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A DECISION FRAMEWORK FOR AGRICULTURAL NONPOINT SOURCE POLLUTION CONTROL IN GHANA

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Segbedzi W. Norgbey

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A DECISION FRAMEWORK FOR AGRICULTURAL NONPOINT SOURCE POLLUTION CONTROL IN GHANA

By

Segbedzi W. Norgbey

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ABSTRACT

A DECISION FRAMEWORK FOR AGRICULTURAL NONPOINT SOURCE POLLUTION CONTROL IN GHANA

By

Segbedzi Norgbey

In Ghana pollution from nonpoint sources is of major national concern because of its adverse effects on land productivity, the natural environment, and human and animal health. Effective control of nonpoint source pollution requires sound decision making based on a good understanding of the complex physical, biological, chemical, socio-economic, and institutional processes associated with the problem. The key to sound environmental management decision-making in a Less Developed Country (LDC) is the development and use of a framework within which optimal decisions can be made at all levels of government. This framework does not exist in a well organized fashion in Ghana. Further, the general magnitude and dimensions of the problem have not been quantified.

The major objectives of this research were threefold: 1) to examine the existing decision making complex for pollution control, 2) suggest an improved decision making framework for nonpoint source pollution control in Ghana, and 3) develop a framework for selection and use of nonpoint source pollution models for decison making in Ghana.

Segbedzi Norgbey

In this study, an assessment was done of the existing framework for environmental management in Ghana. The assessment indicated that several deficiencies exist in the environmental planning and decision making system reflecting poor management of environmental and in particular nonpoint source pollution. Based on the assessment, proposals were made to incorporate nonpoint source pollution decision making into the existing planning framework. An institutional framework designed to facilitate coordination of planning and management functions of existing agencies responsible for environmental planning and control was suggested for implementation. It was recommended that the resource planning units of the Ministry of Finance and Economic Planning be deconcentrated to the district level and made to coordinate nonpoint source pollution control at the local level. A pilot nonpoint source pollution project was proposed for implementation in a specific geographic area in order to test the effectiveness of the institutional arrangements proposed in this study. It was further recommended that the statutory framework be reviewed and local ordinances established consistent with the Land Planning and Soil Conservation Act to give effect to the control effort.

Segbedzi Norgbey

In order to select an appropriate model for evaluating the nonpoint source pollution problem in Ghana, a criteria-based screening system was developed. The screening system was based on a survey designed to determine a ranking of a selected set of criteria. A selected set of the most commonly used nonpoint source pollution models was then reviewed and screened using the criteria arranged through a logical flow-chart. The Agricultural Nonpoint Source Pollution Model (AGNPS) was selected and recommended for further evaluation. Recommendations were also made for adapting specific algorithms within the model for use in Ghana.

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CHAPTER 1

INTRODUCTION

The term "non-point source pollution" emerged in the 1970s to identify those sources of pollution which are different in type from readily identifiable sources. Nonpoint source pollution is defined as pollutant loading that originates from diffused sources. This means that there is no specific outfall (point source) to which a discharge to a water body can be attributed. Over the past two decades, a great deal of attention has been focused on the problem of pollution from nonpoint sources particularly in many industrialized countries. The concerns stem from the adverse effects of nonpoint pollution in the environment and their ultimate hazards to health. Nonpoint sources of pollution vary from place to place. These sources may be airborne or landbased (Krenkel, and Novotny, V 1980). By far, the most pervasive sources are agricultural (Loehr, 1974; Novotny and Chesters, 1981). Loehr (1974) noted that, from all sources of nonpoint pollution, sediment transport is the most important in terms of the volume of material transported. Closely associated with sediment transport is the transport of other substances either in solution or adsorbed to the sediment.

Next to sediment, the pollutants of greatest concern, particularly from rural areas, are plant nutrients often associated with lake and stream eutrophication. Several other pollutants exist to contaminate surface waters from diffuse sources. They are smaller in quantity than plant nutrients but are of extreme importance because of the hazardous effects on human and animal health. Some of the commonly used pesticides, for example, pose potential threats to the quality of surface and ground water systems.

Additional concerns are the off-site damages caused by soil erosion from agricultural lands and runoff from urban areas. These concerns stem from the highly toxic nature of pesticides and such metals as cadmium and lead derived mostly from industrial processes. The magnitude of the risk posed by pollution from toxic organic and inorganic substances in runoff and precipitation is still an area where extensive research is in progress in many industrialized countries [Novotny and Chesters, 1986]. While chemical pollution has been the main focus of water quality planning and research in most industrialized countries, the off-site damages caused by erosion are the critical water quality concerns in many Less Developed Countries (LDCs) [Hauck, 1985].

