winds of 110 knots, with gusts of up to 165 knots, were recorded, which formed waves of 6-7 m in height (Hubbard, 1992). Both storms were responsible for remobilising massive volumes of sediment. Storms are thought to be amongst the most important factors in the cycling of sediments through open-marine environments (Hubbard, 1992). Sediment mobilisation during storm events has been linked with damage to large areas of coral in nearshore coastal areas (Hubbard, 1992; Nowlis *et al.*, 1997).

Studies of the fate of sediment derived from road building on St. John confirmed the importance of storm events in mobilising sediment. Mean annual flows of 3 m^3km^{-2} (*sic*) were reported in rivers during storm events with a maximum flux of 45 m^3km^{-2} (*sic*) which flushed sediment through the lower gradient sections of channels (MacDonald *et al.*, 1997). In addition to mobilising sediment, tropical storms with high rainfall intensities cause much greater rates of soil erosion, removing exposed soil from between rows of plants and from unpaved roads and tracks in agricultural areas (Greenland and Lal, 1977). Pesticides sorbed to sediments are also mobilised during intense rainfall events. High concentrations of pesticide residues caused chronic insecticidal toxicity resulting in a fish kill in Kingston Harbour (Goodbody, 1961 *cited in* Mansingh and Wilson, 1995).

3. AGRICULTURAL PRACTICES

The major constraints on agricultural production throughout the Caribbean are a lack of natural fertility and irrigation, and, in some areas, erosion, salinization and water-logging. Poor soils and/or serious erosion problems limit productivity in some areas, such as Curacao and Aruba in the Netherlands Antilles; Caricou and Nevis in the Lesser Antilles, Haiti, Jamaica and Trinidad and Tobago (Gumbs, 1981). Coastal ecosystems on small islands throughout the Caribbean are particularly prone to soil erosion and contamination by agricultural chemicals for the following reasons (Mansingh *et al.*, 1997):

- steep hillsides with thin soil cover are tilled using poor agronomic practices, leading to soil erosion.
- there are many small holdings with mixed cropping systems which require a wide variety of pesticides.
- intense rainfall leaches nutrients and pesticides into streams.
- agriculture occurs predominantly in the coastal zone.

The increased, and often indiscriminate, use of agrochemicals, particularly to boost the yield of export crops, has been identified as a growing source of aquatic pollution throughout the Caribbean region (UNEP, 1992).

There are three systems of agricultural production which dominate in the Caribbean; large plantations, small sedentary agriculture and migratory or shifting systems. The region's agricultural production is not sufficient to feed the population because a significant proportion of the arable land is used to produce export crops on large-scale mono-cropping plantations (Gumbs, 1981). The main export crops from these plantations are sugar, coffee, cocoa, cotton, bananas, rice and to a lesser extent citrus fruits, coconuts and tobacco. Several SIDS are reliant on one export crop, such as, sugar in St. Kitts, and in Barbados where 55% of the total surface area is permanently under sugar cane (Gajraj, 1988), or bananas in the Lesser Antilles.

The dominance of plantation agriculture has resulted in the marginalisation of much of the farming community and has forced smaller-scale farmers onto marginal land on steeper slopes. Migratory or shifting agriculture is less common on the Caribbean islands than on the mainland states, but the slash-and-burn method of forest clearance prior to the planting of crops does still exist. Vegetation clearance on the steeper slopes has led to serious problems of soil erosion in the region. In some cases over-grazing which occurs on the smaller farms of Caribbean islands has also contributed to soil erosion.

Both volcanic and limestone islands have traditionally been used for plantation agriculture (the former for bananas and the latter for sugarcane) although in both cases the increasing populations and ready markets have led to a gradual increase in vegetable cultivation. The latter requires more inorganic fertiliser to overcome the generally poor nutrient status of the thin limestone soils, and higher applications of a broader range of pesticides because there are more pests which affect vegetables than plantation crops.

The history of agriculture in the Caribbean region has varied for different islands. Throughout the 18th and 19th centuries, land on St. John in the **U.S. Virgin Islands** was predominantly used for plantation agriculture. The poor soils and rugged topography compared to other islands led to the abandonment of agriculture by the 1900s, and in 1956 most of the island became a national park (MacDonald *et al.*, 1997). **Jamaica**, on the other hand, has over 45% of its land area under cultivation or used as pasture. Sugar-cane plantations were started by the British in the mid-17th century on the higher quality agricultural land of the coastal plains and flat lands. Following emancipation in 1834 the marginal lands on hillsides were utilised by ex-slaves and slopes of up to 70° were cultivated. Modern synthetic pesticides have been used since the 1940s fairly indiscriminately throughout the island particularly to control pests such as the coffee berry borer (Mansingh *et al.*, 1997). Sugar plantations dominated agricultural production on **Barbados** between 1939 and 1945 but food shortages led to the conversion of at least 35% of plantation land to subsistence crops. This resulted in an increase in vegetable, fruit and root crop production and a wider variety of pests, which have subsequently been controlled by up to 312 approved pesticides (Aldridge and Irons, 1980; Watt, 1980; Chilton *et al.*, 1990, 1991a, 1991b). Current land-use practices in two catchments on Barbados were studied in detail to assess the risk of groundwater pollution. This is probably the most detailed study of small farm practices in the region (Chilton *et al.*, 1990, 1991a, 1991b). Monitoring showed that cultivation practices relating to sugar cane did not pose a threat to groundwater from nitrate pollution, but there was some risk from pesticides. A change from cane to horticulture would involve a greater risk however, due to the higher application rates of fertilisers and pesticides, increased soil aeration and nitrification of organic nitrogen, leading to nitrate leaching.

The agricultural production indices provided by the Food and Agriculture Organisation (FAO; Table 3) show that in general agricultural production in the region has increased since 1961, although there are some exceptions. Islands such as Barbados, Dominica, the Netherlands Antilles, Jamaica, St. Lucia and St. Vincent showed a moderate increase in productivity. The Dominican Republic, the Bahamas and Monserrat have seen much greater increases in productivity. By way of contrast, islands such as St. Kitts and Nevis, Trinidad and Tobago, the U.S. and British Virgin Islands and Antigua and Barbuda have had a slight reduction in productivity. This general pattern of increasing productivity should be considered in conjunction with land-use changes in the region. The recent expansion of oil production, agricultural processing and the tourist industries has led to a reduction in the area of land available for agricultural production. Hence, greater total agricultural productivity has been derived from smaller areas utilising greater quantities of pesticides and fertilisers, leading to a higher pollution load.

Table 3 - Data for net primary agricultural production, fertiliser use and pesticide imports for selected mainland and island states of the Caribbean. (source: Food and Agriculture Organization, internet database, Annex B).

CARIBBEAN STATE	AGRICULTURAL PRODUCTION INDEX			TOTAL FERTILISER USE (MT)			PESTICIDE IMPORTS (1000$)		
	1961	1978	1997	1961	1978	1995	1961	1978	1995
Anguilla									
Antigua & Barbuda	105.3	78.2	94.9				61	358	900
Aruba							0	0	2,000
Bahamas	43.4	94.0	122.9	5,126	1,200	200	202	716	4,400
Barbados	98.8	101.6	110.6	800	5,900	2,700	201	2,714	5,443
Belize	29.2	68.2	139.6	360	1,612	6,300	44	1,597	4,891
British Virgin Islands	143.4	89.2	104.0				30	100	170
Cayman Islands		161.6	84.9				120	480	800
Cuba	65.9	89.1	64.3	105,000	451,000	276,000	2,000	43,788	80,000
Dominica	53.6	79.4	81.1		4,500	4,800	20	410	2,200
Dominican Republic	58.4	88.8	111.2	13,997	57,078	100,000	870	7,665	10,000
Grenada	81.5	122.2	96.1				100	432	700
Guadeloupe	138.5	132.7	88.3	7,600	7,810	3,000	304	4,063	15,187
Guyana	119.5	155.0	184.6	8,655	12,679	15,000	220	2,143	2,000
Haiti	74.5	103.1	90.5	100	3,600	4,800	70	1,439	1,500
Jamaica	76.5	92.8	118.3	13,506	15,962	27,000	1,098	6,666	8,500
Martinique	105.4	101.5	91.8	7,060	11,799	11,400	407	5,990	15,676
Monserrat	52.7	71.1	110.2				5	47	90
Netherlands Antilles	176.7	166.0	201.4				235	2,300	2,000
Puerto Rico	114.9	104.9	83.9						
St. Kitts & Nevis	165.5	151.5	126.4	735	2,100	900	30	209	650
St. Lucia	58.2	68.7	93.2	450	1,164	7,000	150	726	4,500
St. Vincent & the Grenadines	63.7	72.0	82.5	1,110	3,900	3,000	0	380	2,500
Suriname	35.6	78.6	88.4	773	3,900	4,300	334	4,046	5,500
Trinidad & Tobago	114.2	116.4	102.5	5,280	8,462	7,000	1,230	4,864	8,296
Turks & Caicos Islands									
U.S. Virgin Islands	173.9	133.9	103.4	300	1,000	1,300	120	229	240

4. SOIL EROSION AND SILTATION

4.1 Soil erosion in the Caribbean

In natural systems in the humid tropics, soil production is slow but generally balanced by low rates of erosion. When vegetation is removed for agriculture or development the bare soil is exposed to the direct action of rain and, to a lesser extent wind, although erosion by wind is generally not a significant problem (Greenland and Lal, 1977). When soil is exposed to the direct action of rain its impact dislodges particles of soil which are then carried away by water moving over the surface of the soil. Vegetation cover reduces these effects in two ways: interception of rain drops prevents impact and the binding of soil by roots prevents removal of particles. In addition to vegetation, the factors controlling erosion are the erosivity of the rain, the erodibility of the soil, the climate and the topography. Erosivity is defined as the potential capacity of rain to cause erosion in given circumstances and erodibility is defined as the vulnerability of soil to erosion in given circumstances (Hudson, 1977).

In the humid tropics erosivity is high due to the occurrence of intense rainstorms. Erodibility is dependent on the intrinsic characteristics of the soil: particle size, cohesivity, porosity, permeability, etc. Attempts have been made to define indices of erosivity and erodibility and many different indices exist (Gerrard, 1981). Following soil erosion studies on ten soils from **Trinidad**, Lindsay and Gumbs (1982) concluded that soil erodibility was not the most important factor contributing to high soil loss in the tropics. This was attributed to the high erosivity of the rain, the steep topography and the methods of crop and soil management. Other research (described below) suggests that the nature of the soil may be more important on other islands.

Steep slopes on many islands are particularly susceptible to erosion, the effects increasing exponentially with the steepness of the slope. Slope length is also a contributory factor, with the depth and velocity of run-off increasing with slope length (Hudson, 1977). The predominance of steep slopes in the region has led to their utilisation as agricultural land by peasant farmers even though they are far from ideal for cultivation. Peasant farming methods are based around shifting agriculture with the fallow periods being preceded by burning of vegetation. This removes the cover and destroys soil organic matter, exposing the soil to the rain and reducing its cohesiveness. Soil erosion also occurs in plantation areas during periods between cropping when the new crop has not had time to establish. Erosion leads to the loss of the fertile top-soil and the exposure of infertile and impermeable subsoil. Run-off increases, leading to flooding and increased erosion of stream and river channels. In the worst cases gullies are cut into the sub-soil resulting in a lowered water table which affects vegetation growth during the dry season (Hudson, 1977).

Eroded soil particles are transported away by streams and rivers, often very rapidly during storm events. On steep-sloped volcanic islands such as **St. Vincent**, rivers have virtually no flood plains or estuaries and run rapidly across beaches into the coastal waters delivering sediment directly into the coastal ecosystem (Harrison and Rankin, 1976). In situations where runoff has a more limited capacity to transport eroded material, sediment collects in low-energy environments such as mangrove stands, harbours and semi-estuarine pools which act as sinks for nutrients and pesticides. Sediment and associated pollutants accumulate gradually until the passage of a major storm event, during which they are largely remobilised into coastal waters. Hurricanes have the capacity to mobilise massive volumes of sediment back into the open marine environment. Measurements of the flushing of sediments from shelf-edge areas by Hurricane Hugo in **St. Croix** registered transport levels of eleven orders of magnitude greater than those measured under normal conditions (Hubbard, 1992). The author considered that these storms were the most important factors in the cycling of sediment through exposed open-marine environments.

4.2 Regional data

The transport of sediment from the land and its discharge into coastal waters is a natural process which is exacerbated by human activities such as deforestation, urbanisation, and agricultural activities in river-basin watersheds. Deforestation, either to increase the availability of agricultural land or for urban infrastructure development, is probably the issue of greatest concern. In 1979 the FAO predicted that deforestation would lead to a reduction in forest cover in the Caribbean from 221 x 10^6 hectares in 1979 to 46 x 10^6 hectares by the year 2000 (FAO, 1979). High rates of deforestation are confirmed in a report by the World Resources Institute (1992) which indicated an average reduction in forest cover of 9.3% between 1977 and 1989 in both mainland and island states of the Caribbean.

Erosion and siltation problems are generally limited to volcanic islands with immature soils and steep slopes. A limited number of documented studies of runoff and soil erosion have been undertaken (Alleyne and Percy, 1996; Ahmad and Breckner, 1974; Gumbs and Lindsay, 1982). Evidence suggests that many tropical soils are not inherently prone to erosion (Lindsay and Gumbs, 1982), although poor soil and crop management practices can lead to significant losses.

4.3 Specific studies

The most detailed studies of run-off and erosion have been conducted on **Trinidad** and **Tobago** (Lindsay and Gumbs, 1982; Mohammed and Gumbs, 1982; Gumbs and Lindsay, 1982; Alleyne and Percy, 1996). The effects of tillage, slope angle, crop type and soil management on soil loss were investigated in the northern mountain range in **Trinidad** (Gumbs and Lindsay, 1982). To prevent severe soil erosion, the authors recommended that soil should not be exposed in the wet season and that the maize and cowpea should not be cultivated during this period on slopes greater than 11%. Northern mountain ranges in Trinidad are dominated by steep slopes, many of which are steeper than 45%, and are therefore highly susceptible to soil erosion. Alleyne and Percy (1996) studied two small watersheds in **Trinidad** to consider the erosion under crops of pangola grass and pineapples on steep slopes of 35% - 38% which were considered typical of the area. Run-off rates were similar for the two crops, but soil loss from the pineapples was an order of magnitude greater. Absolute rates of soil loss in this case were small, though this was attributed to terracing.

Soil erosion appears to be more severe in **St. Lucia** than on **Barbados**. The former has steeper slopes, higher annual rainfall and soils of volcanic origin which are more prone to erosion (Madramootoo and Norville, 1990). Erosion on **Barbados** occurs mainly on the more unstable soils of the Scotland District, not on those areas underlain by coral limestone (Cumberbatch, 1969). A study of soil erosion in the Scotland District of **Barbados** was carried out as part of a geology and mineral resource assessment of the island (Barker and Poole, 1981). It was found that the district was particularly susceptible to erosion because it is comprised of unconsolidated clays and muds. These rocks are subject to land slip and valley erosion during the rainy season; the clay rich soils become saturated and land slip occurs readily. In stream and river valleys, sudden heavy rainfall in the rainy season leads to torrential flows for short periods of time which cause drastic erosion of channels.

The soils of **St. Lucia** are immature and soil erosion is a problem over the entire island, but particularly where vegetation has been removed, resulting in landslips, creep and gullying (Madramootoo and Norville, 1990). The authors have produced maps of the rainfall-runoff erosivity factor (R), for both **St. Lucia and Barbados**. The map can be used to predict site-specific values of soil loss, using the Universal Soil Loss Equation, and to identify areas where soil conservation techniques could be most effective to minimise soil erosion.

A watershed management project focusing on drainage and soil conservation issues in two selected catchments was initiated on **St. Lucia** following the devastation wrought by Tropical Storm Debbie (9-10th September, 1994). The mobilisation of large quantities of soil into watercourses and coastal areas following the storm is considered to have been exacerbated by forest clearance to increase banana cultivation, resulting in degradation of coastal living resources. Although a draft version of the watershed management project has been completed by the consultants (Hunting Technical Services), it has not, to date, been presented as part of the National Environment Action Plan. Therefore, the study has not been made available for incorporation into this review.

In **Jamaica**, where hillside farming occurs on slopes of up to 70°, primitive agronomic practices have been responsible for enormous soil erosion of about 1300 tonnes year $^{-1}$ (*sic*) (Eyre, 1990 *cited in* Mansingh *et al.*, 1997). One study, currently being undertaken in **Jamaica** funded by the UK Department for International Development (DFID) between 1995 and 1998, has wide implications for the prevention of soil erosion in steeply sloping hillsides in the Caribbean. The aim of this study is to improve the management of tree-based systems to reduce soil erosion leading to sustainable methods of hillside farming (ODA, 1995). Although results have not been published to date, outputs from the project will include data on the effects of the establishment of trees and increases in organic matter content on soil processes and the prevention of erosion.

4.4 Siltation

Sediment transport can have adverse impacts on the environment, not only in areas of erosion but also in areas where sediments are eventually deposited. The effects are especially deleterious in areas of reef-building coral. Coral growth is known to be favoured by clear water. Suspended sediment particles reduce water clarity and, following deposition, are known to smother coral polyps. Corals do have the ability to reject sediment but this is limited and size specific in different species (Johannes, 1975). High levels of suspended sediment cut down the light levels on the reef and reduce the photosynthesis of the zoo-xanthellae, which in turn restricts coral growth (Tomascik and Sander, 1985). Even low mean sedimentation rates of approximately 10 mg cm^{-2} d^{-1} may cause stress to coral reefs (Rogers, 1990). Mangroves are effective in trapping sediment of terrestrial origin, hence the scale of the effects of siltation in the coastal zone depends on coastal typology.

A detailed study of siltation at Cahuita point (**Costa Rica**) suggested that deforestation for timber and subsequent agricultural production has resulted in degradation of the coral reef (Cortes and Risk, 1985). Local inhabitants observed that, prior to logging, streams were clear during the dry season, but now have a muddy appearance throughout the year. The assertion that the degradation of the reef is principally caused by siltation stress has been questioned by Hands *et al.* (1993) who suggest that the development of mature coral is limited by the absence of hard substrate and exacerbated by stress caused by the passage of major storms. The combination of land development (agricultural and civil engineering (road building)) and a tropical storm were considered to be responsible for coral reef degradation through siltation on the west coast of **St. Lucia** (Nowlis *et al.*, 1997). This study is unique in its consideration of both agricultural and road building impacts on sediment mobilisation and siltation effects on coral reefs.

5. NUTRIENT ENRICHMENT OF FRESHWATER AND NEARSHORE COASTAL WATERS

5.1 Pollution pathways

Many coral reefs in the wider Caribbean are considered to be suffering from the effects of eutrophication (Wells, 1988) including Jamaica (Lapointe, 1989) and Barbados (Tomascik and Sander, 1985, 1987) caused by increased nutrient loads from mainland river discharges and small-scale local runoff from islands. Typically, the loads of nutrients discharged from arable lands are an order of magnitude greater than those discharged from pristine forested areas. Large areas of coastal wetlands, which can act as a nutrient buffer between freshwater and coastal water, have been reclaimed in recent years for urban and tourism developments, or drained for agricultural production.

There are a number of pathways by which nutrients enter coastal waters. These include terrestrial run-off and groundwater seepage, point-source effluent discharges such as sewage outfalls, recycling of contaminated coastal sediments, regeneration from coastal sediments, ocean-current upwelling, and atmospheric fall-out. Excess nutrients from point and non-point sources (e. g. agriculture) have increased the nutrient load above its natural level, and in certain circumstances may exceed the nutrient-assimilation capacity of the ecosystem, leading to a deterioration in water quality. This deterioration may take the form of algal blooms, reduction in water clarity and reductions in dissolved oxygen concentrations (Turner and Rabalais, 1991). The relative importance of point and non-point sources of nutrients in coastal regions depends on population density and the intensity of agricultural production. Point source discharge of nutrients, such as urban and tourist hotel sewage outfalls, are, by their nature, more amenable to treatment at source than diffuse sources, such as those from agriculture.

The nutrients of prime interest for algal growth in the marine environment are nitrogen (N) and phosphorus (P), and to a lesser extent Si and micronutrients such as Fe and Mo. Phosphorus occurs both in both organic and inorganic forms, but neither is very soluble, tending to sorb strongly to suspended particulates. Nitrate (NO_3^-), which is generally the dominant form of inorganic nitrogen in surface run-off and groundwaters, is not strongly adsorbed to soil or sediment. Organic nitrogen stored as organic matter in sediment is converted into inorganic nitrogen via mineralisation and nitrification.

The proportion of the **global** anthropogenic flux of N and P attributable to domestic, industrial and agricultural activities has been estimated by Van Bennekom and Salomons (1981). If only the dissolved forms of N and P are considered, they estimated that agricultural sources accounted for 19% of total N flux and 4% of total P flux. However, when the particulate forms of N and P are included the agricultural proportion of the total load increases significantly to 56 and 59% respectively. It should be noted that the proportion of nutrients derived from point (sewage outfall) and non-point (agricultural) sources in the Caribbean may be significantly different to the global average (see section 5.2). Clearly, soil erosion and its subsequent transport via streams and discharge into coastal zones are crucial factors in the export of N and P. This particulate fraction, although not immediately available for assimilation by phytoplankton, is stored in the sediment nutrient pool and may subsequently be recycled into the dissolved form.

Estimation of the annual export of sediment and nutrients from diffuse sources in catchments is complicated by the large number of factors which affect the load including, land use, runoff, rates of soil erosion, the proportion of the soil which reaches watercourses, the annual variability in river discharges and catastrophic events such as hurricanes.

In coastal ecosystems with long water residence times, the transfer of nutrients between sediment and the water column is considered to be important in controlling the occurrence of algal blooms (Gabric and Bell, 1993). The adsorption of P to benthic sediments has been shown to be an important buffering mechanism that controls water column P concentrations (Pomeroy *et al.*, 1965). A more recent study suggested that under elevated P loading rates the buffering mechanism breaks down and sediments are less effective in regulating dissolved concentrations (Hinga, 1990). Whilst the assimilation of nitrogen by marine algae in mangrove lagoons may result in severe localised degradation, this may help to prevent the effects of eutrophication impacts from nutrients on reefs and seagrass beds (Siung-Chang, 1997). Mangroves and wetlands act as sinks, with a large retentive capacity for nutrients (Harrison and Rankin, 1976) hence the need for their conservation.

5.2 Distinguishing between nutrients from agricultural and sewage sources

In addition to nutrients derived from agriculture, sewage from coastal urban, residential and tourist development may be an important factor leading to nutrient enrichment in nearshore coastal waters. Discharge of groundwater containing elevated concentrations of nutrients is of most concern for the more densely populated and highly developed of the limestone islands (Table 2). Although **Bermuda** is not strictly in the Caribbean region, it is a limestone island which shares many features of the islands and it has been extensively studied. Jickells *et al.* (1986) examined nutrient and trace metal fluxes in coastal waters and concluded that the dominant source of the observed elevated nutrient concentrations was groundwater discharge rather than street runoff, cooling water returns or atmospheric deposition.

Assessment of the effects of agricultural pollution needs to take account of other possible sources. Thus, in the study of **Barbados** by Chilton *et al.* (1990) referred to above, estimation of the possible nitrogen loading from septic tanks in the densely-populated Bridgetown suburbs suggested that groundwater recharge in these areas could contain additional nitrate. Comparing monitoring results from agricultural and suburban areas confirmed this to be the case, as groundwater nitrate concentrations beneath the latter rise above the WHO guideline value of 10 mg l^{-1} NO_3-N (WHO, 1993) and are correlated with the most frequent and highest positive faecal coliform counts (Chilton *et al.*, 1990). Similar impacts of dense coastal urban development have been seen in the observed high groundwater nitrate concentrations in **The Bahamas** (Stuart, 1992) and **Bermuda** (Thomson and Foster, 1986). In the latter study, highest nitrate concentrations coincided with the greatest density of housing dependent on unsewered sanitation, and much lower concentrations were observed beneath sewered areas.

Research conducted at Hellshire Bay, **Jamaica**, cited in Siung-Chang (1997), identified three principal sources of nutrients; Kingston Harbour storm gullies, agriculture and (sewage) contaminated groundwater (Goodbody, 1989). The occurrence of marine algae along the Hellshire coast has been attributed to these land-based sources of nutrients. Any study of the effects of agricultural pollution on nutrient enrichment must account for natural and anthropogenic sources (e. g. sewage). The measurement of coprostanol in sediments has been widely used to indicate human sewage contamination (Goodfellow *et al.*, 1977; Venkatesan and Kaplan, 1990) although extensive use of this method has not been reported for the Caribbean region.

5.3 Regional data

One approach to assessing regional trends in nutrient loads of agricultural origin is to compare the use of fertiliser over several years. The average annual use of fertiliser in 17 Caribbean states increased by 30% between 1979 and 1989, from 62.3 to 81.6 kg ha^{-1} respectively (World Resources Institute, 1992). However, these data generally relate to mainland and large island states. Detailed data from the FAO for annual fertiliser use for a number of SIDS of the Caribbean is provided in Table 3 for the years 1961, 1978 and 1995. Fertiliser imports between 1961 and 1995 increased markedly for all small islands for which data is available. The scale of this increase varied significantly; imports in megatonnes increased three-fold in Barbados (from 800 to 2,700 MT) and St. Vincent and the Grenadines (from 1,100 to 3,000 MT), four-fold in the U.S. Virgin Islands (from 300 to 1,300 MT) and 15-fold in St. Lucia (from 450 to 7,000 MT). Although this pattern was also observed for some of the mainland and larger island states, notably Belize, the Dominican Republic and Haiti, fertiliser imports fell over the same period for Guadeloupe. The large increase in fertiliser use between 1961 and 1978 for practically all states of the region suggests that there was a concomitant rise in nutrient loads in agricultural run-off or groundwater flow at both regional and local scales. There was no clear pattern in the change of fertiliser use between 1978 and 1991 (Table 3), although in most cases total imports were approximately the same, and therefore nutrient loads were still likely to be greater than in 1961.

Typical non-polluted coastal waters in the Caribbean have combined nitrate/nitrite levels of 0.70 $\mu g\ l^{-1}$ and phosphate levels of 0.10 $\mu g\ l^{-1}$ (Bellairs Research Institute, 1989 *cited in* Singh and Ward, 1992) compared with levels of >4.0 $\mu g\ l^{-1}$ and 0.5-1.5 $\mu g\ l^{-1}$ respectively at polluted sites (Bellairs Research Institute, 1989; Wade, 1976 *cited in* Singh and Ward, 1992).

In addition to the transfer of agriculturally derived N and P from SIDS, freshwater discharges from the Orinoco and Amazon river basins of south America represent a significant nutrient load to the eastern Caribbean sea. Although the occurrence of plumes of discoloured water in the western tropical Atlantic were originally attributed to eddy upwelling (Longhurst, 1993), more recent studies presented evidence suggesting that the plumes are of riverine origin (Bonilla *et al.*, 1993; Muller-Karger *et al.*, 1995). The two plumes occur from August to November each year, are over 100 km wide and extend over 1000 km into the western Atlantic Ocean. The Orinoco plume flows into the Caribbean sea, remaining in shallow waters off Venezuela and Trinidad (Bonilla *et al.*, 1993), extending as far as Puerto Rico by October (Muller-Karger *et al.*, 1995). The plumes represent an important potential source of nutrients for the tropical Atlantic Ocean and Caribbean sea. The implications are that poor land management and the indiscriminate use of fertilisers in central South America could have a deleterious effect on the coastal water quality of the south-eastern Caribbean sea.

5.4 Specific studies

There have been very few published studies of baseline data for nutrient export from catchments of Caribbean islands. The variety in the number of forms of N and P and the scarcity of pristine systems makes it difficult to quantify background nutrient fluxes to coastal waters. One study which was undertaken on the islands of the Lesser Antilles: **Dominica, St. Lucia,** and **St. Vincent** (McDowell *et al.*, 1995), investigated the effects of land use on nutrient export. They measured the concentrations of N, P and major ions for streams draining mountain watersheds. Patterns of inorganic nitrogen export correlated well with population density; the greatest export occurred in the most populated catchment. There was good agreement between nitrogen export from the catchments and the predictions of a model based on average rural population densities (Peierls *et al.*, 1991). However, this model does not account for other anthropogenic effects, such as the leaching of agricultural fertilisers and there has been no attempt to account for these factors. Somewhat unexpectedly, phosphorus concentrations were lowest in streams draining from areas of high population density and agricultural land-use. The authors suggested that this was may be attributable to anomalous high concentrations of P which were reported in the Layou catchment stream (**Dominica**) which may be explained by natural (geothermal), rather than anthropogenic, sources.

Higher than expected concentrations of nitrogen monitored in groundwater flow into Discovery Bay on the north coast of **Jamaica** were considered to be derived from natural, rather than anthropogenic sources (D'Elia *et al.*, 1981). The combination of a hydrographic mechanism for transporting nitrogen-rich waters from inside the bay directly into the shallow reef area, and the potential for anthropogenic activity to enrich the groundwater in phosphorus (or increase in nitrogen concentrations) could rapidly subject the reef to eutrophication. Nutrient enrichment of back-reef habitats (including rock platforms) resulting from poor land-use practices, when combined with overfishing has also been reported to increase the dominance of algae on reefs on the north coast of **Jamaica** (Lapointe, 1989).

Baseline concentrations of N and P in streams draining three montane tropical rain forest watersheds of **Costa Rica** were published by McDowell and Asbury (1994). However, no data from comparable agricultural or mixed land-use catchments have been reported which can be used to quantify the impacts of fertilizer use on nutrient export.

5.5 Groundwater

The impact of agricultural activities on groundwater quality has been investigated in **Barbados** (Chilton *et al.*, 1990) as part of a broader study of the risk of pollution of public water supplies on the island. Within the study, surveys of agricultural activities and fertiliser and pesticide use were accompanied by regular sampling of groundwater quality. Agriculture on the island was still dominated by sugar cane cultivation, although vegetables were becoming more important. Infiltrating rainfall collects nitrate as it passes through the soil, and groundwater nitrate concentrations were generally in the range 5 to 8 mg l^{-1} NO_3-N, consistent with leaching of some 25-30% of the applied nitrogen (Chilton *et al.*, 1990). Phosphate from the fertiliser was strongly adsorbed in the soil and did not reach groundwater. The impact of agriculture was ubiquitous; no groundwater samples had nitrate concentrations which could be considered to reflect the low background that would be expected on such a limestone island. This is not surprising, as the total volume of groundwater storage in the thin freshwater lens is probably of the same order as the annual recharge. Groundwater residence times are, therefore, relatively short, and no groundwater unaffected by agricultural activity remains in the aquifer. Regular monitoring during and since the study confirms the impact of agriculture, but suggests the situation is relatively stable with respect to nutrient leaching.

If the groundwater contains nitrate, and recharge rates and hydraulic conductivities are high, then discharges of polluted groundwater must affect the coastal zone. A hydraulic gradient towards the coast is required to maintain the fresh groundwater lens shown in Figure 1. Although groundwater resource estimation was not a major component of the study of Chilton *et al.* (1990), simple groundwater balances for the studied catchments in the south of the island suggested that, in spite of the rapid growth of groundwater use, there was still a small excess which would discharge to the sea. That this must be so was confirmed by the quality monitoring; groundwater chloride concentrations are not deteriorating with time and the saline/freshwater interface (Figure 1) must be relatively stable.

On the west coast of **Barbados**, groundwater abstraction is much smaller and there is even greater scope for groundwater discharge. Lewis (1985, 1987) reviewed estimates of groundwater discharge to the coastal zone from previous water balance and modelling studies of groundwater resources and made direct measurements of water and nutrient fluxes using seepage meters and shallow piezometers. The measured seepage velocities and fluxes were used to estimate the discharge for the whole 30 km length of the west coast limestone aquifer as 128,000 $m^3\ d^{-1}$ in the dry season and 296,000 $m^3\ d^{-1}$ in the wet season, comparable but slightly larger than the previous estimates. Analysis of water collected in the seepage zone confirmed that the groundwater contained elevated nitrate concentrations but little phosphate. A strong inverse correlation between salinity and nitrate indicated that the latter was contained in the discharging groundwater (Lewis, 1987). It should be noted that nitrate concentrations observed in the coastal seepages were apparently much lower than in groundwater taken from inland wells. This was ascribed by Lewis (1985) to dilution and mixing with seawater and possible nitrate reduction, and he cautioned against using inland nitrate concentrations to estimate nitrogen fluxes at the coast. It is also necessary to exercise caution in extrapolating from point and instantaneous measurements to regional and annual estimates of nutrient fluxes.

6. PESTICIDE CONTAMINATION

Pesticides, present a particular pollution problem because they are specifically designed to have long lasting toxic effects on living organisms, and persist in soil, water and sediment for long periods. Although pesticides do undergo decomposition, their intermediate breakdown products may also be toxic to living organisms. Three main groups of insecticides are currently used in agriculture: organochlorines, organophosphates and carbamates. Organochlorines have been widely used for the last 50 years and are the most persistent of all groups of pesticides. Persistence decreases in the order DDT > dieldrin > lindane (BHC) > heptachlor > aldrin, with half-lives from eleven (DDT) to four years (aldrin). Organophosphates, which are toxic to animals, and carbamates are less persistent than organochlorines.

The potential for negative environmental impacts of pesticides in the wider Caribbean region was recognised more than twenty years ago. A seminar and workshop was held in the region in 1980 to: i) review the problems associated with pesticide contamination affecting the Caribbean, ii) identify obstacles hindering the development of economically and environmentally sound pest and pesticide management programmes in the region, iii) to identify needs and steps that various national and international institutions could take to remove these obstacles (Gooding, 1980; Hammerton, 1980).

Bananas and sugar cane, the two most important foreign exchange earning export crops of Jamaica in 1980 were both prone to disease and attack from insect pests. Rust of sugar cane was typically controlled by the application of Dithane or Manzate at a rate of 0.5 kg ha $^{-1}$. The major pests affecting banana were leaf spot (sigatoka disease), banana weevil borer (*Cosmopolites sordidus*), nematodes, and peel scarring pests. The control of leaf spot requires regular spraying using benlate (benomyl). Mocap has been widely used as a chemical control for the weevil borer. Chlordane has been applied to fields foliage sprayed with Thiodan to control the most important inset pest affecting coffee, the coffee berry borer (*Hypothenemus hampei* (Ferr)). Where infestations are particularly severe, a systemic insecticide dimethoate is added and a copper fungicide (e. g. Kocide) is used to prevent against the disease. Nematodes which attack tobacco and cause extensive damage have been controlled by the application of DD or mocap 10G. Further examples of the chemicals applied to specific crops in Jamaica are listed in Table 4.

In addition to direct application, pesticides enter the environment through spillage, although very little information on spills had been reported in 1980 (Aldridge, 1980). In Jamaica, large scale application of pesticides is conducted in two ways; regular spraying of sizeable acreages, or occasional aerial spraying of dengue over urban areas and more populated rural areas. Small scale applications were often undertaken by unlicensed, and frequently untrained, pest control operators.

Pesticides are predominantly adsorbed by humic material in the surface horizons of soil and sediments. Elevated concentrations of dissolved organic matter enhance the mobility of organic contaminants due to binding to the soluble ligand. Pesticides are relatively insoluble and do not move down the soil profile, with the exception of organophosphate insecticides which are more readily leached. In general most pesticides that reach water courses are sorbed to soil particles in run-off.

There has been some work on chemodynamics of pesticides in tropical conditions; Singh *et al.* (1985) measured the dissipation rates of dieldrin under laboratory conditions and attempted to correlate these data with dissipation rates measured in the field. Total dissipation rates were studied for one year in a coffee plantation after application to foliage and in a citrus orchard after application to soil. Further work by Singh *et al.* (1991) studied the volatilization, hydrolysis and photolysis of deldrin and α- and β-endosulfan under simulated tropical conditions.

Table 4 - Examples of pesticides used for the control of crops from diseases in Jamaica (Watt, 1980)

Crop	**Disease**	**Pathogen**	**Pesticide control product s**
Banana	Leaf spot	*Mycophaerella musicola*	Maneb, Kocide, Benlate
Citrus	Citrus scab, Stem knot of lime	*Elsinoe fawcetti* *Sphaeropsis* spp.	Benlate
Coconut	Lethal yellowing	mycoplasma	Tetracycline
Coffee	Anthracnose	*Glomerella cingulata*	Difolatan, Kocide
Pimento	Rust	*Puccinia psidii*	Maneb, Zineb
Pineapple	Heat and root Rot Base or butt Rot	*Phytophora pasrasitica* *Ceratocystis paradoxa*	Difolatan Difolatan
Rice	Blast	*Pyricularia oryzae*	Thiram, Captam
Sugar cane	Rust Smut	*Puccina melanocephala*	Zineb, Dithane, Manzate
Tobacco	Blue mould	*Peronospora tabacina*	Rodomil, Zineb
Yam	Black rot	*Rosellinia* spp.	Kocide, Perenox

6.1 Regional data

Data for 14 large states in the Caribbean indicate a general increase in the use of pesticides between 1974 and 1984 (World Resources Institute, 1992; UNEP 1994). The smaller islands showed an increase in average annual pesticide use from 861 (1974-1977) to 1,420 metric tonnes (1982-1984). Some of the highest application rates of pesticides in the world (up to 80 kg ha^{-1}) have been reported for cotton fields in the Caribbean (UNEP, 1992). Data from the FAO presented in Table 3 shows a wholesale increase in pesticide imports throughout the region between 1961 and 1995. The increase in Dominica was two orders of magnitude, whereas imports into the U.S. Virgin Islands have only doubled over the same period (FAO, 1995; Table 3). Guyana and the Netherlands Antilles have shown a slight decline in imports since 1978.

Over the past three decades changes in pesticide usage throughout the Caribbean have been brought about through international law. The ban on the use of DDT, aldrin and lindane in 1973 and chlordane and dieldrin in 1980 significantly reduced organochlorines contamination throughout the region (Mansingh *et al.*, 1997). In 1985 the most widely used pesticides were organophosphates which represented 56% of the total pesticide use (Singh and West, 1985). Organochlorines accounted for (27%) and carbamates (9%), in addition to smaller quantities of other pesticides such as arsenates and bipyridyls. The majority of published information from the Caribbean region on the concentration of pesticide residues in sediments and marine organisms relates to the Mussel Watch Programme from the Gulf of Mexico (Sericano *et al.*, 1990). This study was preceded by pioneering work on the concentration of organochlorine insecticides in oysters from coastal lagoons of the Gulf of Mexico by Rosales *et al.* (1979). However, as shown below, few studies monitoring pesticide residue concentrations have been undertaken on or around SIDS.

6.2 Specific Studies

The National Oceanic and Atmospheric Administration's Status and Trends Mussel Watch Program collected 590 samples of sediment and oysters during 1986 and 1987 (Sericano *et al.*, 1990). Samples were collected in the **Gulf of Mexico**, Atlantic and Pacific coasts of the Americas. Alpha-chlordane, *trans*-nonachlor and dieldrin were found to be the most abundant non-DDT pesticides in both sediments and oysters. These three compounds on average accounted for 70-75 % of the total non-DDT pesticides in sediments and 80-85 % in oysters. However, it was found that when the two types of sample were compared the oysters had concentrations 10-30 times those of the sediments. Significant concentrations of DDT and its metabolites, DDE and DDD, were found in nearshore sediments despite it having been banned in the early 1970s. Although DDT and its metabolites have remained as widespread pollutants the average concentrations are reduced by a factor of 2-10 when compared to results from the early 1970s (Butler, 1973 *cited in* Sericano *et al.*, 1990). Butler and Schutzmann (1978) carried out further work in the mid-seventies using juvenile estuarine fish as organisms more suitable for monitoring on an annual basis. This monitoring found that the magnitude and frequency of biotic residues of DDT, dieldrin and eldrin had declined substantially between 1965-1970 and 1972-1976.

Elevated concentrations of lindane, dieldrin, DDT and their derivatives were reported in waters by Singh and Ward (1992) at seventeen coastal sites around **St. Lucia**. Concentrations were generally lower when compared with North American data from the 1970s which was attributed to four factors:

- low aqueous solubility of organochlorine pesticides at ambient environmental temperatures
- adsorption of organochlorine pesticides to marine sediments and colloidal solids
- ban on usage of organochlorines in agriculture and public health
- dilution factor for pesticides entering the marine environment from small island ecosystems will be high, except in very sheltered and highly contaminated areas

Higher levels of residues were found in animal tissue suggesting bio-accumulation in the food chain. Concentrations in fresh sediment samples were considered as background levels when compared to the guidelines of the Canadian Ocean Dumping Control Act (Government of Canada, 1980 *cited in* Singh and Ward, 1992).

Oysters from nine locations in the **Gulf of Mexico** were analysed for a range of organochlorines including DDT and dieldrin (Rosales *et al.*, 1979). The concentrations of these compounds were an order of magnitude lower than results of a study carried out on the **eastern and Gulf coasts of the USA** (Butler, 1973 *cited in* Rosales *et al.*, 1979). DDT levels in the oysters in the Gulf of Mexico were in the range 6-28 ppb compared to levels of 11-1000 ppb in those from the coasts of the USA. Concentrations of dieldrin in the Gulf of Mexico ranged from 0.03-1.1 ppb, again much lower than the levels of 5-200 ppb measured on the USA coasts. Rosales *et al.* (1979) did observe that the highest measured values were in oysters from areas adjacent to intensive agricultural activity.

Much of the research into pesticide contamination in Caribbean SIDS has been carried out in **Jamaica** where modern synthetic pesticides were first introduced in the mid-1940s (Mansingh *et* al., 1997). Williams and Chow (1993) carried out tests to establish the toxicity of endosulfan to the mangrove guppy *Gambusia Puncticulata* Poey, a common fish in Jamaican mangrove environments. Endosulfan is used widely in Jamaica to control the coffee berry borer, a destructive coffee pest. Toxicity tests revealed that the 24 hour LC_{50} for endosulfan in the mangrove guppy was 0.050 ppb, concentrations of 0.1 ppb resulted in an instant reaction in the fish and 100% mortality within 1 hour. Samples from the Hope, Salt and Mammee rivers consistently recorded levels in excess of the LC_{50} value, with concentrations of over 3.4 ppb reported for some Jamaican rivers (Lawrence, 1985). Of particular concern to the ecology of Jamaica are the sulphate derivatives of endosulfan which are very stable and have the ability to concentrate in organic sediments. Thus there is the danger that mangroves will become sinks for endosulphan sulphates.

The Pest and Pesticide Research Group at the University of the West Indies in **Jamaica** have conducted an extensive programme of monitoring to assess the insecticide contamination of the Jamaican environment. The four main rivers of the Hope River watershed (Hope River, Mammee River, Hog Hole River and Salt River) were monitored on a monthly basis between 1989 and 1991 (Mansingh *et al.*, 1995). This area is the site of the Blue Mountain coffee plantations and as such is subject to intensive cultivation with the steep slopes making it particularly susceptible to soil erosion. The use of pesticides is widespread, the use of endosulfan has been particularly high since the 1970s in an attempt to control the coffee berry borer. Monitoring revealed the presence of endosulfan in 29-57%, 40-60% and 9-55% of the samples in 1989, 1990 and 1991 respectively. Diazinon was detected in 14-29%, 0-10% and 0-9% and dieldrin in 0-14%, 0-46% and 9-46% of samples in the same years. In many cases the levels were found to be above the LC_{50} values for several aquatic fauna. These results are particular cause for concern because prior to monitoring the area was devastated by hurricane Gilbert in September 1988 and only about 50% of the plantations were operational and subject to pesticide sprays. It was found that the concentrations of residues detected could be correlated with the type and amount of pesticide sprayed, the time and frequency of application and the seasonality of rainfall. This led to the recommendation that coffee farmers adopt integrated management of coffee pests and pesticides. Recommendations were also made to reduce pesticide contamination in run-off by promoting their microbial degradation prior to their entering the rivers.

The waters and sediments of Kingston Harbour were monitored during July 1992 (Mansingh and Wilson, 1995) to determine the effects of run-off from the Rio Cobre which drains from one of **Jamaica's** richest agricultural valleys. Residues of six organochlorine and one organophosphorus pesticide were detected in the samples, with 41.7% of water and 62.5% of sediment showing residues above the detection levels. Pesticides were detected most frequently in water in the Hunt's Bay area, where human activities are at their maximum, and the highest levels in sediment were reported in the mangroves at Port Royal. Sinks at these sites were considered to be consistent with the flow of currents in the area. Limited study of fish and oyster samples also showed traces of endosulphan, aldrin and diazinon but too few samples were analysed to draw firm conclusions.