Nonpoint Source Pollution in Less Developed Countries

In most developing countries, the importance of environmental pollution has been recognized. For example, in 1969, the heads of states of the Organization of African Unity (OAU), recognizing the effects of development on the environment, organized a convention on the conservation of nature and natural resources in Africa (Yarney-Ewusie, 1974). The convention confirmed the awareness of the delegates that soil, water, flora, and fauna are vital to the survival of man. The convention further confirmed its concern for the degradation of these resources in Africa and affirmed that it would initiate individual, bilateral, and multilateral actions to conserve these resources through rational exploitation.

Natural resources was defined at the convention to strictly refer to renewable resources. The convention proposed the establishment of conservation areas in all forms in each country. Guidelines for strict regulation were also proposed to govern the activities of these conservation areas. The delegates recognized the absolute importance of agriculture in the economies of African countries and recommended actions that would conserve soil and water. Among the recommendations was the call for the preparation of land use plans based on scientific investigations and, in particular, on land capability classifications. Recommendations were made to individual governments to initiate action to reduce soil erosion and sediment loss from agricultural lands.

Most studies related to nonpoint source pollution in Less Developed Countries (LDCs) involve estimation of erosion from agricultural lands and the impacts of erosion on crop productivity. The causes of increased soil erosion are fairly well known and documented (see for example, Eckholm, 1976; EPA, 1975; Brown and Wolf, 1984; and El-Swaify and Dangler, 1982) and, therefore, do not constitute a subject matter of detailed discussion in this study. Suffice to mention that the causes can be natural or anthropogenic. The anthropogenic causes relate primarily to the effects of land cultivation, deforestation, and overgrazing of pasture lands. Detailed information is not readily available at the local level for many developing countries (Brown and Wolf, 1984). However, the most recent figures on soil sediment loads of some major rivers in developing countries indicate that rivers are carrying heavier loads of sediment annually. El-Swaify and Dangler (1982) estimate that the Nile, Amazon, Ganges, and Irrawady rivers carry respectively, 111 million, 363 million, 1,455 million, and 299 million metric tons of sediment annually. Table 1.1 provides estimated annual loads for selected major rivers.

The USAID Mission to Ethiopia, in 1978, observed that over 1 billion tons of topsoil flow from Ethiopia's highlands annually. In South Africa, the Institute of Natural Resources (1980) estimated a loss of 200 million tons of topsoil in the province of Natal annually. Brown and Wolf (1984) note that information on soil erosion in most third world countries is largely indirect. Therefore, data on sedimentation of reservoirs, river silt loads, and cropland abandonment

Table 1.1 Sediment Load of Selected Major Rivers

River	Country	Annual Sediment Load (million metric tons)
Yellow	China	1,600
Ganges	India	1,455
Amazon	several	363
Irrawady	Burma	299
Kosi	India	172
Mekong	several	170
Nile	several	111

Adapted from El-Swaify and Dangler, (1982).

resulting from severe erosion are used as a guide for estimates.

Effects of Nonpoint Source Pollution

Sediment generally consists of organic materials, as well as clay, sand, boulders, and other materials, in various stages of decay. Depending on flow regimes of rivers and streams, sediment may be suspended in the water column or may travel along the stream bed. Sediment in water reduces light penetration and plant growth; thus disrupting the food chain supporting aquatic fauna (Duda, 1985). Even turbidity, it has been demonstrated, can increase water temperature, decrease dissolved oxygen, and may ultimately result in fish kills (USDA, 1975).

Erosion of soils can result in erosion of productivity of the land. Research on West African soils indicate a marked decline in crop productivity from topsoil loss. For example, the loss of 3.9 inches of topsoil cut corn yields by 52% while yields of cowpeas reduced by 38% (EL-Swaify and Dangler, 1982). The costs of soil erosion are not confined to agricultural lands alone. Soil is transported from cultivated lands by runoff and often ends up in streams, canals or irrigation and hydroelectric reservoir.

In most of the third world, national development strategies are organized around multi-purpose dams. Volta Lake in Ghana, Aswan High Dam in Egypt, and the Mangla reservoir in Pakistan are among several such efforts. The effects of increased population pressure on the watersheds feeding the reservoirs have been phenomenal. In the Mangla watershed for example, increased agricultural activity and deforestation have resulted in increased rate of siltation. It has been estimated that at the current rate, the reservoir will likely fill up with silt in at least 25 years (Brown and Wolf, 1984). Table 1.2 illustrates the rates of siltation from selected reservoirs in less developed countries.

Soil erosion reduces soil fertility. This means that in order to increase crop output on a given unit of land, the quantity of nutrient required will increase significantly. Studies in the United states indicate that nitrogen and phosphorus requirements for growing corn on severely eroded land could increase by 31 pounds per acre (Rosenberry et al., 1980). The use of nitrate fertilizer has increased very sharply in the last two decades in developing countries. Table 1.3 shows the growth in fertilizer consumption in selected developing countries. Compared to industrialized market economies where fertilizer consumption averaged 271 pounds per acre of arable land, fertilizer use in low-income economies is relatively low. The very high percentage increases shown for the selected countries, however, indicate that plant nutrient will become an important environmental concern. In Sub-Sahara Africa, this argument is further supported by the fact that the retail price index for nitrate fertilizer fell from 147 in 1973/75 to 96 in 1980 due to a deliberate policy of the respective governments to subsidize

Table 1.2 Siltation Rates in Selected Reservoirs

Country	Reservoir	Annual Siltation Rate (metric tons)	Time to Fill with silt (years)
Egypt	Aswan Dam	139,000,000	100
Pakistan	Mangla	3,700,000	75
Philippines	Ambuklao	5,800	32
Tanzania	Matumbulu	19,800	30
Tanzania	Kisongo	3,400	15

Source: El-Swaify and Dangler, (1982).

Table 1.3 Growth in Fertilizer Consumption in Selected Developing Countries

Country	Fertilizer Consumption (1970)	(1980)	(kg/ha of arable land) (% increase)
Zimbabwe	46.6	57.6	24
Bangladesh	14.2	59.6	319
Ethiopia	0.4	3.5	775
Malawi	5.2	16.4	215
India	11.4	39.4	246
Kenya	22.4	37.6	68
Ghana	0.9	7.7	776
Sri Lanka	49.6	74.0	49
Philippines	24.1	32.0	50
Nigeria	0.3	8.7	2800
Thailand	7.6	24.0	216
Turkey	16.6	158.1	852

Adapted from World Development Report, World Bank: 1986 fertilizer in order to increase agricultural production (FAO, 1986). Subsidies mean increased fertilizer consumption. This is reflected in the increasing trends in fertilizer use shown in Table 1.4.

Both nitrogen and ammonia are added to the soil in many forms. Once applied, the compounds go through several microbial transformations and transport processes (USDA, 1975). Among the most important transport processes are direct runoff, erosion, and percolation. Leaching can carry nitrate-nitrogen vertically through the soil to ground water and, depending on the nature of the slope of the land, may emerge in springs or as base flow in streams. Studies indicate that between 75% and 80% of surface nitrogen losses in watersheds occurred in runoff (Donigian and Crawford, 1977). Phosphorus applied in soluble form converts to insoluble form in the soil. The insoluble form which adsorbs strongly to soil particles are moved along with sediment in runoff water.

The use of chemicals to control pests has, along with fertilizer, increased very sharply in the last two decades in developing countries. Like nutrients, pesticides find their way through transport processes into both surface and ground water systems. Some chemicals, especially the organo chlorine insecticides and some herbicides are toxic to fish

Table 1.4 Trends in Fertilizer Consumption in Africa
(1000 Metric Tons)

Region\Yr	1961-2	1970-1	1979-80	1980-1	1981-2	1982-3	1984
Mediterr & N. Africa	330	619	1117	1299	1236	1343	1983
Sudano-Sahelian Africa	34	53	89	127	135	124	149
Humid & Sub-Humid W.Africa	12	44	191	248	330	275	344
Humid Central Africa	5	36	40	46	52	50	47
Sub-Humid E. Africa	37	99	111	143	161	150	179
Sub-Humid & Semi-Arid S. Africa	68	194	275	387	417	372	342
TOTAL	495	1045	1711	2250	2310	2314	2524

Source: Adapted from FAO, 1986

and other aquatic fauna and do persist in the aquatic environment for a long time. For that reason, pesticides found in runoff, even at very low concentrations, may be of environmental concern.

The literature (EPA, 1981, 1985; Novotny and Chesters, 1981; Beasely et al., 1982) on nonpoint source pollution control indicate that approaches that combine legal and regulatory activities, administrative and institution building efforts, technical research including monitoring and wide use of simulation modeling, and the implementation of Best Management Practices (BMPs) will produce significant results in the control of pollution from diffuse sources. The following sections discuss the nature of the nonpoint source pollution problem in Ghana and the existing decision framework for managing the environment in general and nonpoint source pollution in particular.

PROBLEM STATEMENT

Nonpoint Source Pollution in Ghana

In Ghana, like in many LDCs, the significance of nonpoint source pollution as a major contributor to poor water quality has been recognized. However, the general magnitude and dimensions of the problem have not been quantified. A survey in 1974 by the Water Research Unit of Council for Scientific and Industrial Research (CSIR), concluded that erosion and sediment are major constraints to agriculture and improved water quality. Other types of pollutants identified included suspended solids, cyanides, arsenic, pesticides, gold, zinc, iron, organic dye, chlorides, phenols, and chromium only to mention a few. Intensive use, which typically makes land more erodible, together with increased use of agricultural chemicals are major causes of pollution from nonpoint sources. For that reason, sediment with its associated nutrients and pesticides may be synonymous with nonpoint source pollution in Ghana.