A summary of environmental monitoring in **Jamaica** since 1982 reviews the pesticide contamination of plantation soils, rivers, wells, natural springs, sea coast and aquatic and marine fauna (Mansingh *et al.*, 1997). It has been found that the most frequently detected residues are endosulphans, chlorpyrifos, diazinon and dieldrin and that these are measured at levels which often exceed LC_{50} values for many fish species. The findings of the studies were felt to be representative of the situation in many tropical island ecosystems. Pesticide application in the mountainous watersheds which are subject to run-off lead to contamination in the lower lying areas. This contamination can be directly related to the use of pesticides with the detection of DDT and later dieldrin declining as their use was restricted. It was found that episodes of heavy rain and floods flush residues from the rivers into sink areas. Residues of DDT, dieldrin, enduring, chlordane and others were still present in the Kingston Harbour area long after their presence was undetected in the rivers. Studies of the treated waters of the Jamaican municipal water supply revealed very low concentrations of residues but results suggested that aquatic fauna were being affected.

Despite having been applied to crops in recent years, none of the 27 different pesticides which were monitored in stream water and sediment samples of **Dominica** were reported to have values above detection limit (Ross and Mann, 1990). In addition to the monitoring programmes, a project aimed at minimising environmental contamination resulting from pesticide application in **St. Lucia** and **Dominica** was recently undertaken by through funding from the ODA between 1992 and 1996 (ODA, 1996).

6.3 Groundwater

The groundwater pollution risk assessment for two groundwater catchments in **Barbados** referred to above included an evaluation of the likelihood of pesticide contamination (Chilton *et al.*, 1990). The inventory of agricultural practices included pesticide usage. Herbicides are heavily used for sugarcane and insecticides in vegetable cultivation. The likelihood of leaching to groundwater was assessed qualitatively from published data on mobility (partition coefficients), solubility and persistence and, on this basis, a small number of compounds were selected for analysis in groundwater. Thus, the triazine herbicide atrazine, used to combat weeds in sugarcane, was detected in every sample at concentrations usually between 0.1 and 0.5 $\mu g\ l^{-1}$, but rising to 3-4 $\mu g\ l^{-1}$ (Chilton *et al.*, 1991a, 1991b). A second triazine herbicide ametryne was rarely detected and the other compounds selected, asulam, diazinon and 2-4D were not detected in groundwater. Atrazine, amongst the most commonly-detected pesticides in groundwater is, therefore, like nitrate widely distributed in Barbados' groundwater and likely to persist long enough once in the groundwater system to reach coastal areas.

7. POLLUTION FROM AGRO-INDUSTRIAL SOURCES

Agriculture in the Caribbean region is linked to secondary processing industries, the products of which include sugar, rum, coffee, edible oils and fruit juices. These agro-industrial activities can also contribute to pollution of the coastal zone. This contribution to overall environmental stress in the region has not been monitored or quantified in any great detail, although the influence of these activities has been noted by some regional review papers (Singh and Ward, 1992; Rodriguez, 1981; UNEP, 1994).

Pollution from agro-industrial sources takes the form of thermal effluents, dunder (liquid effluents from sugar cane alcohol distilleries), oil, high organic matter (BOD) and suspended solids, effluents, inks and adhesives, bagasse, rice husk, seed kernels and shells. In general most of the liquid waste and some solid wastes are disposed to water courses which drain into the coastal zone. There has been very little research into the impacts of these pollutants when they enter the humid tropical ecosystem of the Caribbean.

8. GAPS IN KNOWLEDGE AND RESEARCHABLE SOLUTIONS

Although several scientific studies or review papers have cited siltation, eutrophication or pesticide contamination resulting from agricultural activities as being responsible for the degradation of coastal living resources in the Caribbean (see section 1.4 and MRAG desk study), few studies have been found which **directly** link cause and effect. Without such studies, attempts to combat the potential negative impacts of agricultural activity may incur unnecessary effort and expense. Only by conducting integrated studies which quantify the flux of agricultural pollutants into coastal waters, *and* determine their impacts on coastal living resources, can appropriate remediation strategies be identified.

8.1 Gaps in knowledge

Numerous soil erosion and siltation studies have been conducted on small islands in the Caribbean. Although the degradation of coral has been attributed to increased siltation stress at a number of sites in the Caribbean (Cortes and Risk, 1985; Nowlis *et al.*, 1997), there appears to be a lack of information concerning natural rates of sediment delivery to streams in relation to that in areas of tilled land, or resulting from other human development activities such as road construction. More studies are necessary to link the erosion of soil from tilled land, its transport via streams and subsequent delivery to the coastal zone both seasonally and during catastrophic events. There is also a need for an assessment of contemporary siltation in a longer term (historical) perspective.

The rise in fertiliser use throughout the region in the last 20 years, at both local and regional scales, suggests a concomitant increase in nutrient loads derived from agricultural sources in both run-off and groundwater. There is an urgent need for baseline studies of freshwater and coastal water quality throughout the region with which to assess nutrient loads as very few such studies have been undertaken to date.

Although baseline studies are central in assessing the extent of agricultural pollution, they cannot alone provide solutions. The relative proportions of nitrate and phosphorus from agricultural sources, sewage and background concentrations in surface and ground waters is crucial in determining whether the application agricultural fertiliser should be restricted. In addition, budgets for storage and transfer of phosphorus from their source in agricultural areas, through transport via streams and semi-estuarine pools, to sinks in mangroves or marine sediments, have not been quantified.

There has been a significant increase in the use of pesticides on almost all small island states throughout the Caribbean region over the past twenty years. At the regional scale, detailed studies of pesticide contamination appear to have been restricted to the Gulf of Mexico and Jamaica, with some limited data from Barbados, St. Lucia and Dominica. In Jamaica, pesticide pollution has been linked to fish kills, and concentrations of pesticides in stream water have been reported above toxicity thresholds. There is a dearth of baseline data for the concentration of pesticides in water and sediments both on and around the majority of SIDS. Likewise, no data are available concerning the transport and fate of pesticides from sources to sinks in the coastal zone, although this is considered to be strongly linked to the fate of organic matter.

8.2 Researchable solutions

As highlighted above, there remains a need to examine and quantify the possible links between agricultural pollution and its effects on coastal living resources. Two specific approaches which aim to achieve this are detailed below. The first is an integrated catchment approach; the second (possibly as a sub-set of the first) is a more detailed study of the role of buffer zones (e.g. nearshore alluvial sediments, mangroves, coastal wetlands, seagrass beds and their host sediments) as long-term stores of pollutants.

From section 8.1 above it is clear that there are many gaps in knowledge relating to the three agricultural pollutants (silt, nutrients and pesticides) on the majority of SIDS including:

- baseline data against which to assess the concentration of the pollutants
- quantifying their sinks in terrestrial, coastal and marine systems
- the scale of the transfers between these sinks and their variation over time

This calls for an integrated catchment study or studies in which fluxes of the pollutants are monitored in water and sediments from source, through streams and groundwater, across the freshwater-marine interface and in nearshore waters. This monitoring should be conducted throughout at least an entire year to determine the importance of seasonal and catastrophic (storm) events on the transfer of pollutants. This should be accompanied by a long-term programme to monitor any impacts and the status of coastal living resources (e.g. coral reefs and seagrass beds) which would enable the link to be made between the scale of pollution and its effects. Such an approach would enable budgets to be calculated for each of the pollutants and the relative proportions of their delivery in run-off and groundwater to be quantified. However, site selection would be crucial, as a range of variables will determine the outcome of the research programme including: type of agriculture (magnitude of fertiliser and pesticide application and crops), geology (limestone or volcanic), local bathymetry and geomorphology, whether the shore is windward or leeward, the extent of urban development. Careful selection of study sites and methodologies would ensure that the role of agricultural pollution on coastal living resources could be clearly elucidated from such a large number of variables.

Managing environmental quality in the coastal zone may require controls on pollution loadings from the land. For the densely populated limestone islands, controlling nitrate pollution needs better knowledge of the sources, in particular distinguishing between agricultural and urban or tourist related inputs. This need is not restricted to the Caribbean region, and recent studies in the UK (Barrett *et al.*, 1997) have used the isotopes of nitrogen to distinguish between fertiliser and sewage nitrate in groundwater. This tool would become even more powerful in combination with the oxygen isotopes of nitrate. There has been considerable interest in developing markers to distinguish urban from agricultural influences on groundwater quality, and other possibilities under consideration include trace metals (especially zinc and boron) and various organic compounds originating in domestic effluents (e. g. coprostanol; see section 5.2).

As part of the integrated catchment approach outlined above, there is a particular need to assess the capacity and sustainability of mangroves and coastal wetlands to act as long-term pollutant sinks or buffer zones. These coastal ecosystems, at the interface between land and sea, are often considered to be crucial in storing and breaking down pollutants, although little published information is available. Pollutant budgets should be calculated for the buffer zone from detailed monitoring of their concentration, and by calculating their fluxes entering and leaving the system over an annual cycle. Selected monitoring upstream and in the nearshore marine environment would help to elucidate the role of the coastal interface in regulating pollution loads.

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10. ANNEXES

10.1 ANNEX A - Acronyms

CAR/RCU	Caribbean Regional Co-ordinating Unit
CARICOM	Caribbean Community and Common Market
CEP	Caribbean Environment Programme
CEPPOL	CEP Assessment and Control of Marine Pollution
CLUWRR	Centre for Land Use Water Resources Research
CIA	Central Intelligence Agency
DFID	Department for International Development (UK)
FAO	Food and Agriculture Organisation
IRF	Island Resources Foundation
LC_{50}	Lethal Concentration 50th percentile
LWI	Land/Water Interface
NOAA	National Oceanic and Atmospheric Administration
ODA	Overseas Development Administration (UK)
SIDS	Small Island Developing States
USDA	United States Department of Agriculture
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organisation
WRI	World Resources Institute

10.2 ANNEX B - World-Wide Web page addresses for organisations with bibliographic source databases and information relating to pollution in the Caribbean.

Food and Agriculture Organisation of the United Nations	http://www.fao.org/
Island Resources Foundation	http://www.irf.org/irhome.html
Island Resources Foundation - A Bibliography of Coastal Zone Materials	http://www.irf.org/irczrefs.html
Millersville University - Caribbean Coastal Studies	http://www.millersv.edu/~ccs/contents.html
Small Islands Developing States	http://www.unesco.org/ioc/sids.htm
The Caribbean Environment Programme	http://www.cep.unep.org/
The Caribbean Regional Co-ordinating Unit	http://www.cep.unep.org/cep/rcu.html
The CIA world factbook	http://www.odci.gov/cia/publications/nsolo/
The Global Environment Facility	http://www.gefweb.com/gefgraph.htm
UNCED	http://sol.oc.ntu.edu.tw/omisar/apec-me/un/agenda21.html
The Small Islands Information Network	http://www.upei.ca/~siin/
United Nations Environment Programme	http://www.unep.org/
UNEP CAR/RCU - CEP Technical Reports	http://www.cep.unep.org/pubs/techreports/techreports.html
UNESCO, United Nations Educational, Scientific and Cultural Organization	http://www.unesco.org/

Review of the impacts of pollution by sediments and agro-chemicals of tropical coastal waters with reference to the Caribbean Region.

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Scope

This document reviews the effects of sedimentation on the coastal zone, with particular reference to those studies undertaken since the major reviews by Hatcher *et al.* (1989) and Roger (1990). The type and effects of agro-chemicals on the coastal habitats in the Caribbean Region are discussed. There are other sources of land-based pollution affecting the coastal zone, such as sewage and industries, but these are not considered here. Watershed problems and management regarding pollution and sedimentation mitigation are examined, using primarily examples from the Caribbean. Gaps in the current knowledge are addressed by listing a number of potential projects.

1. *Introduction*

As part of a research programme, the Land/Water Interface (LWI) commissioned MRAG Ltd to review currently available literature on "the quantification of movement of sediments and pollutants of agricultural origin into the coastal zone, and of the impacts of these pollutants and sediment loads on coastal resources". The review should also address issues of watershed management as they relate to the generation of these potential pollutants. By request, the review is centred on the Caribbean Region (where the LWI intends to conduct research) but includes the results of research undertaken in other areas.

Chapter 17 of Agenda 21 discusses the sustainable development of Small Island Developing States (SIDS) in relation to marine and coastal area management. The role of science is emphasised as the primary tool to determine and to monitor all renewable resource management. This is of particular relevance to the review, as a result of which knowledge gaps will be identified that would be amenable to researchable solutions and of value to the aims of SIDS/Programme of Action (SIDS/POA).

1.1 Environmental issues in the Caribbean

This brief overview is provided in order to put the review in context, and to emphasise the complex political/economic nature of the Caribbean region which has a bearing on the work that needs to be done and can be achieved.

The economies of the countries in the Caribbean region are based on export agriculture and fisheries, tourism, mining and hydro-carbon exploration, with manufacturing as a growing secondary sector. Belize, Guyana and Surinam have extensive forest reserves. Commercial mineral resources of bauxite exist in the Dominican Republic, Guyana, Haiti, Jamaica and Surinam. Trinidad and Tobago has oil and natural gas. The marine environment, however, is the dominant feature of the whole region. In the case of most of the islands, particularly the smaller ones, land-based activities like construction and agriculture, have a direct bearing on the coastal habitats. Indeed, it has been argued, that since the coastal area to landmass ratio is large, the whole island comprises the coastal zone (OECS-UNDP, 1994). The majority of the population lives along the coast, including the continental states of Surinam, Guyana and Belize (e.g. in Guyana with a land area of 216,000 km^2, 90% of the population lives within 5 km of the coast). For all the states their Exclusive Economic Zone (EEZ) represents a major natural resource. Land use is often intensive, because of the scarcity of land, and creates conflicting demands.

The environmental problems affecting the coastal and marine resources are recognized as problems stemming from population pressure, the expansion of recreational areas, inappropriate agro-forestry practices, the concentration of industrial activities in the coastal zone, accompanied by inadequate environmental, technological and economic policies. Jurisdiction for coastal and marine resources is often sectoral, resulting in 'piecemeal' development, unregulated activities and competition. The physical and ecological degradation of coastal and terrestrial areas, and the pollution of inland and near-shore waters from land-based sources are accelerating in the wider Caribbean region.

1.2 Status of coastal habitats in the Caribbean Region

About 14% of the area of the world's coral reefs are found in the Caribbean region. Fringing and patch reefs are the most common around islands. Of note are the barrier reef system of Belize (approx. 220km long) and the Andros barrier reef system in the Bahamas (approx 175km long) (Stanley 1995). The status of coral reefs was reviewed in detail by Wells *et al.* in 1988 (UNEP/IUCN, 1988) and updated in 1992 (Brown *et al.*, 1992) and, in the context of identifying sites for protection, by Stanley (in GBRMPA/WB/IUCN, 1995). Possibly the least well known reefs in the Caribbean are those around Haiti, where little work has been done. Reefs situated in outlying areas and therefore not much visited or affected by land run-off (e.g. Grand Turk, southern Bahamas) are healthy and in a good condition. The reefs of the small volcanic islands of the Lesser Antilles, which are easily accessible to fishermen and subject to run-off and land-based pollution, have some problems. Long-term studies show that reefs in Jamaica have deteriorated as a result of hurricanes, overfishing and sea urchin mass mortality (Hughes, 1989; Koslow *et al.*, 1988). Stanley (1995) summarised the ecological features and resource problems of Caribbean countries, and not surprisingly coastal construction, sand mining, erosion, fertiliser run-off and other pollution, were highlighted as particularly widespread problems (see also Appendix II).

The distribution of mangrove forests in the Caribbean has been mapped by WCMC (1995). The most extensive mangrove forests can be found along the coast lines of countries with extensive river systems, such as Central and South America, and the Greater Antilles. Of the true mangrove species occurring in the Wider Caribbean, the red (*Rhizophora mangle*), black (*Avicennia germinans*) and white (*Laguncularia racemosa*) mangroves are the most widely distributed. In marginal environments mangroves remain scrubby and small, but in suitable areas, such as the Rio San Juan in Venezuela, the trees can grow up to 40m. Threats to mangroves has been highlighted extensively (UNEP/IUCN, 1988; UNEP-CEP, 1989). Stanley (1995) briefly summarised some of the impacts on mangroves, such as clearing for shrimp ponds in Costa Rica, and destruction for fuel wood in Haiti and the Dominican Republic.

The seagrass meadows in the Caribbean are usually composed of *Thalassia testudinum*, or turtle grass, which is the dominant species, interspersed with *Syringodium filaforme* and *Halodule wrightii*, as well as such algae as *Halimeda*, *Penicillus*, *Udotea*, *Caulerpa* and *Rhipocephalus*. The blades of *Thalassia* are extensively covered with epiphytes. The status of seagrass beds is less well known. There is as yet no distribution map of seagrass beds for the Caribbean, although the need for such vital information is recognised and funding is being sought to fill this information gap (Ed Green, WCMC pers. com. .17.07.98). The main problem affecting seagrass beds in the Caribbean is increasing sedimentation (Stanley, 1995).

1.3 Impacts on the coastal zone

1.3.1 Natural Impacts

Natural impacts on the coastal habitats are many. They are listed here to make the point that, coupled with natural impacts, human disturbances can have far more long-term and destructive consequences, as the communities are already stressed and therefore more prone to damage. Natural impacts include hurricanes (e.g. *Hurricane Luis*, 1995), fluctuating water temperatures and extreme tides (e.g. ENSO), natural sedimentation levels, diseases and tectonic events (see also the Special Issue of Coral Reefs, Vol. 12, dedicated to disturbance effects on coral reefs). In the long-term, these disturbances may have a positive effect on the reef community, by increasing biological diversity (Connell, 1978). Coastal communities have evolved to cope with such disturbances as long as they are single events, not occurring too frequently, allowing time for repair and recovery. It is being proposed, however, that extreme climatic events will be occurring with greater frequency and more intensity as a result of changing atmospheric conditions (Pearce, 1989).

The effects of sedimentation, nutrient elevation and pollution on the organisms and habitats in the coastal zone are not easy to observe. Elevated nutrient levels, which may lead to eutrophication and thus increased phytoplankton growth, cause higher turbidity levels, which is easily confused with increased sedimentation effects, as suspended particulate inorganic matter also causes higher turbidity. To a layperson, sedimentation and eutrophication may mean pollution, however in the context of this review pollution is defined as unnaturally high levels of particular chemicals dissolved in the water column, which have an effect on the coastal zone. Fertilisers (nutrients) and pesticides are often mixed in with terrestrial sediment run-offs as the chemicals can bind to the soil. Chemicals bound to particles on land may be released in seawater. It is therefore difficult to distinguish between the various impacts these may cause, either in combination or individually.

1.3.2 Human Impacts

The effects of pollution and other anthropogenic stress on coral reefs have been reviewed by Brown and Howard (1985), Hatcher *et al.* (1989), Rogers (1990), Richmond (1993) and Dubinsky and Stambler (1996), and the effects on mangroves and seagrass beds have been described by Fortes (1988), Eng *et al.* (1989), Preen (1991), and Oehman *et al.* (1993). Pollution generated on land, such as upriver through farming practices, deforestation and mining operations (Sudara 1981; Dugan 1990), can have just as devastating an effect as direct pollution within the coastal marine habitat, such as sewage outfall, dredging or sand mining. In all cases, pollution decreases local diversity and can lead to a complete change in the ecological community.

For the purpose of this review, land -based sources of pollution and sedimentation are the main focus. A recent global review on the state of the marine environment (GESAMP, 1990) shows that pollution from land-based sources is on a much greater scale than from atmospheric or ocean-based sources (e.g. Yellow Sea, Zhang 1994). Sewage and/or siltation is regarded as one of the most widespread problem(s) resulting in the degradation of the coral reefs and other coastal environments in the Philippines (Gomez *et al.*, 1989; Wilkinson, 1993), Singapore (Chou, 1991), Indonesia

(Wilkinson, 1993), Sri Lanka (Rajasuriya *et al.*, 1995), in the Pacific Islands (Brodie *et al.*, 1990; Richmond, 1993a and b), Hawaii (Hunter and Evans, 1995), in the Persian Gulf (Lindén *et al.*, 1990), the Gulf of Aqaba (Fishelson, 1995), Eastern Africa (Coughanowr *et al.*, 1995) in the Caribbean (Smith and Ogden, 1993; Siung-Chang, 1997), along the Columbian and Costa Rican Caribbean coast (Garzòn-Ferreira and Kielman, 1993; Cortes, 1993) and in Cuba (Alcolado *et al.*, 1993).

Most studies on the impact of elevated nutrient levels on corals have been carried out on sewage (e.g. Littler *et al.*, 1992; Parnell 1992; Miller and Mendes, 1992; Grigg, 1994; Grigg, 1995). Other studies have shown the effects of organic effluents from industries, such as sugar refineries for example (Cuet and Naim, 1992). Enclosed bays or reefs with little water circulation are particularly at risk (Maragos *et al.*, 1985; Grigg, 1992). Chemical pollution is often accompanied by enhanced sediment levels, making the effects difficult to separate (Walker and Ormond, 1982).

Since this review is primarily addressing the effects of agricultural activities, a summary (Table 1) has been compiled to show some of the main potentially harmful effects of agriculture on the coastal zone. The effects of sedimentation and pollution have been reviewed in more detail.

Table 1 Main harmful effects of agricultural activities on coastal ecosystems (adapted from FAO 1998).

Activity	Environmental change	Impact of social concern
Estuary flood control. impoundment or diversion of coastal rivers	increase estuarine salinity. reduced circulation. sediment trapping. decreased supply of beach material to shoreline. shoreline erosion	reduced crop yields. reduced fish yields. increased water-borne diseases
Agricultural pesticides	toxic pollution of estuaries and inshore waters	killing of fish. reduced fish yields. potential human consumption of toxic fish. coral pollution and loss
Fertiliser use	increased amount of nutrients. eutrophication and pollution of estuaries	killing of fish. reduced fish yield, coral pollution and loss
Overcropping or grazing in coastal watershed	watershed erosion. estuary sedimentation and increased turbidity. increased deposition in flood plains	corals and beaches covered with sediment. coral death, decline in fish yields. decreased recreation and tourism attraction. obstruction of navigation channels with sediments
Irrigation from coastal aquifers	depletion of coastal aquifers	saltwater intrusion, contamination of groundwater
Coastal wetlands reclamation	draining or dyking, physical destruction of habitat. toxic (acid) drainage. change in sedimentation patterns. change in water circulation/ drainage. loss of coastal protection (mangroves). increased waterborne diseases	loss of wetland and forest/ wildlife production. loss of biodiversity, loss or rarefaction of endangered species. killing of fish. reduced fish yields. increased storm damage and coastal erosion
Intensive livestock activities	organic effluent. eutrophication and pollution	killing of fish. reduced fishery yields. coral pollution and loss. reduction in recreation and tourism attraction
Over-grazing on coastal dunes	destabilisation of dunes	initiation or increased dune migration on to agricultural or urban areas and on infrastructure
Agro-industries	organic and toxic effluents. eutrophication and pollution	killing of fish. reduced fishery yields. coral pollution and loss. reduction in recreation & tourism attraction

2. Sedimentation

2.1 Introduction

Before discussing the effects of enhanced sedimentation on the coral reef, it has to be pointed out that sedimentation is also a natural process (Marshall, 1983; Davies, 1983). Through the accumulation of sediments which result from the breakdown of some of the constituent biota (i.e. bioerosion), reefs are responsible for the formation of beaches, cays and atolls. In addition, the reef organisms have evolved to cope with the natural influx of sediments from terrestrial run-offs, and stirred up bottom sediments through waves and currents. Normal sedimentation rates have been suggested to be less than 10mg/cm²/day (Rogers, 1990). Coral reef organisms, such as scleractinian corals are well adapted to cope with natural sedimentation rates (Lasker, 1980; Stafford-Smith and Ormond, 1992; Stafford-Smith, 1993).