Ad hoc studies indicate that sheet and gully erosion found in the northeastern parts of the country have denuded between 0.9 and 1.2m of top soil. In the tropical forest regions and upland areas, rates of erosion are equally high (Adu, 1972). Bonsu (1985) studying the erosion reduction potential of organic residues in Ghana estimated average soil loss on a 7.5% slope, bare fallow semi-deciduous forest field between 1978 and 1980 at 63.5 tons/ha. Average annual runoff was 1,340 mm. On an agricultural field of a 2% slope in the northern savanna region, average soil loss in 1979/80 was 5.18 tons/ha. Recognizing that the top 10 to 30 cm of top soil contain the largest proportions of nutrient and organic matter, these trends in soil erosion will reduce much of the fertile layers in a few decades, especially in the highly populated and most cultivated parts of the country.

A USAID Draft Environmental Report on Ghana (1980) note that:

> Land use practices have stripped the soil of fertility. Erosion rates are high and infiltration is low throughout the country. Slash and burn agriculture tend to increase the propensity to erode. Drought, overgrazing and expanding cultivated areas combine to reduce the vegetative cover, thereby decreasing the nutrient replacement in the soil and increasing the tendency to erosion (Turner, 1980).

Soil may be considered the most valuable natural resource in Ghana if only because agriculture remains the cornerstone of the economy. For that reason, increased erosion and runoff of agricultural chemicals are a major national problem. A survey by the Water Research Unit of the Council for Scientific and Industrial Research (CSIR) in Ghana concluded that rivers including Birim, Offin, Volta Densu, and Ankobra have significantly elevated sediment loads due to erosion (CSIR, 1976). Turner (1980) argues that cultivation of the Volta River Basin leaves the soil exposed for erosion to take place. Further, increased use of fertilizer and insecticides affect all biotic components of the Volta Lake resulting in significant impacts through time. It has been estimated that at current rates, the Volta reservoir will fill up with sediment in 75 years (Smithsonian Institution, 1974). Environmental degradation resulting from deforestation, overgrazing, and their attendant soil erosion have not only polluted water resources but have resulted in a shift towards a more desert-like environment particularly in the savanna.

As early as 1953, legislation designed to preserve and reclaim land, prevent erosion, and protect water resources had been passed in Ghana (Dyasi, 1985). However, this legislation has not been implemented in an effective manner. Neither do the administrative capacities necessary for coordinating implementation of the provisions of the legislation exist at the local level. Studies designed to determine the general magnitude of the problem and the conservation potential of land and water management practices are limited. These major deficiencies in the environmental and natural resource management system reflect poor decision making and a lack of effective action for prevention and mitigation of environmental degradation.

In particular, the major institutional problem is the lack of coordination within the governmental structure. Several agencies including the Ministries of Agriculture, Finance and Economic Planning, and Works and Housing, as well as the Council for Scientific and Industrial Research (CSIR), Environmental Protection Council (EPC) and other nongovernmental organizations have major responsibilities in managing the environment. While the Ministry of Agriculture has the mandate to prevent soil erosion and protect water resources (Land Planning and Soil Conservation Act) from pollution from agricultural sources, the necessary institutional capacity was never fully developed. In Ghana national priorities are defined in the form of national development plans. National development plans over the past two decades have been silent on the general subject matter of environmental protection.

The lack of a clearly defined national policy on the environment and pollution from agricultural sources in particular has resulted in a lack of coordinated effort to determine the magnitude and extent of the problem. Limited studies aimed at quantifying the problem exist. The applicability of the Universal Soil Loss Equation (USLE), for example, has been tested (Quansah, 1981) but has not been applied widely. Studies on the conservation potential of soil and water management practices are limited (Bonsu, 1985). Water quality monitoring is done in selected watersheds but the results are not used in a coordinated fashion to develop a strategy for solving the nonpoint source pollution problem in Ghana.

Another important problem worth noting is the lack of decentralization of the relevant government agencies to the local level for implementation of environmental legislation. Strategies directed at control of nonpoint source pollution must, of necessity, be implemented at the local level. Without a clear national policy and representation of the appropriate agencies at the local level the mandate to develop environmental protection programs does not devolve along with development responsibilities.

The successful implementation of any nonpoint source management program depends on the ability of planners to quantify the magnitude and extent of the problem and develop the necessary institutional capacity to manage it. To that end, planners would greatly benefit from a model of the system to determine cause-effect relationships. The level of sophistication of the models may vary. However, if existing models are used, the models must first be screened using pre-determined criteria in order to select the most applicable and cost-effective model for application.

To help characterize the nonpoint source pollution problem and define a decision making framework for controlling nonpoint source pollution in Ghana, it is the purpose of this research to conduct a detailed analysis of the status of nonpoint source pollution and its control in Ghana in order to suggest a decision support system for the control of nonpoint source pollution in Ghana.

Objectives of the Study

The objectives of this study are threefold: a) to examine and describe the decision making complex for nonpoint source pollution in Ghana to better understand the existing environmental decision making framework, and b) to identify inadequacies in, and suggest an improved decision framework for managing agricultural nonpoint source pollution in Ghana and c) to identify appropriate nonpoint source pollution models for decision making in Ghana.

Research Approach

In order to achieve the objectives stated above this research will involve activities discussed below.

a) In examining the existing decision framework for nonpoint source pollution control in Ghana, a detailed review of literature was conducted in order to characterize the decision problem related to nonpoint source pollution control in Ghana.

b) In order to create a decision framework for managing nonpoint source pollution in Ghana the following activities were undertaken:

1) decisions regarding what alternative scenarios to pursue in the control of nonpoint source pollution in Ghana must be made within a well organized institutional framework taking account of existing resources. To remedy the institutional inadequacies which impede the decision making process, elements of an institutional framework for managing the nonpoint source pollution problem were defined. On the assumption that nonpoint source pollution control is best achieved at the local level, a review of the existing planning framework was done. The aim was to develop a framework for incorporating the management functions associated with nonpoint pollution control into the existing planning system.

2) a set of criteria was developed for comparing the analytical tools (in the form of nonpoint source pollution models) necessary for the study of the nonpoint source pollution problem. This was accomplished with a criteria- base screening system designed to be used in isolating appropriate models for the study of nonpoint source pollution problems in Ghana. To illustrate how the screening system would operate, the most prominent nonpoint source pollution models were compared on the basis of how well they meet the model selection criteria. The emphasis in the design of the screening system was on the logical processes involved in selecting a decision making tool rather than on the identification of a specific nonpoint source pollution model.

Organization of Remainder of the Study

Chapter 2 of this study is an evaluation of the existing decision framework for managing the environment in Ghana. This evaluation will provide the basis for suggesting an improved framework within which nonpoint source pollution decisions in particular and environmental management decision in general could be made.

Chapter 3 is devoted to the design of an institutional framework for nonpoint source pollution control in Ghana.

Chapter 4 discusses the use of nonpoint source pollution modeling as a management decision tool. It emphasizes the current status of the technology, and discusses approaches, uses, and problems, of nonpoint source pollution models.

In chapter 5 a screening process which identifies important factors influencing selection of models by planners is developed.

Chapter 6 discusses the major conclusions of the study and outlines limitations, recommendations, and areas of further inquiry.