2.2 Source and type of sediments

Activities, such as land clearing, logging (e.g. Costa Rica, Cortes and Risk, 1985; Philippines, Hodgson 1993), construction mining and dredging, result in increased sedimentation in the coastal zone, adding terrigenous matter of varying particulate size to the already existing background sedimentation. For example, a study by Hodgson and Dixon (1988) at Bacuit Bay in the Philippines, showed that heavy logging in the forests surrounding the bay increased erosion to 200 times the normal rate and resulted in 5% of the reefs in the bay dying. Even if the reefs are a long way from the source of activity, such as upland road building or forestry close to a river, the increased sediment load can be carried by the river or, during heavy rains, by land run-off to the coast (e.g. St. Lucia, where heavy rains during tropical storm Debbie in 1994 caused massive soil erosion to the West Coast Road project, despite exemplary erosion control practices; the soil washed onto coral reefs where they caused coral bleaching and death (Nowils *et al.*, 1997).

The knock-on effects of inland activities are particularly noticed on small islands, where the coast is never far away (OECS-UNDP, 1994). In the Wider Caribbean Region many of the major watersheds are suffering from serious devegetation and erosion as a result of shifting cultivation, seasonal burning, fuel wood collection and road building. More than 2 million hectares of Caribbean tropical forests are destroyed annually, while a mere 70,000ha are replanted (UNEP-CEP, 1989). Locally, in Central American countries annual soil erosion rates have been found to be as much as 500 metric tons per hectare. Extremely high sediment loads have been recorded in rivers, coastal bays and estuaries (Tables 2 and 3).

Table 2 Sediments discharged by major rivers into the Caribbean Sea (adapted from UNEP-CEP 1989)

River	Drainage Area (1000km^2)	Sediment discharge (10^6 tons/ yr)	Specific transport (t/km^2/year)	Mean turbidity (mg/l)
Magdalena (Colombia)	235	234	1000	1000
Orinoco (Venezuela)	950	85	91	90

Table 3 Surface Drainage in Central America into the Caribbean Sea (adapted from UNEP-CEP 1989).

Country	Area (10^3 km^2)	Percent
Nicaragua	117	90%
Honduras	92	82%
Guatemala (incl. Gulf of Mexico)	86	79%
Panama	24	31%
Costa Rica	24	47%
Belize	23	100%

2.3 Recorded effects of sediments on the coastal zone

2.3.1 Coral Reefs

The effects of sedimentation on coral reefs have been reviewed extensively (Hatcher *et al.*, 1989; Rogers, 1990) and are briefly updated here by more recent research.

In summary, Hatcher *et al.* (1989) noted that increased sediment load in waters surrounding coral reefs resulting from land clearing, construction, mining, dredging, and drilling activities continued to be a major threat to their conservation in many regions. When sedimentation occurs, adverse effects on sessile benthic organisms were strongly species-specific, ranging from minimal to catastrophic. Studies on corals demonstrated decreased calcification, photosynthetic and nutrient uptake rates, and increased production of mucus, zooxanthellae expulsion and pathology. Adaptive responses by corals restrict mortality. Rogers (1990) was also highlighting the fact that unprecedented development along the tropical shorelines was causing severe degradation of coral reefs primarily from increased sedimentation. Heavy sedimentation was associated with fewer coral species, less live coral, lower coral growth rates, greater abundance of branching forms, reduced coral recruitment, decreased calcification, decreased net productivity of corals, and slower rates of reef accretion. It was concluded that the decline of tropical fisheries was partially attributable to deterioration of coral reefs, seagrass beds and mangroves from sedimentation. The review highlighted the need for longterm datasets for tracking these complex ecosystems and to develop predictive models for impacts.

The effects of sedimentation on sessile coral reef organisms depends on whether the sediment is delivered directly (through dumping or dredging) or passing through the ecosystem resulting in lowered turbidity. In addition, the duration of the impact is important, whether the sedimentation event is acute or chronic. The impact of direct sedimentation on corals is species specific depending on coral morphology and polyp size (Hodgson, 1993), ranging from little effect to death of coral (Riegl, 1995; Rice and Hunter, 1992) although initially unaffected species will eventually succumb to high prolonged sedimentation (i.e. smothering). Laboratory experiments on corals are notoriously difficult, but it has been possible to measure physiological responses to different sediment and light levels (Riegl and Branch, 1995). Sediments and turbidity affect the daily energy budget of the coral, through reduced photosynthesis and mucus production. Indeed, it was shown that mucus production was an important carbon sink, deflecting from coral growth. For example, a sediment rate of 1.1 mg/cm^2/day above normal was enough to inhibit the growth rate of *Montastrea annularis* (Dodge *et al.*, 1974). Some evidence suggests that sediment, especially after forming a depositional layer, may stimulate the reproduction of pathogenic bacteria, indicating that bacterial infections play a role in increasing coral tissue necrosis due to sedimentation (Hodgson, 1990a).

The settlement of *Pocillopora damicornis* larvae appeared to be affected by sediment, where the larvae seemed to recognise loose fine sediment and avoided it for attaching onto (Hodgson, 1990b). This study indicated that sedimentation, even at lower levels not necessarily detrimental to the adult colony, significantly reduced larval recruitment by inhibiting larval settlement (Babcock and Davies, 1991; Te, 1992). Success of larval development of corals was reduced by runoff, in some cases by as much as 50% (Richmond, 1993). At the coral community level, increased sedimentation over a longer time scale can severely affect settlement of coral larvae. It was suggested, as a result of experiments, that a decrease in overall light penetration would make many of the cryptic microhabitats unsuitable for coral recruitment due to sub-optimal light regimes. This would then restrict coral settlement to the upper surfaces, exposing spat to higher levels of sedimentation and grazing activity, resulting in a substantial reduction in settlement, growth and survivorship of corals (Maida *et al.*, 1994).

Increased turbidity levels limit coral growth (Te, 1997) and reduce coral species diversity, as tolerance to turbidity levels is coral species specific, and dependent on coral morphology, where flat plate-like shapes can cope with less light influx. Tolerance also varies with reef location and depends on background turbidity conditions and hydrodynamic setting. Along some coasts, unusually high turbidity can be generated by strong tidal flows which resuspend bottom sediments. Such chronic turbidity can constrain reef accumulation rates and compress reef colonisation depth (Kleypas, 1996). In the Atlantic tolerable levels of suspended sediments for shallow water corals have been estimated at 5-10ppm, with concentrations of 100ppm severely limiting coral growth (Pastorak and Bilyard, 1985). In the GBR it has been suggested that fringing reefs at Cape Tribulation have become acclimatised to higher sediment loads in excess of 100mg/l (Hopley *et al.*, 1989). On a short time scale there is no doubt that corals are stressed by increased turbidity, as they produce mucus in response to this stress (Telesnicki and Goldberg, 1995). Corals under stress are much more likely to succumb to bacterial infections, as elevated bacterial levels grow on mucus strands (Segel and Ducklow, 1982). A study by Iglesias-Prieto and Trench (1994) showed that the endo-symbiotic dinoflagellate *Symbiodinium microadriaticum* responds to lower irradiance by increasing in numbers, thus suggesting that certain coral species can cope with elevated turbidity by boosting their number of photosynthetic units.

Alcyonarians have been shown to be able to survive in high turbidity, but unable to cope with settling sediments as they have no physiological mechanism to rid themselves of sediments, instead depending entirely on wave action and currents to do that (van Katwijk *et al.*, 1993; Riegl, 1995; Riegl and Branch, 1995). Reef communities adapt to the level of sediment influx, as an 8 year study in Kenya by McClanahan and Obura (1997) showed. The study reefs appeared to tolerate permanent changes in sediment input through the continued growth of more sediment-tolerant species.

Little work has been done on the impact of increases in turbidity on coral reef fish. This is most likely due to the difficulty of conducting field observations in turbid waters. It was suggested that for fish species that actively search by sight, hunting efficiency was reduced in turbid waters (Hecht and Vanderlingen, 1992). For macrobenthic feeders turbidity has little impact on their feeding ability but may reduce the efficiency of their predators. Benfield and Minello (1996) showed such an effect on the hunting ability of the killifish *Fundulus grandis* in the Gulf of Mexico, where increased turbidity lead to the reduction in the numbers of shrimp taken in any hunting period.

2.3.2 Mangroves

Mangrove swamps are often regarded as marginal land and are being systematically degraded and destroyed, despite their critically important role in sediment retention as well as coastal protection from erosion. About 65% of all mangrove swamps in Tabasco State, Mexico, have been eliminated by petroleum activities, threatening the continues existence of the shrimp fishery in that area (UNEP-CEP, 1989). Often selected as sites for dumps or landfills, mangrove areas, with few exceptions, are devoid of meaningful protection. For example, Trinidad's 15,000 acre Caroni Swamp supports the principal land fill for Port-of-Spain and is the disposal site for dredged material from the harbour (Toppin Allahar, pers.com. 1995).

Although mangroves are adapted to grow in areas of higher sedimentation, e.g. at river mouths, they can still be affected by uncharacteristically high sedimentation rates, e.g. dumping and dredging operations. This is because sediments can smother root extensions (pneumatophores and prop roots) that supply the underground parts of the roots with oxygen. If the rate of sediment accumulation is faster than root growth the mangrove tree will die.

2.3.3 Seagrass Beds

Despite their vital role within the coastal ecosystem, comparatively little in-depth work has been done on seagrasses. Most human activities affect seagrasses either through a reduction in light availability or changes in sediment dynamics, often caused by hydrodynamic changes. Loss of seagrass beds in the vicinity of coral reefs can have a negative impact on the reefs, since the beds retain and stabilise sediments preventing reef abrasion or burial during storm conditions.

Seagrass meadows occur between an upper limit imposed by exposure to desiccation or wave energy, and a lower limit imposed by penetration of light at an intensity sufficient for net photosynthesis. Growth form and light use are significant for the capacity of seagrasses to survive increased turbidity and siltation (Vermaat *et al.*, 1997). A small increase in turbidity will therefore reduce the depth range of seagrasses (Larkum and West, 1990) and thus affect their distribution (Calem and Pierce, 1992). Large shoot size or the capacity to elongate vertical stems enables several species to raise their leaf canopy closer to the water surface and thus suffer less in turbid water (Vermaat *et al.*, 1997). Elongate vertical stems also allows a response to siltation where sedimentation rates between 2-13cm/yr can be coped with depending on the species (Vermaat *et al.*, 1997). Particulates on leaves could eliminate meadows over extensive areas of shallower water. Seagrasses are absent from areas with high turbidity (Calem and Pierce, 1992).

Chemical wastes (mainly oil and fertilisers), dredge and fill operations, thermal discharges and sedimentation are degrading seagrass beds at an alarming rate worldwide. A survey in Australia showed that seagrasses have reduced in area by over 45,000ha over the last few decades (Walker and McComb, 1992). An increase in sedimentation has been partly blamed for this decline, as a result of increasing coastal construction activities and poor watershed management. It was shown that the effects of sedimentation was species specific, with flat-bladed genera such as *Posidonia* and *Heterozostera* being more likely to be blanketed by fine sediment. Seagrass beds adjacent to a smothered or damaged seagrass site (e.g. from dredging or sand extraction) may recover through reseeding from the undamaged site (Penn, 1981). Shoot size and horizontal rhizome growth rates vary considerably between species. Rapid rhizome expansion at rates between 1m and 10m per year was measured for the Mediterranean species *Cymodocea nodosa* and for the Philippine species *Cymodocea serrulata, Syringodium isoetifolium,* and *Halophila ovalis.* This should allow efficient colonisation following disturbance (Vermaat *et al.*, 1997). The ability of a seagrass bed to cope with increased sedimentation and turbidity depends also on location, (e.g. wave action or bays) and on whether the sediments include toxins or there are changes in the herbivore community caused by the impact (Walker and McComb, 1992).

Very little is known about the distribution and health of the seagrass beds in the Caribbean.

3. Agro-chemicals

3.1 Introduction

Aside from physical and ecological degradation of the coastal and marine environment, pollution from land-based sources is at present the single most important threat to the marine environment and impediment to the use and sustainable development of the coastal zones. It is estimated that worldwide land-based sources contribute about 77% to the pollution load of the oceans: 44% through run-off and discharges, and 33% through the atmosphere. Solutions to the problem may be costly, with estimates in billions of dollars in the Caribbean Region alone, but the benefits derived and the value of damaged ecosystems and resources at risk (including public health, fisheries, tourism, etc.) outstrip these costs (UNEP(OCA) / CAR 1992).

In the Caribbean Region, it is estimated that land-based sources account for 80-85% of marine pollution (OECS-UNEP, 1994). Sources include residential, agricultural and industrial origins which are transported to the coast via streams and water run-off, by leaching and infiltration through the soil, and by direct (piped) discharges into the sea. Overwhelmed by the need to treat domestic sewage, there is almost total disregard of the dangers posed by industrial effluents. Chemical plants, car battery salvage operations, metal plating plants, petroleum refineries, printing plants, and hospitals, all, to some extent, produce highly toxic, non-biodegradable waste products that infiltrate into ground and surface waters, or are directly discharged into the sea (UNEP-CEP, 1994). For example, toxic chemicals, such as chromates, zinc and cyanides, from a galvanizing operation near Belize City have caused extensive fish kills over the past few years (UNEP-CEP, 1989). In 1988 a massive fish kill in the Gulf of Paria was reported by the Institute of Marine Affairs of Trinidad and Tobago, an incident resulting from oxygen depletion associated with an outbreak of algal blooms. A common source of pollution is effluent generated by the refining of sugar and the distillation of alcohol (in Barbados for example). Such effluents contain high amounts of solid residue which cause an extreme oxygen depletion and result in rapid environmental deterioration.

Adding to the pollutants from industries, are the less obvious but equally damaging leachates from land-fill sites. Traditionally in the Caribbean islands, solid waste is disposed of in poorly designed land-fill sites, frequently located in lagoons and coastal swamps. The effects of the leachates have been little quantified or even qualified.

A recent review by Siung-Chang (1997) specifically addressed marine pollution issues in the Caribbean, concentrating on oil pollution, marine debris, sewage and industrial waste. Sewage was identified as causing the most widespread pollution and is possibly the most serious marine pollution problem. Pesticides were not specifically mentioned, although nutrient input from animal husbandry was regarded as a serious local issue.

The following sections differentiate between pesticides and fertilisers, both of which are classified generally as agro-chemicals.

3.2 Source and type of pesticides

3.2.1 Background

The issue of organochlorine pollution is rather complicated since it is difficult to obtain a clear picture on the amount of production and usage of these chemicals in the various countries. Loganathan and Kannan (1994) provided a generalised assessment of the existing situation for organochlorine trends in the global environment. Human populations in developing countries are exposed to high levels of organochlorides from food and air as a result of increasing use of such chemicals (Mowbray, 1988; Balk and Koeman, 1984; Indian Chemical Statistics, 1986). Since many industrialised nations import foodstuffs from developing agricultural countries, the populations in the developed nations are exposed to organochlorides through the food. A few countries, which once banned DDT, have now started using it again because of increased outbreaks of malaria after the ban on DDT (Chapin and Wasserstrom, 1983; Thompson, 1990). In addition, many developing countries are being used as dumping grounds for hazardous and highly toxic pesticides because many have virtually no policy to check the inflow of undesirable chemicals (Vir, 1989; French, 1990; Jain, 1992). Despite this no comprehensive contaminant monitoring programmes, including long term trend studies and toxicological investigations, have been carried out in the developing countries, due to the economic and political implications of such studies (Martin and Richardson, 1991;Mrinalini, 1984).

Pesticides used in agriculture include a number of chemicals that are favoured because of their wide application, broad spectrum toxicity, cheap production and chemical stability and therefore long environmental half-lives. However, the range of chemicals in use includes 9 Persistent Organic Pollutants (POP): Aldrin, Chlorane, DDT, Dieldrin, Endrin, Hexachlorobenzene, Heptachlor, PCB and Toxaphene. These POPs are 9 out of the 12 (the other 3 are mirex, furans and dioxins) that have been identified as most hazardous, although they are still being produced, distributed and used as pesticides. Noticeably missing from this 'most-hazardous' list are endosulfan and organotins which are of particular concern in the Philippines (IFCS, 1996).

Most of the listed POPs are pesticides and industrial chemicals that were widely produced as marketable commodities following *World War II*. These products are synthetic substances that did not exist in the global environment prior to the advent of industrial chemistry. Their production, use and release into the environment peaked in the 1960s and 1970s. Dioxins and furans, on the other hand, have never been intentionally produced as marketable commodities. It is generally acknowledged that pre-industrial environmental dioxin loadings amounted to only a small fraction of current loadings

The use of the nine listed POPs for pest and disease vector control has decreased in most developed countries since the 1970s (Loganathan and Kannan, 1994). This can be partly attributed to the growing concerns about the adverse human health and environmental impacts associated with their use, and the consequent implementation of legal restrictions in these countries. In developing countries, information on sources, patterns of use and release of the nine listed pesticide POPs is inadequate and needs to be improved. However, the information that is available clearly indicates that most of the nine listed pesticide POPs are being traded and imported by developing countries in significant quantities. The listed commercially produced industrial POPs are the PCBs and HCB (which is also used as a pesticide). PCBs have been produced commercially around the world since 1929 for a wide variety of uses. World-wide production has been estimated to be 1.2 million tonnes, although production in most industrialized nations has been halted. In 1982 it was estimated that approximately 31% of PCBs had been released to the general environment, 4% had been destroyed and the remaining 65% were still in use or storage or deposited in landfills. Incineration has been widely used for the destruction of PCB stockpiles and for the clean-up of soils, sediments and industrial equipment. This practice, however, is subject to considerable controversy as incinerators can generate and disperse dioxins, furans, and other toxic substances into the environment. They can also disperse uncombusted PCBs to the air or transfer them to ash and dusts collected by pollution control equipment. New technologies are emerging that destroy PCBs and other chlorinated organics by non-combustion methods in enclosed systems. HCB was never manufactured on a large scale. It does arise as an unwanted by-product from industrial processes, in the manufacture of certain pesticides and chlorinated solvents and during waste incineration (IFCS, 1996).

Dioxins and furans are generated as unwanted by-products during the production of materials such as chlorinated plastics, solvents, various chemicals (including pesticides), and during chlorine-based pulp bleaching processes. The degree of dioxin and furan emissions that may arise from these processes has not been well quantified, either on a national or a global basis. Significant advances in a full range of cleaner technologies have been developed for certain industries and industrial processes to reduce or eliminate the production of these unwanted byproducts (IFCS, 1996).

3.2.2 Trade in POPs

A UNEP survey on sources and releases of POPs (IFCS, 1996) tried to establish world trade of these widely prohibited chemicals (Table 4 and Table 5). The study does suggest that on a global level, trade in severely restricted chemicals still occurs, particularly of those chemicals that have been forbidden in the producing countries. Inadequate enforcement resulting from socioeconomic difficulties has encouraged chemical companies to build new or move existing facilities to developing countries in the disguise of economic investments, thereby facilitating export of highly toxic pesticides to these countries. The majority of the pesticides used in the Philippines, for example, particularly by subsistence farmers and plantation workers, are older products that are off-patent and relatively cheap. Most of these belong to WHO Categories I and II. In Table 4 restrictions on the use given for a certain export or import quantity may account for some of the trade but it is probable that some domestically banned chemicals were exported and/or imported in 1994.

Table 4 Summary Indication of Trade in Restricted Chemicals in the Philippines

	1990			1994		
Import	Production	Export	Import	Production	Export	Import
Aldrin	+	0	+	+	0	+
Chlordane	+	+	+	0	+	+
DDT	+	+	+	+	+	+
Dieldrin	+	0	+	+	+	+
Endrin	0	0	0	0	0	+
Hexachlorobenzene	0	+	+	0	+	+
Heptachlor	+	+	+	0	+	+
PCB	0	+	0	0	+	+
Toxaphene	+	0	+	+	0	+

Key:

+	Data have been submitted that show production, export or import takes place.
0	Either no data have been submitted that indicate trade takes place or no production, export or import takes place.

Table 5 Global overview of legal status of the nine most important POPs

Chemical	No. of countries having banned/ prohibited chemical	No. of countries having restricted chemical	No. of countries having restricted import of chemical
Aldrin	26	7	52
Chlorane	22	12	33
DDT	30	10	46
Dieldrin	33	9	53
Endrin	28	2	7
Heptachlor	23	8	36
Hexachlorobenzene	13	-	4
PCB	2	6	5
Toxaphene	18	5	1

It is unclear from the survey to what degree the 9 POPs are being phased out and how much of the ongoing trade is in existing stocks. It is also not clear whether the PCBs reported are wastes or are being traded for commercial purposes. The survey showed how difficult it is to get information on remaining uses, production and trade of POPs. Data on emissions and releases of by-products are also scarce, especially in developing countries and in countries with economies in transition.

The survey identified the need for some mechanism to monitor trends, including methods for monitoring emissions of dioxins and furans. There is a need for harmonization of definitions and reporting methodologies. For example, the Philippines is one of the countries in the Asia and Pacific Region with significant advances in adapting pesticide regulations in conformity with UNEP/FAO and other internationally-recognized regulatory agencies. It complies with one of the main prerequisites for efficient risk management, i.e. an appropriate registration scheme.

3.2.3 Health aspects of POPs

The hazards associated with persistent organic pollutants or POPs have been known for years and the knowledge of the extent of harm they cause has increased. They are highly toxic, remain in the environment for long periods, become more concentrated as they go up the food chain, and can spread thousands of kilometres from the point of emission. The weight of scientific evidence strongly suggests that over-exposure to certain POPs can cause serious immune and metabolic effects, neurologic defects, reproductive anomalies, cancer and other abnormalities in both humans and animals (see also Appendix II which lists some of those chemicals known to be used in the Caribbean).

Some of the reasons why pesticides pose a particular health risk, besides their chemical make-up, are given here. For example, the instructions on pesticide labels may at times be too complicated for farmers to understand and apply. Farmers may experiment with pesticide combinations and also deliberately underdose due to financial considerations. The manner of disposal of pesticide left-overs, pesticide-contaminated containers and stockpiles of banned products also increase the risk of exposure to pesticides. Most pesticide handlers use backyards or open fields for disposal purposes while some sell the used pesticide containers or throw them into nearby water bodies. In developed parts of the world, hazardous wastes are chemically treated, incinerated, landfilled or recycled. In many developing countries, like the Philippines, no major facilities exist to properly dispose toxic and hazardous wastes including unwanted pesticides. There is only one incinerator in the country.

There is general agreement among experts that enough scientific knowledge exists on the adverse human health and environmental impacts of POPs to warrant immediate national, regional and international action, including bans and phaseouts. Work has started among nations to develop legally binding agreements to ban or restrict the production, distribution and use of POPs (IFCS, 1996). As part of this review, information on some of the most important and still widely used POPs has been collated in order to give an overview on their characteristics and trade details (Appendix II). This is of particular relevance in conjunction with the proposed research priorities in Section 5.

3.2.4 POPs in the Caribbean

On many Caribbean islands, traditional small scale family farms are giving way to large scale industrial-sized agricultural enterprises with a correspondingly increased and frequently indiscriminate use of fertilisers and pesticides to boost yields of export crops. The consumption of pesticides has almost doubled between 1973 and 1985 (Table 6; UNEP-CEP, 1994). Few restrictions are enforced on the importation, production and use of pesticides. On some cotton fields up to 80kg of insecticides are used per hectare, one of the highest levels of use in the world. In Costa Rica during the 1980s the average pesticide consumption was about 195kg per km^2 of land, almost 10 times the estimated 20kg per km^2 for the land surface of the entire earth. Accidents from pesticide poisoning are not rare, mainly due to ill-informed application. The easy availability of agro-chemicals, some of them extremely toxic, is also indicated by the common poisoning of humans throughout the region. For example in Costa Rica alone an average of 553 cases of pesticide poisoning are reported each year (National Report of Costa Rica to UNCED, 1992).

Table 6 Average annual pesticide use in 14 countries of the Wider Caribbean Region (adapted from UNEP-CEP 1994)

Country	Pesticide use in tons 1974-77	Pesticide use in tons 1982-84
Colombia	19344	16100
Costa Rica	3037	3667
Dominican Republic	1961	3297
Guatemala	4627	5117
Guyana	705	658
Honduras	940	859
Jamaica	861	1420
Mexico	19148	27630
Nicaragua	2943	2003
Panama	1542	2393
Suriname	974	1720
Venezuela	6923	8143

The extensive use of pesticides (insecticides, herbicides, fungicides, etc.) is due to intensive export-driven agricultural activity in many Caribbean countries (sugar cane, bananas, cocoa, coffee, cotton etc.). Through run-off, erosion and misapplication significant quantities of pesticides reach the marine and coastal environment where they may affect non-target species, and through the contamination of seafood, may become a public health problem. It has been estimated that about 90% of pesticides which are applied do not reach the targeted species (Tolba *et al.,* 1992). Consequently pesticide contamination is a serious concern because of its high toxicity and tendency to accumulate in the coastal and marine biota.

Monitoring programmes to determine the presence of pesticide residues accumulated in sediments and marine biota in the Wider Caribbean Region have concentrated on those chemicals known to have long-term environmental impact and considerable toxicity. These include DDTs, Chlordanes, Dieldrin, Endrin, Aldrin, HCB's, Heptachlor and its epoxides, and Endosulfan (UNEP-CEP, 1994).

During the last decade pesticide usage has changed to replace persistent compounds with less persistent chemicals such as organophosphorus compounds, carbamates, phyrethroids etc. At present there is little information available on the behaviour of these compounds when applied in the tropical coastal marine environment, including degradation rates, fractionisation partition and biological uptake, and transfer through the food chain to humans.

3.3 Recorded effects of pesticides on the coastal zone

Pesticides are by their very nature biologically active and in many cases have the central and peripheral nervous system as their target tissue. There are few direct studies on the effects of pesticides on marine organisms in the tropics, where the efficiency of these chemicals may be enhanced by the warmer water. Temperature may also affect the half-life of certain pesticides. As far as could be ascertained for this review, there are no baseline studies on pesticide contamination in the coastal zones of the Caribbean (pers. com. WRI 24.07.98; pers. com. UNEP-CEP 22.07.98).

The effects of the pesticides Carbaryl (a contact and stomach action insecticide), Naphthol (similar actions to Carbaryl but more stable; a degradation product of Carbaryl) and Chlorpyrifos (a non-systemic insecticide with strong cholinesterase action) on coral planulae has been examined. Chlorpyrifos was shown to be the most toxic of the 3 pesticides, 10ppm killing 100% of the *Pocillopora damicornis* larvae within 12 hours. Whereas it needed 100ppm of the other 2 pesticides to kill all the larvae (Acevedo, 1991). Concentrations of 100ppm of Carbaryl are unlikely to occur under natural conditions, but with use in nearshore areas and a short but strong rainstorm, enough may be washed into the coastal zone to cause damage. Another experiment with chlorpyrifos found seawater passed through a column of soil treated with a quantity of chemical equal to that applied to golf courses, was toxic to the coral *Pocillopora damicornis* (Te, 1992b). Coral tissue sloughing and death occurred after exposure to the herbicide 'Weed-B-Gon' at a concentration of 0.1ppm (Glynn *et al.*, 1984). Phenoxy acid is the main active ingredient of several herbicides, and relatively high concentrations between 0.01- 0.05ppm were found in coral tissues in Panama, especially in an area of high insolation, strong tidal flux and warm seawater. Tolerance tests showed that these concentrations were close to what the coral could cope with. It has therefore been proposed that corals stressed by such pollution levels may succumb much earlier to additional stresses such as raised seawater temperatures (e.g. ENSO events).

A baseline survey on the levels of organochlorine pesticides in tissues of corals, fish and molluscs was conducted on the GBR (Olafson, 1978). Analysis of currents and river inputs suggested that Lindane used on the sugar cane crops of Queensland was the major source of this pollutant. The concentrations found in the animal tissues were often just within the sensitivity range of the detection procedure. Pesticides such as dieldrin and DDT are known to be lethal to crustaceans of commercial importance at mg/l concentrations, but the concentrations found in 1978 were two orders of magnitude lower, and therefore not considered to pose a threat. Klumpp and von Westernhagen (1995) measured the pesticide contamination in ovaries and livers of marine and estuarine fish species from approximately 1000km of the Queensland coast, concentrating on DDT and dieldrin which were still being used, chlorinated hydrocarbons, PCBs, and organophosphates. The data revealed, not surprisingly, that the highest residue levels were concentrated in the main sugar cane growing areas and the major developed areas. The incidences of morphological defects and chromosomal aberrations in fish embryos was used to collect baseline data of the biological effects of pesticide pollution along the Queensland coast (Klumpp and von Westernhagen, 1995). The survey showed that the region as a whole can be classed as pristine on a world scale. Galindio *et al.* (1992) studied the insecticides contamination along the coast of Mexico, measuring concentrations of Lindane in the water, sediments, shrimps and clams.

The acute toxicity of the pesticides endosulphan and DDT were tested on brachyuran crab larvae *Nanosesarma batavicum* (Selvakumar *et al.*, 1996) and it appeared that these larvae were able to tolerate concentrations of 155ppb for DDT and 31 ppb for endosulphan (using the 96h LC_{50} test). Lindane, a fungicide, was rapidly accumulated in the tissue of *Diploria strigosa* but once placed in clean water the chemical was as quickly eliminated, although a residue remained bound to the tissue (Solbakken, Knap and Or, 1985). A study in New Zealand it was shown that bivalves were most noticeably affected by Chlordane, with the three most common species declining in abundance Pridmore *et al.*, 1992).

Sediment samples taken along the Central American Caribbean coast and Mexico showed that the new generation organophosphorous insecticides, which are extensively used in tropical agriculture, were accumulating. Chlorpyrifos was the most widely distributed compound, but traces of parathion and methyl-chlorpyrifos were also detected. Chlorpyrifos is extremely toxic, the 96 hour LC_{50} for tropical shrimp has been reported as $10ng/dm^3$ and results demonstrate that it is sufficiently stable to contaminate marine systems (Readman *et al.*, 1992). Little is known concerning the effects on benthic fauna from prolonged exposure to sediment bound pesticides.

3.4 Fertilisers as nutrients in the coastal zone

The two main sources of nutrient enrichment in the coastal zone are sewage and fertilisers and it is difficult to separate the relative impact. Fertilisers are designed to enhance the nutrient levels in the soil. Excess fertilisers washing into the coastal zone will elevate the nutrient levels of marine coastal waters (see also review by Gabric and Bell, 1993; Soicher and Peterson, 1997). This can lead to eutrophication, particularly in sheltered bays and enclosed coastal areas. Coral reefs are sensitive to the effects of eutrophication. An increase in nutrient availability invariably results in a considerable increase in phytoplankton standing stocks. This is usually reported as an increase in chlorophyll *a* and causes a steep decrease in the light available to the underlying corals. Bell (1992) noted a eutrophication threshold for chlorophyll *a* at or below $0.5mg/m^3$, with the corresponding concentrations of nutrients being Dissolved Inorganic Phophorus (DIP) 0.1-0.2 µM and Dissolved Inorganic Nitrogen (DIN) 1µM.

The effects of eutrophication on the abundance of macroalgae is widely accepted as a mechanism for the deterioration of coral reefs over the last two decades (e.g. Weiss and Goddard, 1977; Hallock, 1988; Lapointe, 1989; Littler *et al.*, 1992; Naim, 1993; Dubinsky and Stambler, 1996; Schaffelke and Klumpp, 1997). Interestingly, the ENCORE programme on the GBR has shown that this may not be true universally (Larkum, 1994; 1997). Agricultural run-off was identified as the cause of large-scale eutrophication in the Great Barrier Reef, posing a direct threat to the coral reefs by enhancing algal overgrowth and indirectly by promotion of the crown-of-thorns starfish through providing a food source for the planktonic larvae (Bell and Elmetri, 1995). Alternatively, phytoplankton blooms may be triggered by nutrient influx (Bell and Elmetri, 1995), increasing turbidity and decreasing the photosynthetic ability of the algae within the coral tissue. Toxic phytoplankton blooms have also been attributed to excess nutrient loading (Gabric and Bell, 1993). The bio-accumulation of toxins in the food chain can not only affect humans (e.g. paralytic shellfish poisoning), but also the devastating effects these toxins can have on fish, birds and mammals (Anderson and White, 1992). Hallock (1988) pointed out that increased nutrient availability will benefit bio-eroders such as sponges and molluscs. As a consequence, bio-erosion would exceed the rate of coral reef growth which on a global scale and rising tropical coastal pollution may result in a net shrinkage of coral reefs (Hallock *et al.*, 1993).

3.4.1 Coral Reefs

Scleractinian corals:

Under normal conditions in nutrient-poor tropical seas, the zooxanthellate corals are successful because they are efficient organisms with respect to nitrogen usage. Growth of zooxanthellae under these conditions is limited by the low rate of nitrogen and not by carbon. As a result, excess fixed carbon is translocated to the animal host. A significant increase in the nitrogen supply will lead to rapid growth of the zooxanthellae and a consequent reduction in carbon translocated to the host. The host then loses control over the symbiotic relationship as the zooxanthellae population expands (Jokiel *et al.* 1994). The maintenance of a balanced coral symbiotic relationship appears to require low ambient nutrient concentrations.

Nitrites / nitrates and phosphates are major components of fertilisers and in large concentrations are poisonous to corals (Muller-Parker *et al.*, 1994), which thrive in a low nutrient (N and P) environment. Increasing phosphate levels in the waters of the GBR are reflected in banding in coral skeletons, the increase over the past 172 years correlating with the expanding coastal human population and intensification of agriculture.

Both coral and zooxanthellae respond to a small increase of dissolved inorganic nitrogen by increasing in biomass (Yellowless, 1994; Muller-Parker *et al.*, 1994; Jokiel *et al.*, 1994). A number of studies have reported reduced calcification and slower linear skeletal extension rates in nutrient-enriched corals (Stambler *et al.*, 1994; Stimson *et al.*, 1996). Studies by Snidvongs and Kinzie (1994) suggested that DIP enrichment could slow down calcification. In Barbados, eutrophication has been shown to reduce zooxanthellae photosynthesis through reduced light levels which may significantly lower the energy available for larval development and maturation (Tomascik *et al.*,1987a and b). Elevated nutrient levels have been shown to reduce the settlement of juvenile corals (Tomascik, 1991; Wittenberg and Hunte, 1992; Ward and Harrison, 1997) and the growth rates of corals (Tomascik and Sander, 1987; Tomascik, 1990; Davies, 1990), although moderate nutrient enrichment of 3.9mmol of N /m^2/day and 0.2 mmol of P /m^2/day stimulated growth in the same species (Meyer and Schultz, 1985). Stambler *et al.* (1994) have shown that different species seem to respond differently to elevated levels of nitrogen: *Pocillopora damicornis* responded with an increase in zooxanthellae density, whereas *Montipora verrucosa* appeared to show changes in algal pigments rather than zooxanthellar density.

It has also been suggested that eutrophication affects tissue regeneration in coral colonies since eutrophication leads to enhanced algal growth and the potential for more rapid colonisation of the damaged areas, and will therefore reduce the chance of a coral colony recovering from tissue damage (Ramati, 1994).

Coral Reef Community:

Coral reefs are sensitive to the effects of eutrophication (Pastorak and Bilyard, 1985; Tomascik and Sander, 1987a). An increase in nutrient availability invariably results in a considerable increase in phytoplankton abundance. This is usually reported as an increase in chlorophyll *a* and causes a steep decrease in the light available to the underlying coral reef community (Bell and Elmetri, 1995). Bell (1992) noted a eutrophication threshold for chlorophyll *a* at or below 0.5mg/m^3, with the corresponding concentrations of nutrients being Dissolved Inorganic Phosphorus (DIP) 0.1-0.2 lM and Dissolved Inorganic Nitrogen (DIN) 1lM.

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Hallock (1988) pointed out that increased nutrient availability will benefit bio-eroders such as sponges and molluscs. As a consequence, bio-erosion would exceed the rate of coral reef growth which on a global scale and rising tropical coastal pollution may result in a net shrinkage of coral reefs (Hallock *et al.*, 1993).

Coralline algae, which are important reef builders, have been shown to be negatively affected by high phosphorous levels, with lower calcification and growth rates. The algae were not affected by nitrate or ammonia (Bj_rk*et al.*, 1995).

In reality, it is difficult to separate out the effects of increased nutrient availability on a coral reef community from all the other factors (both natural and anthropogenic) acting upon the organisms living on a reef (Hughes 1989, 1994; Lessios, 1995). It is comparatively easy to assess the effects of nutrient enrichment at point source, but once diluted in the coastal waters, such effects are not easily attributable to any one cause. For example, an observed increase in macro-algae biomass on a coral reef may be due to increased nutrients (Littler *et al.*, 1992; Lapointe *et al.*, 1992; Cuet & Naim, 1992), alternatively it may also be due to decreasing herbivory (Foster 1987; Forrester & Szmant, 1992). To separate these effects as well as natural events, long-term quantitative data on species composition of the reef benthos and structure of the fish community is necessary, including data on catch composition (Liddell & Ohlhorst, 1992).

3.4.2 Seagrasses

Macroalgae dominate seagrasses under conditions of marked eutrophication, as macroalgae can absorb much more nutrients than seagrass. Nutrient limitation is generally the most important factor controlling macroalgal photosynthesis in environments where light is not limiting (Schaffelke and Klumpp, 1997). This was shown in a study by McGlathery *et al.* (1992), who looked at the nutrient limitation of *Penicillus capitatus*, which is common in seagrass meadows in the Caribbean. Other algae may originate as attached epiphytes on seagrasses. Increased epiphytic growth results in shading of seagrass leaves by up to 65%, reduced photosynthesis and hence leaf densities (Larkum and West 1990). In addition, the epiphytes reduce diffusion of gases and nutrients to seagrass leaves. A study in Florida on *Thalassia testudinum* showed that turtle grass biomass and productivity was affected by elevated watershed nitrogen loads (Tomasko *et al.* 1996), indeed, a mature community of *Thalassia testudinum* was replaced by *Halodule wrightii* after 2 years of nutrient enrichment with bird faeces (Powell, 1986 in Tomasko *et al.*, 1996). However, observations (pers. obs.) have shown that turtle grass does grow well in mangrove channels, which may be expected to have a slightly elevated level of nitrogen due to the decomposition of organic matter.

Recent observations (<5 years) of increasing algal blooms, seagrass epiphytisation and die-off, and loss of coral cover on patch and bank reefs, suggest that nearshore waters of the Florida Keys have entered a stage of critical eutrophication (Lapointe and Clark, 1992). This is not helped by heavy rainfall events which cause episodic discharges of groundwater contaminated with septic tank effluent into nearshore waters (Lapointe and Matzie, 1996). It has been suggested that toxic effluents could reduce grazer population densities, thus reducing grazing pressure and allow increased growth of epiphytes, which in turn reduces light availability for photosynthesis (Howard and Short, 1986).

Since macroalgae are efficient at absorbing higher nutrient concentrations, it has been suggested to use the for the removal of nutrients from sewage water (Brix and Schierup, 1989). A study in Zanzibar has demonstrated that this would be a feasible mechanism for small-scale purification of sewage (Haglund and Lindström, 1995).

3.4.3 Other related studies

A study in Barbados showed that the crustaceans associated with *Madracis mirabilis* reacted to eutrophication by moving away. The total number of individuals and densities were lowest at the most polluted site, but there was no difference in species richness (Snelgrove and Lewis, 1989). Competitive advantage in some octocorals is apparently enhanced in inshore waters of the GBR in the presence of nutrient enrichment and lower levels of predation and light (Alino *et al.*, 1992).

3.4.4 The Caribbean

The major contribution of nutrient loads (N and P) to the coastal areas of the wider Caribbean comes mainly from non-point agricultural run-off and rural run-off sources, with a relatively smaller contribution from domestic and industrial point sources. There has been a large increase in the use of fertilisers in recent years (Table 7). The ecological effects of eutrophication include algal blooms, changes in aquatic community structure, decreased biological diversity, and fish kills through oxygen depletion (Turner and Rabalais, 1991). In a comparative study in the volcanic Lesser Antilles, McDowell *et al.* (1995) showed that the pattern of inorganic nitrogen export reflected land-use with the highest export from the most densely populated catchment. Phosphorous followed a different pattern, where the greatest export of P was from catchments with lowest population density and least agriculture. The authors suggest that land-use patterns affect the soil chemistry which in turn affects export of N and P from these volcanic islands.

Table 7 Average annual fertiliser use per hectare of cropland in several countries of the Wider Caribbean (adapted from UNEP-CEP 1994).

Country	1979	1989
Barbados	162	91
Belize	36	71
Colombia	55	90
Costa Rica	143	191
Cuba	133	192
Dominican Republic	41	50
Guatemala	53	69
Guyana	22	29
Haiti	4	3
Honduras	13	20
Jamaica	55	105
Nicaragua	31	55
Panama	44	62
Trinidad & Tobago	61	28
Suriname	49	74
USA (Gulf Coast)	106	95
Venezuela	51	162
Average	62.3	81.6

4. Land-use management in watersheds

The initial European vision of the West Indies as a land of plenty has been replaced by an awareness of the ecological fragility of the area, although the exploitative agricultural systems of the colonial and recent Caribbean islands have not adjusted to the demands of the environment. Caribbean agricultural activity is exemplified by the production of sugar cane and a few other favoured crops such as banana, coffee, and citrus. The importance of sugar is demonstrated in Table 8.

Table 8 Caribbean sugar production in 1000 tonnes (adapted fromWatts 1990)

Region	1923-4	1962-3	1982-3
World	13837	29639	68886
Cuba	4067	3881	8039
Puerto Rico	398	915	incl. in USA
Dominican Republic	229	807	1285
Trinidad	52	235	79
Barbados	44	197	88
Jamaica	33	506	198
Guadeloupe	28	189	59

Sugar also survives because of its role in the more profitable rum industry. Almost every island manufactures rum, and the EU and US are the principal export markets (Ferguson, 1997).

The advent of the banana as the regions most important export crop can be traced back to the decline of the sugar industry and the need for alternative crops. Bananas can be grown on hilly terrain unsuitable for other crops, tended by smallholders . The recent banana crisis has intensified the search for other crops and commodities with which to rebuild an export economy. In St Lucia some farmers are now into dairy production and cut-flowers, Dominica has started limited exports of passion fruit, Guadeloupe has moved into large-scale melon production, and Martinique exports pineapples (Ferguson, 1997).

As the area placed under cultivation has expanded additionally during the twentieth century, so also have the processes of environmental decline become more visible, except when land use has been exceptionally careful and conservative (e.g. terracing on St. Vincent, and intercropping on peasant plots in the Blue Mountains in Jamaica). Vast forests have been felled down to make way for the enormous sugar estates in Cuba, lowland Puerto Rico and the Dominican Republic. In many places soil erosion has set in, or has been extended from a former high level (Watts, 1990). The extent of soil erosion in Puerto Rico is particularly dramatic, as measured by Larsen (1998). During the peak of land use conversion for pasture and subsistence cropping in Puerto Rico, 95 percent of original forest cover had been eliminated. This period, during the 1930's and 1940's, coincided with several large magnitude hurricanes each of which delivered up to 1,000 mm of rainfall in 1928 and 1932. Through examination of 1937 and 1995 1:17,000-scale stereo aerial photographs, more than 1,000 mass-wasting scars have been mapped and may be attributable to a combination of factors: hurricane-associated rainfall, intense land use practices, and the highly weathered substrate (granodiorite). An additional 1,000 scars were visible but not yet mapped (Larsen 1998). Erosion also has severely depleted environmental resources in the former coffee growing districts in Jamaica's Blue Mountains. Pressures from small scale farming and the grazing effect of the numerous domesticated animals (mainly sheep and goat) has seriously depleted soils on the steeper slopes of the Scotland District of Barbados (Watts 1990).