CHAPTER 2

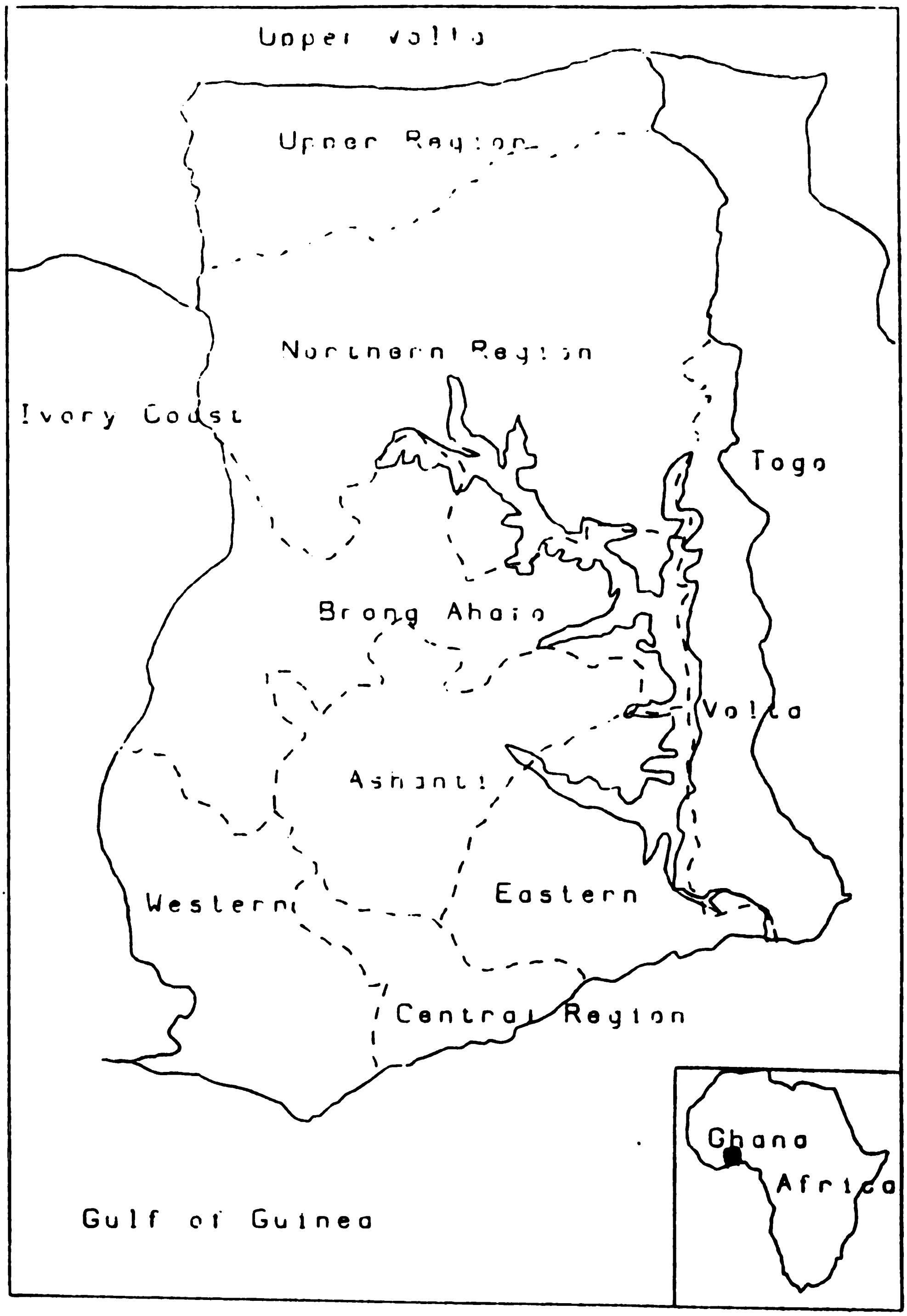
EXISTING DECISION FRAMEWORK FOR ENVIRONMENTAL MANAGEMENT IN GHANA

General

Ghana is situated in the great bulge of West Africa (see Figure 2.0) between the Republic of Togo on the east, Ivory Coast to the west, Burkina Fasso (formerly Upper Volta) to the north and northwest, and the Gulf of Guinea to the south. The country lies near the equator, extending from latitude 4 1/2° N to 11° N and between longitude 1 1/2° E to 3 1/2° W. It covers 238,539 sq km. Ecologically, the country is diverse but largely dominated by tropical rain forest and savanna (Dickson and Benneh, 1970; Kaplan et al, 1971). Five major geographic zones are distinguishable (Kaplan et al., 1971). They are: the low plains in the south and along the coastal areas of the Gulf of Guinea; the upland areas; Volta basin; Akwapim-Togo ranges to the north of the low plains; and the high plains to the north and northwest.

Rainfall varies geographically and seasonally. Rainforests receive over 1905 mm (75 in.) while the northern savanna receives about 1016 mm (40 in). In the southeastern

FIGURE 2.0 MAP OF GHANA



plains, rainfall is approximately 762 mm (30 in.) [Dyasi,1985]. The northern region of the country has one rainy season between May and August. In the south, rain falls from May to August and in December and January. In contrast to the variability in rainfall, temperatures are relatively stable throughout the year with a mean of 25° C (77° F). There is significant diurnal variation, however. Considerable variation exists in soil types even over short distances (Dickson and Benneh, 1970). Soils in the rainforests are generally acidic porous loams (oxysols) that leach substantially. In the semi-deciduous forests, alkaline ochrosols characterized by comparatively smaller rates of leaching are found. The wooded savanna is characterized by shallow lateritic soils underlain by an impervious iron pan which often causes waterlogging. The laterites are deficient in organic matter and are acidic. Depth, pH, fertility, and erodability vary widely between soil types. The water retaining capacity of the soils are generally poor under conditions of insolation induced by extreme sunlight. This results in substantial runoff. The fragility of the environment suggests a need for effective management to maintain a sustainable production system.

Patterns of Resource Use and Environmental Pollution

Approximately 57% of the active labor force in Ghana is engaged in some form of agriculture (GOG, 1977b). Sixty percent of those engaged in agriculture are food crop producers who practice crop rotation. This practice has a built-in system of environmental conservation. These systems include intercropping, retention of selected trees to prevent erosion, and "rotation in space" or shifting cultivation. With rapid population growth (6.7 million in 1960, 8.5 million in 1970, and 12 million estimated for 1980) and, for that reason, increased pressure on land, the balance which has hitherto been maintained in a delicate ecosystem has been disturbed. In the densely populated areas of north eastern Ghana, for example, soil deterioration from agricultural activity has forced farmers to cultivate marginal lands causing further degradation and increased soil erosion and sediment loss (Dorm-Adzobu, 1982).

As part of a national atlas project a general survey has been conducted by the Soil Research Institute to determine erosion hazard areas. The resulting erosion hazard map was published in 1974 (CSIR, 1974). Detailed studies of soil loss and the conservation potential of existing agricultural management practices are scanty. A soil survey of the Navrongo-Bawku area in the north-east indicate that in moderately eroded areas about 0.9m of soils have been removed while soils of approximately 1.2m thickness have been denuded by gully erosion (Adu, 1972). The resulting soil erosion maps constructed for the area show a close correlation between intensified agricultural activity and severe soil erosion.

The mono cropping systems associated with the cash crop economy (cocoa, coffee, oil palm, tobacco, and rice) and the requirements for the use of nitrate and phosphate fertilizer, pesticides, and herbicides with their attendant environmental problems are a permanent feature of the agricultural production system. The State Farms Corporation, for instance, was established as a government agency to engage in mechanized and large scale agricultural production. The results of the activities of the State Farms Corporation was summed up by Dyasi (1985) as follows:

> To start the farms, trees were cut and uprooted; the top soil was turned over and exposed to intense insolation resulting in the alteration of its physiochemical and boitic properties. Other undesirable results were increased soil erosion and rapid reduction of soil fertility.