Watershed protection and better management practices are now recognised as a vital measure to reduce and prevent soil erosion and subsequent sedimentation along the coast. The situation in Belize demonstrates well the need for effective watershed management:

> *Although Belize has ample supplies of high quality water in rivers draining forested mountains, there are signs of degradation and potential conflict over water. Specific issues concerning agriculture involve growing demands for irrigation water for rice and sugar cane, discharge of organic waste from citrus processing plants, and increasing flooding and sedimentation in rivers (arising from the encroachments of agriculture into the upper forested watershed. This situation causes particular concern about potential adverse effects on the economic and environmental status of the coastal area, which supports an important fishing industry and a developing tourism trade. The killing of fish and damage to coral reefs have already been observed as a result of sedimentation and organic pollution of rivers. Measures proposed to address these issues include the establishment of a legal and institutional framework for water management and environmental protection, adoption of more efficient irrigation methods, development of drainage and water treatment facilities, and monitoring of water quality to control, prevent and remedy water pollution from agro-industrial chemicals and municipal waste (adapted from Belize 1992).*

Another example for the need of better agricultural practices and watershed management comes from the Philippines.

> *In the Central Visayas region provides a dramatic illustration of both direct antagonistic effects and secondary socio-economic effects linking agricultural intensification to coastal ecosystems and the livelihoods of rural people. Near total deforestation of the Central Visayas and extensive corn farming on very steep slopes, resulted in erosion that stripped the slopes of top soil. Harvests and farm incomes have been steadily declining. Rapid rainfall runoff from bare slopes has increased the frequency and intensity of floods and deposited vast quantities of silt on the once productive coral reefs. Declining farm incomes have encouraged more people to turn to fishing to support their families. As a result, the vast coastal fishery resource once thought to be inexhaustible has come so much under pressure, that combined with other factors (mangrove*

over exploitation and additional coral destruction) many shallow water fishing areas have been abandoned as no longer productive. (adapted from FAO 1998).

Agricultural planners must carry out environmental impact assessments. with special emphasis on the effects of irrigation and drainage projects and of pollution induced by agricultural activities. Table 9 suggests means of designing and implementing improvements in agricultural development activities affecting coastal systems.

Table 9 Actions to improve agricultural development affecting coastal ecosystems (adapted from FAO 1998)

Agriculture:

- plan upland farm layouts to respect natural drainage patterns:
- encourage sustainable intensification of agriculture on suitable land to reduce pressure on unsuitable dry lands and coastal wetlands:
- in important coastal wetland habitats. only promote crops that are compatible with wetlands. such as taro or rice:
- avoid reclamation of important habitat areas for agricultural development;
- implement soil and water conservation practices to control cropland erosion and surface water run-off:
- utilise fertiliser and pesticides in a manner that will minimise their loss and transport towards coastal areas: and
- promote organic fertilisers. biological pest control and non-persistent biocides:

Specific attention to pest control can be given by:

- the selection of location-specific resistant varieties and strategic planting dates:
- balanced supply of plant nutrients:
- the creation of a friendly environment within and around the crop which encourages populations build-up of natural enemies by utilizing sound crop management practices:
- need-based application of safer pesticides:
- the use of rotational cropping to disrupt insect and pathogen cycles: and
- use of local materials like indigenous plants as part of the crop protection systems.

Feedlots. ranching and range management:

- control livestock population levels on rangelands to avoid denuding the land. soil erosion and sedimentation (note: also livestock distribution and movement for water):
- require replanting and other erosion control measures on rangelands/ ranch lands:
- impose stringent pollution control practices and standards on feedlots and other concentrated livestock operations: and
- encourage integrated livestock. mixed farming and tree crop systems.

Water development and control:

- regulate groundwater withdrawal to prevent saltwater intrusion. land subsidence and de-watering of bodies of surface water:
- utilise non-structural solutions for flood damage control (flood proofing. raising structures. setback from flooding zone) to the maximum extent possible:design all diversions. dams and impoundment to preserve the existing water quality volume and rate of flow for marshes. estuaries. deltas. etc:
- design water diversions to accommodate the seasonal migrations of aquatic fauna up- and downland: and
- ensure adequate treatment and disposal of wastes.

Forestry practices that will help to prevent soil erosion include (Thaman. 1990 and 1991: Carpenter and

Maragos, 1989; FAO, 1998):

- maintaining vegetation along streams and rivers;
- interspersing crops with forestry species (intercropping), a traditional agroforestry method promoted in the Pacific; multiple cropping contour planting of woody species to stabilise soils and provide firewood;
- minimal tillage methods such as planting seeds directly in holes to reduce cultivation.

In summary, reduction of nutrient and pesticide runoff from agriculture ultimately depends on a reversion to less intensive farming methods. Prevention of pollution from pesticides requires making pesticides less easily available or more expensive or both and thorough training of farmers in the use of these pesticides in order to reach the target species at specified low concentrations, rather than dumping indiscriminate amounts of chemicals on the field, hoping that some will reach the pests.

5. *Research priorities*

5.1 Current activities

The St Lucia Watershed and Environmental Management project, funded by World Bank/IDA and executed by BDDC is underway. Based on the watershed management plans developed for two pilot sites, the project aims to produce a strategy for extending the pilot plans to the entire island system. The watershed management plans include elements to design and test management options for such problems as quantifying and controlling the impacts of nutrients, sediment and pesticides in agricultural run-off from the upper watershed on the lower watershed ecosystems (e.g. coral reefs). OECS/NRMU is involved in this project, looking at aspects of sedimentation for example. Indeed, CANARI has secured funding from UNEP to look at sedimentation effects, rates and quantities at watersheds in Negril (Jamaica) and Soufrière (St Lucia) (pers. com. Allan Smith, CANARI, 10.07.98). The results from the study at Soufrière will be fed into the OECS/NRMU component.

This review identified a number of knowledge gaps and projects are outlined here to fill these. The proposed projects involve research, including socio-economics, well within the remit of projects ultimately funded by development aid. The list of projects below is not in order of priority, and it may be possible to link aspects of projects into one study (e.g. project 1 and 2).

5.2 Proposed research projects

Outputs from projects on pollutants should be designed so that they can be incorporated into relevant international initiatives. The most important identified in this review is FAO/UNEP the Prior Informed Consent Procedure based around Joint Working Groups which assess the toxicity of chemicals and Designated National Authorities (DNAs) in participating countries which make national decisions on control actions and identifying alternatives (Annexes 1 and 3).

It should be noted that a great deal of work has already been done on chemical toxicity and environmental effects of sedimentation. The projects suggested here are adaptive research projects, aimed at ensuring the large body of academic research is used in management practices.

Project 1 The distribution and effects of pesticides in the Caribbean Region

The need for this information has also been identified by UNEP-CEP. The UNEP-CEP project proposal document for the biennium 1996-1997 (UNEP(OCA) / CAR 1994) listed the following project to be conducted in conjunction with CEPPOL: '*Baseline studies on pesticide and organo-metallic contamination, risk assessment, environmental impact and formulation of control measures*'. The objectives of the project are to assess the environmental issues associated with the use of pesticides and organo-metallic compounds in selected areas and to develop measures which may reduce these problems in the Caribbean. The work was to be carried out by national institutions. It has not been possible to ascertain the exact status of this project, other than to hear that participation from Caribbean countries was low. It appears that this important work is being delayed.

Therefore a different approach is being proposed here, into which LWI could fit more effectively.

This proposed project comes in 3 parts:

1. collection of baseline data on pesticides in the coastal zone throughout the Caribbean;
2. determination of toxicity of pesticides once they are in the coastal zone; and
3. long-term monitoring of these pesticides (part of water quality monitoring).

Objective:
To establish the effects of pesticides and their behaviour in the coastal zone, in order to monitor toxicity build-up and health hazards to ecosystems and humans. The results of the study will have a direct effect on watershed management practices.

Methods:

1. Collection of baseline data:
   a) Application of 2 highly sensitive and well established indices of the biological effects of pollution, namely indices in morphological defects and chromosomal aberrations in fish embryos to establish baseline data for future monitoring (see also Klumpp and Westernhagen, 1995). Also, sampling of coastal sediments (Guzmán and Jiménez, 1992) and testing for pesticides and their concentration will give a good database to determine the region-wide distribution of pesticides in the coastal zone.
   b) Similar to the global Mussel Watch programme, identify benthic organisms which bio-accumulate and /or bio-magnify pesticides in their tissues. For example, Vanadium has been identified as a tracer for oil pollution in coral skeletons (Guzmán and Jarvis, 1996). Something similar may be possible for pesticides, that is a reliable yet inexpensive method to use.

2. Toxicity of pesticides:
   Similar to LD_{50} tests done on marine organisms in temperate waters, LD_{50} tests need to be conducted on tropical organisms, in particular as water temperature will affect the toxicity and/or half-life of a pesticide. Such tests could be performed on fish, planulae larvae of corals, mussel larvae, etc. Ecotoxicology tests can be performed on corals, using the pioneering work by Spencer Davies (1995). The American EPA has published comprehensive guidelines for chemical testing of toxins (see EPA Office of Pesticide Programs). Similarly, the OECD Environmental Health and Safety publications contain much information material on methods for pesticides testing, health risks, and baseline work.

The work should include identification of Maximum Residue Limits (MRL) of pesticides in particular organisms, as an aspect of environmental health determination.

3. Long-term monitoring of these pesticides.
As part of regular water quality testing throughout the whole Caribbean Region (see CEHI remit), regular pesticide residue testing needs to be established, based on the best working methodologies determined in part 2). A long-term database is vital in order to determine the effects of pesticides on organisms in the coastal zone, as well as establishing their half-life. Long term monitoring may use techniques developed for part 1.

Institutional linkage:
It is proposed to conduct the work through CEHI, as it fits well into the work programme of this institution which covers the whole Caribbean.

Project 2 Type, source and quantity of pesticides in the Caribbean

It was impossible to get detailed information on the type, source and quantity of the pesticides used in the Caribbean, whether for agriculture or termite control. For meaningful watershed management, it is important to know how much of which pesticide is used. This can be used to compare expected pesticide residues against those observed using the monitoring programme. This information should be used to develop and set import controls, such as import quotas, for Maximum Residue Limits.

Information on how much pesticide comes into each country can be obtained from Customs and Excise records, although some countries may have poor record keeping, or the chemicals may not be itemised. Export records from source countries may also need to be checked, as any relevant trade information.

Once in the country, it may be more difficult to trace the movement of the pesticides, but it should be possible to get some idea on the quantities through internal trade records from shops and businesses. Particularly those Caribbean countries with an industrial-sized agriculture sector may keep information on pesticide stocks and purchases as part of the auditing. Small scale farmers may be more difficult to assess, but could be estimated using interviews and a sampling approach.
Institutional linkage: CEHI and UNEP-RCU, based on the work by CEPPOL.

Project 3 The impact of agro-industrial practices on inshore fisheries production

This is a multi-sectoral project, studying the physical/chemical effects of large scale agricultural practices on inshore fisheries. The study would address bio-accumulation and bio-magnification in inshore fish, lobster and conch, as well as sedimentation effects on the coastal habitats. This would require development of a dispersion-transport model, as described by GESAMP(1992).

It is important to assess the effects of pesticides on inshore fisheries, both from a human health and environmental health aspect. The results of such a study may suggest, for example, that no fishing should take place within a certain time frame after the spraying of crops or timber-yard wood treatment where effluents are flushed into the ocean.

For logistical reasons the project would be based in one country only, which has industrial-scale agriculture and important inshore fisheries like Belize, Barbados, Jamaica or Cuba. The work could be implemented through CEHI, as environmental health is one of its remits. An output of the project should include methodology for application in other countries.

Project 4 Valuation of watershed management activities

This project would develop methods for extending the cost and benefits of different watershed management practices to include downstream effects. The project should provide guidance on full cost-benefits of common development projects (e.g. reforestation, industrial agriculture for export). This is particularly important in developing agriculture, where otherwise environmental costs and costs born by communities downstream are treated as externalities, and not taken into account in land management decisions. Methods would be based primarily on a socio-economic approach, using the parameters and techniques already available (e.g. Winpenny, 1991) and from the other projects suggested here (Projects 1 and 3). The research should particularly address those circumstances where little information is available, and so costs have to be included in the form of a risk assessment. It is important that a lack of information does not result in potential environmental costs defaulting to zero, but that a precautionary approach is developed. A result from the project should be practical guidelines for the inclusion of environmental costs in cost-benefit analyses in land management activities.

Project 5 The status of seagrass beds in the Caribbean Region

Since seagrasses are probably sensitive to sedimentation and eutrophication, and since these beds are very important coastal habitats, it is proposed that a study quantifying impacts on these habitats is undertaken. The project would have to include a Caribbean-wide survey of seagrass beds. Very little information was found on the status and distribution of seagrasses in the Caribbean, as most of the work has concentrated on coral reefs and mangroves. Yet seagrasses are equally important in terms of their productivity and coastal protection they provide. This information would be important to baseline assessments of the impact of watershed management practices (Projects 1 and 4).

Using satellite imagery, ground truthing, correspondence with local institutions and GIS mapping it will be possible to get a good data set on seagrass status and distribution within a reasonable time frame. The information could be similar to that collected for mangroves and coral reefs by the World Conservation Monitoring Centre (WCMC).

Institutional linkage: CCA in Barbados together with WCMC.

Project 6 Maximum Residual Limits for pesticides

Rather than conducting detailed studies on the physiological effects of pesticides on organisms in the coastal zone, the US has adopted target values for pesticides along the coast of the Gulf of Mexico. Based on these MRLs agricultural practices were changed. Using the methods designed by the EPA in the US, such an approach to pesticide control could be adapted for the Caribbean Region.

The project would look at determining feasible MRLs for target species living in the coastal zone using information from, among others, all proposed projects (Projects 1-5). The determination of MRL values may be different in each country and for each user-group (see also Acevedo, 1991). Therefore the eventual MRLs implemented would partly be based on political decisions, taking the regionality of the issue into account. Advice on appropriate MRLs could be obtained through a joint scientific working group convened by MARPOL, FAO/UNEP-CEP and/or CARIFORUM. This project could either make recommendations on MRLs for the most toxic chemicals, and/or guidelines for working groups on setting MRLs.

6. *Conclusions*

Although there is probably a great deal of research done into improving management of watersheds (e.g. see Winpenny, 1991), little of this work incorporates downstream effects into the coastal zone. Consequently, there is little information available to the effects of agro-chemicals on the ecosystems in the tropical coastal habitats, although much work has been done on determining the toxicity of agro-chemicals on marine and fresh water organisms in temperate and arctic regions. There was little data to be found on pesticide use in the Caribbean, apart from summary documents provided by UNEP/RCU. This review has identified a number of knowledge gaps and projects were outlined to fill these. The proposed projects involve research, including socio-economics, well within the remit of projects ultimately funded by development aid.

7. Appendices

Appendix I Ecological features and resource problems of some Caribbean island countries (adapted from Stanley 1995)

Country	Ecological Features	Resource Problems
Antigua/Barbuda	low flat volcanic island on coral platforms and narrow submarine shelves: white sand beaches, seagrasses, fringing reefs.	Excessive sand removal destroying reefs; over-exploitation of lobster; resort building on beaches
Bahamas	large cluster of flat islands; extensive reef system.	exploitation of fisheries; pollution from boats; anchor damage on reefs
Barbados	low flat volcanic island on coral platforms, narrow submarine shelves; sand beaches, mangroves, seagrasses, fringing reefs.	near-shore fisheries over-exploited; coastal erosion from dredging and construction stressing reefs, changing water circulation patterns and quality; pollution from sewage, wastes, fertilisers.
British Virgin Islands	small cluster of low hilly volcanic islands; mangroves, seagrasses, salt ponds, coral reefs.	mangroves cleared for tourism development, increasing sedimentation in seagrasses and coral reefs; anchor damage on reefs; domestic sewage pollution.
Dominica	high rugged volcanic mountains, no coastal plain; numerous rivers and rain forest cover.	hurricane devastation to reefs; maintenance of coastal road encouraging coastal erosion; oil pollution; ship-based wastes on beaches.
Grenada	steep volcanic islands; mangroves, seagrasses, reefs	over-exploitation of all fisheries; beach erosion near tourism centres; coastal tree removal and sand mining increasing erosion; seaborne and solid waste pollution.
Montserrat	high rugged volcanic island; black sand beaches, rainforest.	over-exploitation of fisheries
Netherland Antilles	2 island groups: leeward (Curacao, Bonaire, Aruba), low hills and bays with mangroves, seagrasses, fringing reefs; windward (St. Marten, St Eustatius, Saba) high rugged volcanic with coral reefs, seagrasses.	marine habitats suffering from heavy industrial and recreational use; depletion of fisheries off Saba bank; sewage pollution and dumping.

St Kitts/Nevis	high volcanic, narrow coastal shelves	near-shore fisheries over-exploited; coastal erosion from sand removal; sewage pollution; inadequate port facilities.
St. Lucia	high rugged volcanic island with extensive seagrass beds, coral reefs, few beaches	erosion from forest clearing and sand mining affecting reef and seagrass habitats; tourism related construction stressing habitats.
St.Vincent/ Grenadines	volcanic, mountainous; reefs, black sand beaches; Grenadines have largest shelf area in Lesser Antilles.	seaborne tar pollution on beaches; excessive sand mining for construction: waste from yachts.
Trinidad/Tobago	tropical forests. swamps, reefs. sand beaches	pollution pressure and recreational misuse of Caroni Swamp; coastal zone resource use conflicts; over collecting of turtles and shells; trampling on reefs:
Cuba	largest marine platform: karstic and marine plains: mountainous; 20% wetlands, extensive mangrove forests.	domestic and industrial pollution; illegal fishing, hunting and collecting of corals; rapid tourism development.
Dominican Republic	mountainous: extensive mangrove areas.	dependence on fisheries imports: extensive new tourism developments: mangrove destruction for fuel wood: overfishing of lobster and conch; illegal collecting of corals. turtles and birds; sewage pollution.
Haiti	low mountains; mangroves. seagrasses and coral reefs	few inventories of marine resources; pollution near urban centres; mangrove destruction for fuel wood: overexploitation of fish, conch, lobster.
Jamaica	large mountainous island; coastal plains; mangroves and coral reefs	overfishing; domestic and industrial pollution; high sediment loading from bauxite mining; coastal erosion from sand mining; dredge spoils into mangroves; unregulated coastal activities including tourism and collection of coral reef curios.

Appendix II Properties of some Persistent Organic Pollutants (POPs)

The following information has been collated from FAO/UNEP Joint Data Base, IRPTC, Geneva; Designated National Authorities (DNAs) in countries taking control actions and reporting alternatives (Annex 3)..

Prior Informed Consent Decision Guidance Documents

The inclusion of these chemicals in the Prior Informed Consent Procedure is based on reports of control action submitted to the United Nations Environment Programme (UNEP) by participating countries, and which are presently listed in the UNEP-International Register of Potentially Toxic Chemicals (IRPTC) database on Prior Informed Consent. While recognizing that these reports from countries are subject to confirmation, the FAO/UNEP Joint Working Group of Experts on Prior Informed Consent have recommended that these chemical be included in the Procedure. The status of these chemicals will be reconsidered on the basis of such new notifications as may be made by participating countries from time to time.

The use of trade names in this document is primarily intended to facilitate the correct identification of the chemical. It is not intended to imply approval or disapproval of any particular company. As it is not possible to include all trade names presently in use, only a number of commonly used and published trade names have been included here. This document is intended to serve as a guide and to assist authorities in making a sound decision on whether to continue to import, or to prohibit import, of these chemicals because of health or environmental reasons.

Captafol

Use: Pesticide (Fungicide)

CAS No.: 2425-06-1

Synonyms/Trade Names: Difolatan, Haipen (Chevron), Crisfolatan, Difolatan (Chevron), Folcid, Foltaf (Rallis), Merpafol (Makhteshim-Agan), Sanspor (ICI), Ortho 5865 (Chevron), Santar (Sandoz), Sulfemide

Mode of action as Pesticide: Non-systemic fungicide (acts by inhibiting germination of spores

Summary of Control Actions:

Control actions to ban or severely restrict captafol have been reported by 12 countries and the European Union and the members associated with the EU in the European Economic Area. (EEA). Of these control actions, two were voluntary withdrawals on the part of the manufacturer. In the United States the manufacturer voluntarily withdrew registrations following initiation of a special review. In New Zealand the manufacturer voluntarily withdrew most uses and products. One country reported that captafol was severely restricted, with a single use retained which represented less than 1% of the previous use level.

Reasons for the Control Actions:

All countries listed carcinogenicity as a primary concern. In addition to carcinogenicity in laboratory animals and incidents of skin sensitisation in workers, environmental concerns were cited as the basis for concern, including very high toxicity to fish; moderate to very high toxicity to freshwater invertebrates; and potential for reproductive effects in birds.

Environmental Characteristics: Captafol is not persistent and rapidly degrades in soil, the rate being a function of soil type and pesticide concentration: the longest determined half-life was 11 days. Under normal agricultural conditions there should be no accumulation in soil. Limited data indicate that captafol per se has a half-life of < 3, 5 and 8 days in non-sterile organic sandy and clay loam soils, respectively. The soil degradates and metabolites have not been identified. The movement of captafol through soil columns by water leaching has been studied. The results show that captafol does not move significantly and will not accumulate in water leaching from treated areas.

Fish: Highly toxic to fish; 96-h LC50s; Rainbow trout, 0.027-0.50 mg/l; Bluegill sunfish, 0.045-0.230 mg/l.

Invertebrates: Moderately to very highly toxic to freshwater invertebrates; 96-h $LC_{50}s$ ranged between 0.04 and 3 mg/l

Birds: Avian toxicity is low; LD_{50} >2510 ppm; LC_{50} >5620 ppm; however, high levels of exposure may cause reproductive impairment. Ten-day dietary LC_{50} for pheasants >23,070, mallard ducks >101,700 mg/kg diet (Royal Society of Chemistry, 1991).

Chlorobenzilate

Other names/synonyms: ENT 18596

Use: Pesticide (Acaricide)

CAS No.: 510-15-6

Trade Names: Acaraben (Ciba Geigy), Akar (Ciba Geigy), Benzilan (Makhteshim Agan), Benz-O-Chlor (Tower), Folbex (Ciba Geigy), G 23992 (Ciba Geigy), Kopmite

Mode of action as Pesticide: Effector of ion permeability (nerve poison)

Summary of Control Actions: Control actions to ban or severely restrict chlorobenzilate use as a pesticide or in agriculture have been reported in a total of seven countries. Cyprus reported that chlorobenzilate was severely restricted with a single use retained that represented < 30% of the previous use level.

Reasons for the Control Actions: Four of the five countries identified carcinogenicity as a primary concern. Cuba and the United States also listed potential reproductive hazards in male workers as an issue. Morocco cited persistence in the environment and the bioaccumulation of residues in the food chain as the basis for their control action.

Environmental Characteristics: The available data are insufficient to fully assess the environmental fate of chlorobenzilate.

Residues on treated fruit are stable to atmospheric and biological influences and, except on leaves which are growing fairly rapidly, the residue levels decline with a half-life of more than 14 days (JMPR,1978).

When chlorobenzilate was applied to a bare silty loam soil at 5 kg a.i/ha disappearance was rapid, with a half-life of less than 30 days, and residues could not be detected after 61 days. Vertical movement was confined to the upper 5 cm of soil. The concentration of the metabolites 4,4'-dichlorobenzilic acid and 4,4'-dichlorobenzophenone reached a maximum after 20 and 61 days, respectively, and rapidly decreased thereafter (JMPR ,1978).

Fish: $LC_{50}s$ Rainbow trout 0.60 mg/l: Bluegill sunfish 1.80 mg/l (Pesticide Manual ,1994)

Birds: Practically non-toxic to birds (Pesticide Manual,1994)

Bees: Non-toxic to bees (JMPR, 1969). Honey bee LD_{50} 1.01 µg/bee in laboratory (48 hr. 65% relative humidity, 26.7°C)

Environment: Chlorobenzilate degrades fairly rapidly and both it and its degradates have low mobility; groundwater contamination is considered unlikely.

Aldrin and Dieldrin

Use: Pesticide (insecticide)

CAS No: Aldrin 309-00-2; Dieldrin 60-57-1

Trade Names/Synonyms: Aldrin: Compound 118, Octalene, Aldrec, Aldrex, Drinox, Aldrite, Aldrosol, Altox, Bangald, Aldrine, HHDN, Rasayaldrin. (Discontinued name: Seedrin Liquid). Dieldrin: HEOD, Dieldrex, Dieldrite, Octalox, Panoram D-31, Compound 497, Dieldrine. (Discontinued name: Alvit).

Mode of Action: Central nervous system stimulant producing convulsions

Summary of Control Actions: Thirty-three countries have reported either banning dieldrin completely or severely restricting its use. At least twenty-one countries, including all members of the European Community falling within the jurisdiction of a 1979 EEC Directive, have prohibited all uses of the compound except for a few relatively minor uses. Another twelve countries have banned most uses, but allow continued application in a few specific cases.

Aldrin is one of the world's most stringently controlled pesticides. At least twenty-three countries have prohibited use of the compound. Another thirteen countries have severely restricted its use.

Reasons for the Control Action: Aldrin and dieldrin, to which aldrin is readily converted in the environment, have been subjected to control actions principally due to their high toxicity, to their persistence in the environment, especially in temperate areas, and to the bioaccumulation of residues in the food chain and in human tissues.

Dieldrin is highly toxic to fish, crustaceans, and many bird and animal species, and is highly toxic to human beings, with short-term, high levels of exposure causing headache, dizziness, and tremors followed by convulsions, loss of consciousness and possibly death. Aldrin is variably toxic to microorganisms and highly toxic to fish, crustaceans, and many bird and animal species. Oral doses of aldrin and dieldrin have caused liver cancer in mice but not rats.

Environmental Characteristics: In biologically active soils, aldrin converts rapidly to dieldrin by epoxidation, with 50-75% of the end-season residues being dieldrin. The half-life of dieldrin in temperate soils is about five years. In tropical areas, dieldrin is lost more quickly, up to 90% disappearing within one month. Resistance to soil leaching generally precludes groundwater contamination, although there is some risk of surface runoff. Biomagnification is high, estimated at 3,140 in fish and 44,600 in snails for aldrin, and 5,957 in fish and 11,149 in snails for dieldrin. Although persisting for years, there is no evidence that aldrin and dieldrin accumulate indefinitely in soils, in water, or the atmosphere.

Effects: Highly toxic to fish and crustaceans (LC_{50}s ranging from 2.2 to 53 mg/l). Toxicity of dieldrin for higher plants is low, even less than that of aldrin. Dieldrin toxicity to birds has been found to vary by species between 6.9 and 381 mg/kg bw, and for aldrin between 6.6 and 520 mg/kg bw; response among mammals varies by species.

Environment: Exposure from air is of minor importance to the general human population. Aldrin concentrations between 0.1 to 0.4 ng/m^3 have been found in the air of agricultural communities. Monitoring studies in the USA, UK, Netherlands, Barbados, and Ireland between 1965 and 1981 found mean dieldrin concentrations ranging from 0.073 to 49 ng/m^3. Higher exposure rates to air-borne aldrin and dieldrin can be expected in homes treated with the compound for termite control. Mean aldrin levels found in inside air in slab constructed homes declined from 77 to 36 ng/m^3 from the day of application to a year later, and in crawl-space constructed homes, the range was 1,970 to ng/m^3 over the same period. Mean dieldrin levels found in inside air one to ten years after application in the UK ranged from 0.01 and 2.7 mg/m^3. Low levels of dieldrin in surface water have been reported in several countries.

DDT

Use: Pesticide (insecticide)

CAS No.: 50-29-3

Trade Names/Synonyms: Anofex, Arkotine, Cazarex, Chlorophenothane, clofenotane, ddt 75% wdp, Dicophane, Didigam, Didmac, Digmar, Dinocide, ENT 1,506, Estonate, Genitox, Gesarol, Guesaphon, Guesarol, Gyron, Ixodex, Klorfenoton, Kopsol, NCI-C00464, Neocid, Neocidal, Pentachlorin, Pentech, pp'zeidane, Rukseam, Santobane, zeidane, Zerdane

Mode of Action: Non-systemic stomach and contact insecticide.

Summary of Control Actions: Control actions to ban or severely restrict DDT have been taken by over 38 countries beginning as early as the 1970's.

In at least 26, DDT has been completely banned and in 12 others it is severely restricted. In these latter cases, it is permitted for use by government agencies for special programmes. Specific actions reported by governments are summarized in Annex 1.

Reasons for the Control Action: The characteristics of DDT to persist, especially in temperate climates, and to biomagnify in the food chain led to significant reproductive effects in birds, such as the brown pelican, osprey and eagles, because of egg shell thinning. These features combined with exposure and accumulation of residues in humans, and the potential oncogenicity of DDT also contributed to health concerns. In addition, there were concerns about general environmental contamination of a longlived nature and uncertainty about the eventual adverse impacts on man and the environment because of continuing, long-term exposure through water, food and other sources. Finally, DDT is toxic to a number of organisms including fish.

Environmental Characteristics: Average half-life is at least 5 years. Preferentially stored in fat, with bioconcentration factors up to 50,000 (fish) or 500,000 (mussel).

Effects: Highly toxic to fish (LC_{50}: 1.5 mg/l for large mouth bass to 56 mg/l for guppy) and aquatic invertebrates (at concentrations as low as 0.3 mg/l): lowers reproductive rate in birds (0.6 mg/kg) by thinning of shells and embryotoxicity, but is relatively non-toxic to earthworms and bees.

Environment: Water concentrations may be high in agricultural areas (0.01 mg/l). Bioaccumulation in the food chain can provide significant exposure for humans and wildlife.

Dinoseb, DNPB, dinitro (WSSA, BSI, ISO)

Use: Pesticide, fungicide, herbicide, desiccant, insecticide, dormant fruit spray

CAS No: 88-85-7

Trade Names/Synonyms: Basanite (BASF), Caldon, Chemox, Chemsect DNBP Nitro, Dinitro-3, Dinitro-General, Dynamyte (Drexal Chem.), Elgetol 318, Gebutox, Hel-fire (Helena), Kiloseb, Nitropone C, Premerge 3, Silnox General, (FMC), Subitex, Unicrop DNCP, Vertac Dinitro Weed Killer 5, Vertac General Weed Kiiler, Vertac Selective Weed Killer, dnpb, dinitro, dinosebe/Hoe 002904, Ivosit (Hoechst AG) Phenotan, aretit.

Mode of Action: Contact herbicide

Environmental Characteristics: Data on persistence is inadequate, but initial residues can be greater than 2000 ppm on short rangegrass, over 1000 ppm on long grass, leaves and leafy crops, over 500 ppm on forage and over 100 ppm on pod-containing seeds and large insects. These levels generally exceed the subacute dietary LC_{50} of non-target mammals. Estimated level in water from application to corn is 29 ppb which would exceed the maximum acceptable toxicant concentration (MATC) in water.

Highly toxic to birds, mammals and invertebrates. Residues occurring after application of dinoseb at maximum label rates have the potential to cause both acute and reproductive effects.

Mammals: Acute toxicity (LD_{50}s: rat-40 mg/kg; guinea pig-25 mg/kg; mouse-41 mg/kg). Reproductive impairment in mice occurs at 1 mg/kg/day which can be reached by a level of 7 ppm fodder residues as compared to the levels of residue of 500-1000 ppm expected from maximum label rates of application. These data indicate that both acute toxic effects and reproductive impairment in mammals are potential concerns.

Birds: Highly toxic to waterfowl and upland game birds. Acute toxicity (LD_{50}) is seen at levels of 11.5 mg/kg in mallard, 42.5 in bobwhite quail and LC_{50} of 515 ppm in ringnecked pheasants.

Concentrations expected from maximum label doses can exceed LC_{50} levels. Field kills of pheasants and songbirds have been attributed to dinoseb exposure.

Aquatic Organisms: Fish 96-hour LC_{50}s are 0.7 mg/l for fathead minnow, 0.067 mg/l for lake trout and 0.110 mg/l for 51 percent soluble concentrate/liquid triethanolamine salt formulation. MATC is 14.5 ppb which would be exceeded by the estimated environmental concentration of 29 ppb resulting from maximum label dose on corn.

Dinoseb is moderately toxic to juvenile estuarine invertebrates (pink shrimp 96-hour LC_{50}-1.96 mg/l) and highly toxic to the embryo-larvae stage of oysters (48-hour EC_{50}-0.209 mg/l).

Environment: As noted in Section 2 above, estimated concentrations resulting from applications at the maximum label dose are expected to result in immediate residues in forage and water which exceed the estimated maximum acceptable concentrations for mammals, birds and aquatic organisms. Bird kills observed in the field have been attributed to dinoseb exposure.

Although quantitative data are not available, dinoseb may pose a substantial risk of inducing birth defects in women exposed through spray drift or indirect routes such as contaminated clothing.

Fluoroacetamide

Uses: Rodenticide, insecticide

CAS No.: 640-19-7

Trade Names/Synonyms: Compound 1081, Baran, Fluorokil 100, Fussol, Megatox, Navron, Rodex, Yanock

Mode of Action: Converts *in vivo* to fluoroacetic acid, leading to the formation and accumulation of fluorocitric acid and inhibiting the Krebs cycle

Summary Of Control Actions: Control actions banning or severely restricting fluoroacetamide have been reported by 7 countries: 4 have banned it and 3 have approved its use only in severely restricted circumstances. Annex 1 summarizes specific actions of reporting countries.

Reasons for the Control Action: The use of fluoroacetamide has been curtailed principally because of its high acute toxicity to man and to other mammals and birds.

Environmental Characteristics: Fluoroacetamide is highly stable in soil and water. Main effects are on nontarget wildlife, since many types of animals may consume bait or prey on sick or dead animals. The compound is highly toxic to most animals except frogs and toads.

Dogs and cats are very susceptible to direct poisoning but barn owls, buzzards, black kites and some reptiles have been found to be resistent.

Environment: Humans may come into contact with baits treated with the compound. The compound's high solubility in water indicates danger of water contamination near manufacturing, preparation and application sites. In the UK, farm animals were reportedly poisoned by effluents from a factory. About 800 dogs were reported to have died after consuming meat contaminated by sodium fluoroacetate or fluoroacetamide.

BHC, HCH (Europe), 666 (Denmark) hexachlor (Sweden), hexachloran (USSR),

Use: Pesticide (insecticide)

CAS No.: 608-73-1

Trade Names/Synonyms: Benzex (Woolfolk Chemical), Dol, Dolmix, Gammexane, Gexane, HCCH, Hexafor, Hexablanc, Hexamul, Hexapoudre, Hexyclan, Hillbeech, Kotol (Shell, UK), Lindacol (Shell, UK), perchlorobenzene, Soprocide, Submar (India Medical), FBHC (discontinued)

Mode of Action: Acts as an ingested and contact insecticide, and has some fumigant action.

Summary Of Control Actions: BHC has been banned or severely restricted in at least 11 countries and by the European Community. See Annex 1. (The gamma isomer, lindane, has been retained for a number of uses but is discussed in a separate decision guidance document.)

Reasons for Control Action: BHC use has been reported banned principally because of oncogenic effects detected in animal studies. When considered in combination with its persistence and bioaccumulation potential, the dietary cancer risk was considered unacceptable. In addition, exposures to workers and other persons applying BHC was of concern. Countries also noted persistence and bioaccumulation, high toxicity and environmental effects as reasons for control actions.

Environmental Characteristics: BHC is persistent but not as much so as DDT. Ten percent of original concentration in sandy soil reported remaining after 14 years. In water, there is no measurable degradation after a period of 8 weeks.

It is liquid soluble in water and tends to bioaccumulate. The beta isomer is the most stable isomer and is also the most environmentally persistent and chronically toxic isomer. Beta-BHC has a 10-30 times greater ability to accumulate in fatty tissue than the gamma isomer.

Alpha-BHC in a complex food chain system showed bioconcentration as high as 267 times in algae and 140 times the ambient concentration in Daphnia.

Fish: LC_{50} (48h) 0.16 mg/l (male guppies); 0.3 mg/l (female guppies). Bob-white quail, LD_{50}, oral, 120-130 mg/kg.

Environment: Persistent and accumulates in body tissue.

Hexachlorobenzene

Use: Pesticide - seed protectant (fungicide). HCB can be generated as a by-product during the manufacture of chlorinated pesticides, chlorine and chlorinated solvents.

CAS No.: 118-74-1

Synonyms/Trade Names: HCB, Perchlorobenzene, Anti-Carie, Ceku C.B., hexachlorobenzol, hexachlorobenzene, HCB, perchlorobenzene, No Bunt., Bent-cure, Bent-no-more

Mode of action as Pesticide: Fumigant action on fungal spores

Summary of Control Actions: Control actions to ban or severely restrict the use of hexachlorobenzene as a pesticide or in agriculture have been reported by six countries and the Member States of the European Union (EU) and the Members associated with the EU in the European Economic Area. In the USA, the registrant has voluntarily withdrawn the substance.

Reasons for the Control Actions: Reasons given for banning hexachlorobenzene include its very high persistency in the environment and its bioaccumulation in the food chain. Two countries indicate concern on health effects, including carcinogenicity.

Environmental Characteristics: Hexachlorobenzene is widely distributed in the environment by virtue of its mobility and resistance to degradation. HCB is very persistent. It is tightly bound to soil and sediments. The half-life in soil has been estimated at 3 to 6 years. Due to its binding to soil and its very low solubility in water, hexachlorobenzene does not readily leach into water.

HCB is a bioaccumulative substance (BCF values range from 375 to >35,000).

Fish: LC_{50}/96 hrs 0.05 - 0.2 mg/l (moderately to highly toxic).

Birds: HCB has the potential to harm embryos of sensitive bird species (IPCS).

Bees: Not toxic to bees

Environment: Airborne dust particles containing HCB have been a major source of exposure near industrial sites. Urban air levels have been estimated to contain 0.3 ng/m3. Concentrations in lake sediments had up to 460 µg/kg in layers of sediment corresponding to the peak usage years 1971 to 1976. Traces of HCB have been found as impurities in some pesticides (IPCS, 1996).

Lindane

Use: Insecticide, Acaracide

CAS No.: 58-89-9

Synonyms/Trade Names: gamma-HCH, gamma-BHC (refers to more than 99% gamma isomer), gamma-HKhTsH, ENT 7796, OMS17; 666; Aalindan; Africide; Agrocide; Agrocide III; Agrocide WP; Ameisenmittel Merck; Ameisentod; Aparasin; Aphtiria; Aplidal; Arbitex; BBH; Ben-Hex; Bentox; Bexol; Celanex; Chloresene; Codechine; DBH; Detmol-Extrakt; Devoran; Dol; Drill Tox-Spezial Aglukon; ENT 7796; Entomoxan; Exagamma; Forlin; Gallogama; Gamaphex; Gammalin; Gammalin 20; Gammex; Gammexane; Gammaterr; Gexane; Grammapox; Hecltox; Hexa; Hexachloran; y-Hexachloran; Hexachlorane; Hexaverm; Hexicide; Hexyclan; HGI; Hortex; Inexit; Isotox; Jacutin; Kokotine; Kwell; Lacca Hi Lin, Lacca Lin-O-Mulsion; Lendine; Lentox; Linafor; Lindafor; Lindagam; Lindagrain; Lindagam; Lindagram; Lindatox; Lindasep; Lin-O-Sol; Lindagranox; Lindalo; Lindamul; Lindapoudre; Lindaterra, Lindex; Lindust; Lintox; Lorexane; Milbol 49; Msycol; Neo-Scabicidol; Nexen FB; Nexit; Nexit-Stark; Nexol-E; Nicochloran; Novigam; Omnitox; Ovadziak;Owadizak; Pedraczak; Pflanzol; Quellada; Sang-gamma; Silvanol; Spritz-Rapidin; Spruehpflanzol; Streunex; TAP 85; Tri-6; Vitron

Mode of action: Pesticide: Insecticide with contact, stomach and respiratory action. Acts as stimulant to the nervous system causing epileptiform convulsions and death.

Summary of Control Actions: Actions to ban or severely restrict lindane have been taken by 11 countries. Seven countries have banned lindane.

Reasons for the Control Actions: Control actions are reported by eleven countries. Eight (Australia, Austria, Cyprus, Finland, Indonesia, the Netherlands, New Zealand and Saint Lucia) indicated that lindane was being restricted or banned because of persistency in the environment, bioaccumulation in the food chain and toxicity to humans, aquatic and terrestrial species. One country (the Netherlands) indicated the impurities of lindane (other HCH isomers) as the environmental problem. Four countries (Austria, Republic of Korea, Sri Lanka and Sweden) referred to their concern over toxicity specifically to humans. Lindane has been associated with various human health concerns for several years.

Environmental Characteristics: Lindane is mobile in sandy soils and non-mobile in clay soils; it is also retained more strongly where humus levels are high. However, the potential for lindane contamination of surface and ground water exists based on the results of a monitoring study conducted in south-eastern USA.

The half-life in soil ranges from 5 days (Kenya) to more than 400 days (temperate soils) depending on both temperature and microbiotic life of the soil (WHO, 1992).

In a series of dissipation studies with lindane, it was demonstrated that persistent pesticides such as lindane dissipate much faster in the tropics than in temperate climates, probably owing to a large extent to volatilization (WHO, 1992).

Fish: LC_{50} : 0.02-0.09 mg/l (highly toxic) (WHO, 1991)

Bees: Toxic to bees (Pesticide Manual, 1994)

Aquatic invertebrates: Crustaceans: 0.005-0.88 µg/L (WHO 1991)

Birds: LD_{50}: 120-210 for bobwhite quail; avian dietary toxicity: 882 ppm for bobwhite quail, 561 ppm for ring-necked pheasant (both moderately toxic); >5000 ppm mallard duck (minimal toxicity)

Environment: Monitoring outdoor air samples in the 1980s, the concentrations found in various continents ranged from 0.039 to 0.68 ng/m³. Much higher lindane concentrations (51-61 µg/m³) could be registered in houses after treatment with products containing lindane (WHO, 1991). Lindane has been detected in surface and drinking water and industrial effluent and sewage in Europe and the USA (WHO, 1991). Lindane (29-398 ng/l) has been found in rainwater in Tokyo (1975). It has also been located in soil in many parts of the world. In a Dutch study from 84 were analysed 96 samples from the upper 10 cm of soil from 38 natural reserves in the Netherlands. Fifty-nine samples contained less than 1 µg/kg, 7 contained 20-80 µg/kg. However, in the Ukraine, 36 of 136 soil samples taken at various locations contained lindane at levels of 0.1-5 mg/kg (WHO, 1991).

Monocrotophos

Use: Insecticide, acaricide with systemic and contact action

CAS-No: 6923-22-4

Trade Names: Azodrin, Crotos, Bilobrin, Crisodrin, Glore Phos36, Monocil, Monocron, More-Phos, Plantdrin, Susvin, Monocrotophos 60 WSC, Harcros Nuvacron, Nuvacron 600 SCW, Red Star Monocrotophos, Monocron

Effects on the Environment: Monocrotophos has a low environmental persistence. It does not accumulate in soil because it is biodegradable. Its half-life is less than 7 days in soil exposed to natural sunlight. *(Tomlin, 1994; IPCS,1993; US-EPA, 1985)*

Monocrotophos and its metabolites are not expected to bioaccumulate.

Fish: Monocrotophos is moderately toxic to fish. LC_{50} 48 hrs (Rainbow trout) 7 mg/l and bluegill sunfish (23 mg/l).

Aquatic invertebrates: EC_{50} 48 hrs(Daphnia) 0.023 mg/l *(103)*

Birds: Acute oral LD_{50}s range from 0.9-6.7 mg/kg bw. Monocrotophos is extremely toxic to birds and is used as an avian poison. Monocrotophos may also kill birds which eat insects poisoned with monocrotophos. Due to the use of monocrotophos, an estimated 15,000 to 20,000 birds were killed in Argentina 1995.

Bees: Hazardous to bees (LD_{50} 28-33 µg/bee) *(Tomlin, 1994)*

Environment: The general population is not generally exposed to monocrotophos from the air or water.

Methyl parathion

Use: Agricultural chemical, insecticide, acaricide

CAS-No.: 298-00-0

Trade Names: Parathion methyl, A-Gro, Azofos, Azaophos, Bladan-M, Cekumethion, Dalf, Devithion, dimethyl parathion, Drexel Methyl parathion 4E & 601, Dygun, Dypar, E-601, Ekatox, Folidol M, M40 & 80, Fosferno M, Fostox Metil, Gearphos, Kilex Parathion, Kriss Liquide M, Metaphos, methyl parathion, Methyl-bladan, Methyl Fosferno, Methylthiophos, Metron, Mepaton, Mepatox, Metacide, Niletar, Niran M-4, Nitran, Nitrox, Nitrox 80, Oleovofotox, Parapest M50, Parataf, Paratox, Paridol, Partron M, Penncap M & MLS, Penntox MS, Sinafid M-48, Sixty-Three Special EC, Tekwaisa, Thiophenit, Thylpar M-50, Toll, Thylpar M-50, Unidol, Vertac Methyl parathion, Wofatox, Wolfatox

Summary of Control Actions: After review by the FAO/UNEP Joint Expert Group on PIC, it was decided that certain formulations of parathion methyl emulsifiable concentrates (EC) with 19.5%, 40%, 50%, 60% active ingredient (a.i.) and dusts containing 1,5%, 2% and 3% (a.i.) should be placed in a hazardous category. A typically used formulation is 50% EC which falls into WHO Class Ib, Highly Hazardous. Dust formulations were included for consideration even though in WHO Class III because of the great variation of concentrations and uncertainty over potential doses by inhalation, especially because formulations of this pesticide are produced by many manufacturers with varying degrees of control over the proportion of respirable particles.