Closely associated with the problems related to the cash crop economy are the environmental problems associated with timber extraction and export. The intensive exploitation of timber resources for export, together with intensive fuel wood harvests over the last two decades have resulted not only in deforestation and widespread destruction of wildlife habitats but also erosion and sediment delivery to rivers and streams (Adu, 1972). The pattern of land use is shown in Table 2.1.

Table 2.1 Pattern of Land use in Ghana

Closed Forest Zone:	Area (sq km)
Forest Reserves (permanent forest estates)	16,853
Unreserved Forest (potential farmland)	3,135
Agricultural Lands	6 2,587
Savanna Zone:	
Forest Reserves	8,840
Unreserved Woodlands	81,777
Other Lands (grasslands, farms, etc)	66,266
TOTAL	239,458

Source: Government of Ghana (1977a).

Political Framework

Ghana's political environment has been in a state of flux since the early 1970s. This is due to the frequent overthrows of constitutionally elected governments. The last national constitution promulgated in 1979 was suspended in 1981. The governmental structure in the constitution comprised of a legislative branch, an executive branch and a judiciary. Table 2.2 is a simple illustration of the governmental structure under the now defunct 1979 constitution. The current structure comprises a ruling council which incorporates the executive and legislative functions of government and an independent judiciary.

Ghana has a unitary system of government. In 1988, a Local Government Act (1971 amended 1974) which was to be implemented under the 1979 constitution was implemented. This Decentralization Act devolves decision making to the local level. The Act set up Regional Councils, District Councils, Local and Area Councils, and Town and Village Development Committees. The District Councils were set up as the basic unit of planning. Water Planning and Management institutions are discussed under the sections entitled "Legal/Regulatory Framework" and "Administrative Framework".

Table 2.2: Government Structure (1979 Constitution)

Legislative	Executive	Judiciary
Parliament Speaker (elected by members)	President Commission for Information and Cocoa Affairs	Supreme Court
		High Courts
	Commission for Economic Planning, Finance, Trade and Tourism	Magistrate Courts
	Commission for Transport Communications, works and Housing	
	Commission for Consumer Affairs and Co-operatives	
	Commission for Agriculture	
	Commission for Sports and Local Government	
	Commission for Education Culture and Health	
	Commission for Justice, Internal Affairs and Attorney General	

Source: Turner, 1980

Economic Framework

Ghana is a middle income country with a Gross National Product (GNP) per capita of $380 (World Bank, 1986). Fifty-seven per cent of the population is engaged in agriculture providing 41% of Gross Domestic Product (GDP). The importance of agriculture is demonstrated by the fact that agriculture was allocated approximately 30% of the national budget in the 1976-80 national development plan (Government of Ghana, 1975a). Industry and mining contributes 20% and trade and finance 22% to GNP. Between 1970 and 1978, Ghana's economy stagnated from declining currency exchange rates and rapid inflation rates of an average of 22.8% between 1965 and 1980 and 57% between 1980 and 1985 (World Bank, 1987). As a result, GNP declined and the per capita growth rate declined by 2.4%. The average annual rate of growth in GNP between 1965 and 1985 is 2.2%.

Agriculture and industry have also had negative annual growth rates between 1970 and 1977. Between 1965 and 1980 GDP grew at the rate of 1.4% but grew at a negative rate of -0.7% between 1980 and 1985. This trend has since been reversed. Import restrictions have resulted in a relatively small foreign debt and the present government is working with the International Monetary Fund (IMF) to stabilize the economy (World Bank, 1987). The rate of growth in GNP has increased to 6% and substantial restructuring of the productive sectors of the economy is taking place (New York Times, Dec 7. 1988).

Legal/Regulatory Framework

Efforts directed at managing the environment dates back to the pre-independence era. Legislation related to the environment before independence was mainly directed at regulating commercial utilization of forest and water resources (Dyasi, 1985). The post independence legislative effort in sum reflects an emerging enlightened environmental policy.

One of the earliest and most important pieces of legislation related to nonpoint source pollution,the Land Planning and Soil Conservation Ordinance (32) of 1953 amended in 1957 as Act 35, established committees to preserve and reclaim land, protect water resources, prevent soil erosion, and utilize swamp lands. The ordinance regulates the breaking and clearing of land, grazing and watering of livestock, afforestation and reforestation, and water resources development. The amendment of 1957 incorporated nonrenewable resources and hazardous substances.

The Town and Country Planning Ordinance (Cap 34) of 1945 (amended in 1958, 1960 as Act 33) is a physical planning Act. Under this Act, planning authorities have to grant permission to developers before significant changes in land uses occur. The permits to develop are based on development plans for each region, detailing present and future uses. As implemented, however, the Act has been applied primarily to large towns and cities and their immediate environment.