Some reports attribute specific cases of poisoning to methyl parathion. These reports refer both to occupational exposure and accidental poisoning .

Registrars need to carefully consider the formulations actually used in each country in determining the risks of continued use of this pesticide. The toxicity of the active ingredient is high, but many formulations will fall into a much lower category of hazard.

Effects on the Environment: Half-lives in soil are in the range of 1 - 18 days under laboratory conditions, degradation being mainly by microbial action and chemical hydrolysis. in aquatic ecosystems, methyl parathion is eliminated from the water phase with DT_{50} values of 2 - 22 days via adsorption on organic substance and microbial degradation. Methyl parathion is rapidly metabolized by both plants and animals and it is not expected to persist.

Methyl parathion has no potential to bioconcentrate due to the low log K_{OW} and to its short environmental persistence.

Fish: Most fish species in both fresh and sea water have LC_{50}s of between 6 and 25 mg/l, with a few species substantially more or less sensitive to methyl parathion.

Aquatic invertebrates: Methyl parathion is highly toxic for aquatic invertebrates with most LC_{50}s ranging from < 1 µg to about 40 µg/l.

Birds: Methyl parathion was toxic to birds in laboratory studies, with acute oral LD_{50}s ranging between 3 an 8 mg/kg body weight. Dietary LC_{50}s ranged from 70 to 680 mg/kg diet.

Bees: Methyl parathion is toxic to bees (LD_{50}: 0.17µg/bee) *(IPCS, 1993)*

Environment: Levels of methyl parathion vaporizing from treated cotton fields have been detected 12 hours (12.6 ng/litre) and 24 hours (0.2 ng/l) after spraying.

Parathion

Other names/ Synonyms: Ethyl parathion. parathion ethyl

Use: Agricultural chemical. insecticide

CAS-No.: 56-38-2

Summary of Control Actions: The 3rd Joint Expert Group Meeting decided to include all formulations of parathion in the PIC procedure except capsule suspensions (CS). The principal reason for actions regarding parathion and its inclusion in the PIC procedure relate to its high acute toxicity. The active ingredient and its most typical formulations fall into the WHO classification by hazard 1a or 1b. The draft WHO health and safety guide noted "there are more reported cases of poisoning with parathion than with any other pesticide currently in use".

Effects on the Environment: Parathion rapidly hydrolyses in alkaline conditions (pH>10) and is hydrolytically stable under sterile conditions at pH 4 – 9. Parathion is degraded in soils. plants and other substrates at a moderate rate. though such conversion may be initially to the more toxic metabolite paraoxon. Such conversion is especially true under dry. hot conditions. Parathion has little or no potential to contaminate ground water.

Parathion does not bioconcentrate.

Fish: LC_{50} 0.05-27 µg/L *(EPA. 1991)*

Aquatic invertebrates: *0.04-15 µg/L*

Birds: LD_{50} 2-30 mg/kg b.w. in various species

Bees: Highly toxic to bees

Environment: Environmental concentrations of parathion are generally low and will be no hazard to human health. In Germany concentrations up to 320 ng/l have been detected in rainwater.

Chlordane

Use: Pesticide (insecticide)

CAS No.: 57-47-9

Trade Names/Synonyms: M-410. Chlor-Kil. Chlorotox. Corodane. Gold Crest C-100. Kilex. Kypchlor. Octachlor. Octa-Klor. Synklor. Topiclor 20. Chlordan, Prentox. Penticklor (Discontinued names: Aspon-chlordane. Ortho-Klor. Niran. Termi-Ded. Velsicol 1068. Gold Crest C-50. Belt)

Mode of Action: Persistent. non-systemic contact and stomach insecticide with some fungicidal activity.

Summary Of Control Actions: Control actions to ban or severely restrict chlordane have been taken by at least 35 countries beginning as early as 1968. In at least 23. chlordane has been completely banned. and in 12 others it is severely restricted.

Reasons for the Control Action: Control actions have been taken for various reasons including: chlordane's persistence and bioaccumulation in the environment. with potential adverse effects on man and the environment because of continuing long-term exposure through water. food and other sources. Of particular concern is its demonstrated carcinogenic response in laboratory rodents and its potential impact on human health from widespread environmental contamination in the food chain.

Environmental Characteristics: The half-life of chlordane in soil when used at agricultural rates is approximately one year. Chlordane is relatively immobile in the environment and not expected to leach since it is insoluble in water. Degradation of chlordane is variable, depending upon the type of application (i.e. surface vs. subterranean) and climate (i.e. temperate vs. tropical/subtropical). Chlordane has been found in a wide variety of agricultural soils where it had not been used for at least five years. Soil drench treatments in three different types of soil in Hawaii demonstrated that 2.3%, 2.9% and 2.4% of the applied dosage of chlordane were present in coral, sandy loam, and clay soils, respectively, seven years later. Studies in the U.S. demonstrate that in sandy loam soil, 15-40% of the applied chlordane was present for up to 14 years. In Florida, soil surface applications demonstrated a half-life of 2772 days, with all the residues within the upper 2.5 cm of soil. Chlordane applied to the surface of a lake resulted in levels declining from 5.5 ppb after seven days to 0.11 ppb after 421 days. Sediment from the lake showed concentrations of 30 ppb at 279 days, declining to 10 ppb 421 days after application.

Human half-life data have shown a whole body half-life of the absorbed dose of 21 days in a young boy, and a serum half-life of 88 days in a four-year-old girl. Both exposures resulted from accidental ingestion. Half-life in rats is 23 days following repeated exposure for 56 days.

Effects: Highly toxic to freshwater fish, aquatic invertebrates, and birds; 96 hr LC_{50} from 42 to 90 mg/L in rainbow trout, 57 to 74.8 mg/l in bluegill: LC_{50} in mallard duck, 858 ppm, in bobwhite quail, 331 ppm, and in pheasant, 430 pm. The biomagnification of chlordane in the environment in such organisms as algae, as well as its low water solubility and persistence in water sediment, can result in bioaccumulation in exposed organisms and possible biomagnification in the food chain.

Environment: Low levels have been reported in air samples (< 1 ng/m^3) and in precipitation (i.e. rain, snow), ppt (ng/L). Higher levels have been reported in river and stream bed sediment (mg/kg).

Chlordimeform

Use: Insecticide, acaricide and ovicide

CAS No.: 6164-98-3

Trade Names and Synonyms: Bermat, C8514, Ent 27567, EP-333, Fundal, Galecron, SN 3626

Mode of Action: Ovicide/larvicide for control of bollworm/tobacco budworm (*Heliothis* spp.)

Summary of Control Actions: Control actions to ban or severely restrict chlordimeform have been taken by at least 10 countries. In at least eight, chlordimeform has been completely banned and in the other two, limited use is permitted for specific crops or under emergency government programmes. Specific actions reported by governments are summarized in Annex 1.

Reasons for the Control Action: Chloridimeform and its principal metabolites are considered probable human carcinogens. Studies in mice indicate dose-related increased incidence of hemangiosarcomas and hemangiomas-malignant tumours of the blood vessel. These data are reinforced by human monitoring data which link a chlordimeform metabolite 4-chloro-o-toluidine (5-CAT), with bladder cancer. The primary concern is for manufacturing plant and agricultural workers handling or applying the insecticide who are subject to exposure to residues over several years. Animal data indicating carcinogenic potential are reinforced by human urine monitoring data which implicate a chlordimeform metabolite with bladder cancer.

Environmental Characteristics: Half-life: loam soils: <60 days (chlordimeform and HCL salt); hydrolysis is enhanced as temperature and pH increase. Current data are insufficient to fully characterize fate.

Effects: Toxic to fish and wildlife. Relatively non-toxic to honey bees. Chlordimeform is moderately toxic to cold and warm water fish species, shrimp and oysters. Rainbow trout: 96 hr

LC_{50}=13.2 mg/l. Channel catfish: 96 hr LC_{50}=20.2 mg/l. The HCL salt appears less toxic to aquatic organisms than the base. End-use formulations may be more toxic to these organisms than the active ingredients. Emulsifiable concentrates are slightly to moderately toxic to birds. Current data are insufficient to fully-characterize effects.

Environment: Although data are not adequate, chlordimeform and its HCL salt are considered to have little potential for leaching to groundwater. They are relatively immobile in mulch and loam soils and short-lived. Residues may move from a treated site in run-off sediment.

EDB

Use: Pesticide (insecticide, nematicide)

CAS No.: 106-93-4

Trade Names/Synonyms: Bromofume, Celmide, E-D-Bee, EDB, EDB-85, KopFume, Nephis (Discontinued products: Soilbrom 40, Soilbrom 85, Soilbrom 90, Soilbrom 90EC, Soilbrom 100, Dowfume)

Mode of Action: Fumigant insecticide, nematicide

Summary Of Control Actions: Control actions to ban or severely restrict EDB have been taken by at least 10 countries, all in the 1980s. In four of these countries, EDB is severely restricted and in six countries it is completely banned. In countries which severely restrict use, permitted uses are primarily for special quarantine purposes. See Annex 1 for a summary of specific actions reported by governments.

Reasons for Control Actions: EDB has been subject to control actions due to health concerns and the persistence of the chemical in groundwater. EDB has been associated with reproductive, carcinogenic and genotoxic effects, in addition to high acute toxicity. Use as a soil fumigant has led to persistent contamination of groundwater aquifers.

Environmental Characteristics: EDB is mobile in air and water and has a half-life in water which ranges from days to years depending on environmental conditions. EDB binds to organic matter in soil and is subject to photo-degradation and volatilization. It is not readily bioacummulated.

Effects: No information available.

Environment: Low levels of EDB have been found in water as a result of pesticidal use. Levels reported in water have ranged from 0.05 to 5.0 ng EDB/1.

Heptachlor, heptachlore

Use: Pesticide (insecticide)

CAS No.: 76-44-8

Trade Names/Synonyms: Aahepta, Agroceres, Drinox, Heptaf, E 3314, ENT 15,152, GPKh, H34, Heptachlorane, Heptacur, Heptagran, Heptamul, Heptox, Rhodiachlor, Heptrex, Velsicol 104; 1, 4, 5, 6, 7, 8, 8 - heptachloro - 3a, 4, 7, 7a - tetrahydro - 4, 7 - methanoindene; Curasemillas

Mode of Action: Persistent, non-systemic contact and stomach poison with some fumigant action

Summary Of Control Actions: Control actions to ban or severely restrict heptachlor have been taken by at least 28 countries beginning as early as 1958. In at least 21, heptachlor has been completely banned, and in seven others it is severely restricted. Specific actions reported by governments are summarized in Annex 1.

Reasons for Control Action: Control actions have been taken for various reasons including: heptachlor's toxicity to man, other mammals, birds, fish and other aquatic organisms, as well as a concem for bio-accumulation, persistence and environmental contamination. Of particular concern is its demonstrated carcinogenic response in laboratory rodents and its potential impact on human health from widespread environmental contamination in the food chain.

Environmental Characteristics: Heptachlor is less persistent in the soil than chlordane, although it may be detected in the soil for as long as 10 years after application. Heptachlor may vaporize slowly from the soil; it may be oxidized to form heptachlor epoxide, a substance more persistent and toxic than the parent compound; or it may be converted to less toxic metabolites by soil bacteria. Heptachlor incorporated into a silty loam soil dissipated from the surface with a half-life of 336-551 days; one author reports the half-life to be 9-10 months. Heptachlor is not expected to leach since it is insoluble in water and should adsorb to the soil surface. The majority of residues are found in the top few inches of the soil.

Effects: Heptachlor is potentially very highly toxic to both warm-water and cold-water fish species; acute LC_{50} to bluegill is 13 mg/l, and rainbow trout is 7.4 mg/l. It is also very highly toxic to freshwater invertebrates; acute 48 hr EC_{50} for *Daphnia pulex, Pteronarcys* sp. and *Orconectes* sp. is 42 m/l, 1.1 mg/l and 0.5 mg/l, respectively. Heptachlor is potentially highly toxic to birds; dietary LC_{50} to bobwhite quail, pheasant, and mallard duck is 92 ppm, 24 ppm, and 480 ppm, respectively. The characteristic of heptachlor to bio-accumulate could produce secondary chronic effects in exposed organisms and possible bio-magnification in the food chain.

Environment: Low levels of heptachlor have been found in air samples of several cities of the USA ranging from 2.3 to 19.2 ng/m . Heptachlor has been reported in drinking water, groundwater, plant effluent, river water, and sediments of lakes and rivers from 18 locations in USA and Europe (3 ng/l to 9 mg/l). Fish examined from the Pacific Ocean have shown detectable levels and oysters from the South Atlantic and Gulf of Mexico have demonstrated levels of heptachlor up to 10 ppb. Earthworms are able to absorb heptachlor from the soil resulting in detectable levels of fat in starlings. Heptachlor epoxide has also been found in the eggs of upland game and waterfowl.

Mercury Compounds

Inorganic mercury compounds: Mercuric oxide, Mercurous chloride, Mercuric chloride, Mercury

Alkyl mercury compounds: Methylmercury acetate, Methylmercury benzoate, Mercuric acetate, Mercury naphthenate, Mercury oleate, Mercury pentanedione, Mercury phenate, Methylmercury acetate, Methylmercury benzoate, Methylmercury nitrite, Methylmercury pentachloropenoxide, Methylmercury propionate, Methylmercury 8-quinolinolate

Alkyloxyalkyl and aryl mercury compounds: Cyano (methylmercuric) guanidine, 2-(Acetoxymercuric) ethanol phenylmercuric lactate, Hydroxymercury-o-nitrophenol, Methylmercuryhydroxide, Methylmercury 2,3 dihydroxypropylmercaptide, N-(phenylmercuric) urea, Phenylmercuric acetate, Phenylmercuric ammonium acetate, Phenylmercuric ammonium propionate, Phenylmercuric borate, Phenylmercuric carbonate, Phenylmercuric chloride, Phenylmercuric dimethyldithiocarbamate, Phenylmercuric-2-ethylhexonate, Phenylmercuric formamide, Phenylmercuric hydroxide, Phenylmercuric-8-quinolinate, Phenylmercuric lactate, Phenylmercuric laurylmercaptide, Phenylmercuric monoethanolammonium acetate, Phenylmercuric monoethanolammonium lactate, Phenylmercuric napthenate, Phenylmercuric nitrate, Phenylmercuric oleate, Phenylmercuric propionate, Phenylmercuric salicylate, Phenylmercuric thiocyanate, Phenylmercuric triethanolammonium lactate, Sodium ethylmercuric salicylate

Uses: Fungicide, herbicide, insecticide, microbicide and bacteriostat

Summary Of Control Actions: The uses of both inorganic and organic mercury compounds as pesticides include seed treatment (dressings), algicide and slimicide (cooling towers, pulp and paper mills), marine antifoulant paints, in-can preservative for water-based paints and coatings, turf, lumber, tree wound dressing, seed potatoes, apples, fabric and laundry uses. Control actions to ban or severely restrict the uses of mercury compounds have been reported by 22 countries. Actions were taken as early as 1969, with the latest in 1990.

Reasons for Control Actions: Control actions have been taken because mercury, in both its inorganic and organic forms, is toxic to man. In addition, various forms of mercury are toxic to aquatic organisms, and residues accumulate in the aquatic biota with the result that potentially dangerous residue levels are reached in aquatic foods (e.g. fish and shellfish consumed by man).

Environmental Characteristics: Mercury in many forms and degrees of volatility can circulate in the environment: water, soil and atmosphere. The rate of vaporization increases with increased temperatures. Mercury compounds are transported into the aquatic environments through volatilization, run-off, leaching and discharges. Aryl mercury and mercury salts in river and lake bottoms can be converted into highly toxic methyl or alkyl mercury by methylation. Methylation is a chemical or biological process by which mercury or mercury compounds are converted to methylmercury, which is highly toxic. Methylation of inorganic mercury in aquatic sediments is a key step in the transport of mercury in aquatic food chains. When introduced into an aquatic environment, mercury becomes attached to particulate matter and settles to become part of the bottom sediments. Micro-organisms in the sediment convert the mercury from inorganic or metallic forms into methylmercury. Both methylation and its reverse reaction, demethylation, take place in both fresh and marine environments. Environmental levels of methylation depend upon the balance between bacterial methylation and demethylation. Methylation in fish appears to arise from bacterial methylation of inorganic mercury, either in the environment or in bacteria associated with fish gills, surface or gut. There is little evidence that fish themselves either methylate or demethylate mercury. Mercury levels then accumulate in the aquatic biota with the result that significant residue levels are reached in aquatic foods consumed by humans and animals. For example, chinook salmon fed 3 ppm accumulated mercury in liver to 30.5 ppm and 17.5 ppm in kidney and analysis of pike muscle suggest biological concentration factors from water to pike in the order of 3000. Elimination of methylmercury for fish and other aquatic organisms is slow (months to years). Bacterial synthesis of methylmercury also takes place in the terrestrial environment. Once methylmercury is released from the microbial system, it enters the food chain. Terrestrial organisms become contaminated. This is best shown in the case of birds where the forms of retained mercury are more variable than for the aquatic organisms and depend upon the species, organ and geographical areas. However. marine birds and those feeding in estuaries are the most contaminated. Large portions of organic mercury (ethylmercury acetate and phenylmercuric acetate) applied to soil were found in organomercury forms after a period of 30 to 50 days. Increasing moisture in soil caused a decrease in the amount of escaping mercury vapour.

Effects: The various forms of mercury are toxic to fish and other aquatic organisms. Mercuric salts and, to a much greater extent, organic mercury are readily taken up by aquatic organisms. Organic forms of mercury are generally more toxic to aquatic organisms than inorganic forms. For mercuric chloride, the 96 hour LC_{50} for several fish species is as follows: catfish, 0.35 mg/l; rainbow trout, 0.22 mg/l; stripped bass, 0.09 mg/l; brook trout, 0.075 mg/l; and mummichog, 2.0 mg/l. A wide variety of physiological and biochemical abnormalities have been reported after exposures of fish to sublethal concentrations of mercury. Fish reproduction is also adversely affected by mercury. Mercuric chloride at 0.5 mg/l caused a 50% inactivation of photosynthesis of giant kelp, *Macrocystis pyrifera*, during a four-day exposure period. For phytoplankton, minimum lethal concentrations for mercury salts range from 0.9 to 60 mg/l. Toxic effects of mercury are increased by the presence of trace amounts of copper. For aquatic invertebrates, methylmercury is more toxic than aryl or inorganic mercury with the larval stage the most sensitive stage of the life cycle. Levels of 1 to 10 mg/l normally cause acute toxicity for the most sensitive developmental stage in many invertebrates. In addition, some forms of mercury bioconcentrate greatly in aquatic plants, invertebrates and fish. Some examples for inorganic mercury, mercuric chloride, show bioconcentration in algae, 8537; duckweed, 70; mussel, 664; pond snail, 795; grass shrimp, 333; mayfly, 38; and rainbow trout (whole body), 5-26. Some examples for the organomercury, phenylmercuric acetate, show bioconcentration in pond snail, 1280; water flea, 3570; and mayfly, 900. Some examples for the organo-mercury, methylmercuric chloride, show pike (liver), 2000 and rainbow trout (whole body), 4225-8033. Organomercury compounds are more toxic than inorganic mercury to birds and cause reproductive effects. For the inorganic mercury, mercuric chloride, the acute oral LD$_{50}$ for Japanese quail is 42 mg/kg and for the organomercury, methylmercury chloride, the acute oral LD$_{50}$is 18 mg/kg. The acute oral LD$_{50}$for the organomercury, phenylmercuric acetate, for the pheasant is 169 mg/kg and for the mallard, 878 mg/kg. For the dietary LC$_{50}$s for birds, mercuric chloride for Japanese quail is 5086 ppm; pheasant, 3790 ppm; and mallard >5000 ppm. For methylmercuric chloride the Japanese quail LC$_{50}$ is 47 ppm; methylethyl mercury chloride, 1750 ppm; and phenylmercuric acetate, 614 ppm.- For phenylmercuric acetate, the pheasant LC$_{50}$ is 2350 ppm and the mallard, 1175 ppm. For methoxyethyl-mercury chloride the pheasant LC$_{50}$ is 1102 ppm and the mallard, 280 ppm. Investigations show that grain treated with ethylmercury phosphate poisoned bobwhite quail in 13 to 20 days. When pheasants were fed methylmercury-treated wheat (20 ppm) for nine days, their eggs had reduced hatchability, and residues ranged from 1. 3 to 20 ppm. In seed-eating birds, mercury residues increased significantly in late spring and early autumn, indicating a correlation with the spring and autumn sowing of treated seed.

Environment: Contamination by mercury may result from natural soil sources, mercury-containing pesticides, tailings from lead mining, or from a variety of chemical wastes. Air levels as high as 10,000 Ag mg Hg/m^3 have been found where mercury fungicides were used. Estimates of average atmospheric levels range between 2-10 mg Hg/m^3. Mercury level ranges in aquatic systems are as follows: open oceans, 0.5-3 ng/l; coastal water, 2-15 ng/l; and rivers and lakes, 1-3 ng/l. The mechanism of synthesis of methylmercury compounds from inorganic precursors in both terrestrial and aquatic environments is via bacterial synthesis. Once methylmercury is released from microbial system, it enters food chains as a result of rapid diffusion rate. Fatalities and severe poisonings in birds have been reported as well as outbreaks of human poisonings. Birds found dead in the area near Minamata Bay showed characteristic pathological changes in the nervous system (as in Minamata disease). Dead fish from the Bay contained high levels of methylmercury, and fish-eating and scavenging birds were also killed. Agricultural use of organomercury fungicides has caused poisoning in birds, and there is a statistically significant correlation between the mercury content of bird eggs and reproductive failure. The organomercury seed dressings have caused death to field birds, mostly grain-eating and predatory birds. Mercury contamination has been implicated in the lack of breeding success in some predatory birds, both in Europe and North America, where residues have equalled those found to cause reproductive problems in laboratory tests

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