An important and, indeed, one of the most significant statutes of the post independence era, the Volta River Development Act (95) of 1961 amended (Act 233) in 1964 mandated the government to construct a hydroelectric dam on the Volta river at Akosombo. The environmental aspects of the legislation sought to reduce the harmful effects of dam construction by limiting intrusion of sea water into freshwater upstream, to control water levels above the dam, to prevent floods and install a flood warning system, and to establish controls on sewage outfalls and other pollutants in the drainage basin. The law mandated studies related to the adverse effects of agriculture on the lake. The law is significant because it constitutes the cornerstone of subsequent legislation designed to identify environmental impacts of economic development projects.

Ghana's Farmland Protection Act (107) was passed in 1962. This Act which was essentially designed to protect the tenure system made an oblique reference to land use and its environmental consequences.

The Ghana Water and Sewerage Corporation Act was passed in 1965. This Act established a government corporation to set and maintain standards related to the supply of clean water and the treatment and disposal of sewage. The corporation was also empowered to identify types and concentrations of toxic materials in sources of water. The Act was generally environmental in scope (Boateng, 1977). As implemented, the Act focused largely on urban areas where the need for clean water was most expressed.

The emerging national policy towards the environment is reflected in the establishment in 1968 of the Council for Scientific and Industrial Research (CSIR). The council consists of representatives of research Institutes, selected government departments, universities, and production and development organizations. Its main function was to advise the government on matters related to the science and technology of natural resource utilization and conservation. Several research institutes covering forest resources, soil, crops, food, water and aquatic biology, and industry were established under the council. These institutes, in total, form the most important source of technical information on Ghana's environment.

The developments outlined above seem to point to an extensive body of laws aimed at protecting the environment and natural resources in Ghana. In spite of these laws problems emerged. The development of the Volta River and the establishment of the Volta lake created problems that have been in the public consciousness and have been discussed publicly. Not only were cultures along the Volta basin dislocated but the population of disease vectors increased leading to increased use of organochlorine and organophosphorus pesticides such as DDT and ABATE. Studies carried out by the Institute of Aquatic Biology for the Onchocerciasis Control Program (OCP), for example, indicated that the residual effects of DDT use in the rivers were unacceptable (WHO, 1978). Monitoring of the Volta and selected tributaries have shown a general reduction of invertebrate fauna by approximately 30%. Noticeable changes have been observed in the structure of plants due to the tendency to break up into microscopic parts.

Efforts to safeguard the environment of the nation continued after 1968 culminating in Ghana's participation in the United Nations Conference on the Human Environment held in Stockholm in 1972. In 1973, a Scientific Committee on the Problems of the Environment (SCOPE) of Ghana held what was Ghana's first public seminar on "Major Pollution Problems in Ghana" (Laryea, 1974). The seminar echoed the problems of the environment in Ghana and recommended the establishment of a body to coordinate environmental policy and activities that had hitherto been performed by different ministries and other government agencies. The Environmental Protection Council (EPC) was formed by government decree (N.R.D.C. 239) in 1974 as a central coordinating institution. The decree further promulgated basic principles and guidelines for environmental management in Ghana. The decree distinctly reflects the national attitude towards the environment. Incorporated in the law was a proviso that at no time was the social and economic development of the nation be compromised by environmental policy.

Among other important legislation for the protection of the environment is the Oil and Navigable Waters Act (235) of 1964 which made it an offense to discharge oil or mixtures containing oil into Ghana's maritime waters or navigable rivers. A more recent Act, the National Investment Code (Act 437 of 1981) stipulates that plans for economic development projects include the projects environmental impacts and determine measures to prevent and mitigate the adverse effects of the projects. These two Acts together with those described above point to an extensive policy direction for Ghana. Other laws relating to the environment include the Wild Animals Preservation Act of 1961, and the Forestry Commission Act which charges a commission to correlate forestry with all other land uses. The Mines and Minerals Act (276) and its subsequent regulation (Regulation L.O. 257) licenses offshore mineral development and prohibits pollution and environmental degradation.

It is important to mention, at this point, that the effective implementation of environmental laws will promote the achievement of the goals of nonpoint source pollution controls. This has not been done in a consistent and effective manner in Ghana. The Land Planning and Soil Conservation Act (the most pertinent to nonpoint source pollution control), for example, has not been implemented effectively. This is reflected in the institutional and administrative set up of the Ministry of Agriculture which had the mandate to administer the requirements of the Act.

The existing institutional framework for environmental management is a subject matter of further discussion in subsequent sections of this chapter. Table 2.3 summarizes the author's perception of the status of existing political will for environmental management.

Administrative Framework

To exercise the authority provided by the legal and regulatory framework discussed above, government levels must develop an administrative structure to implement programs and install mechanisms for coordination among and within various levels of government. The discussion of statutes and national policies have touched on some of the major institutions and the roles they perform in environmental planning and management.

The following provides a summary description of the major institutions and the roles they perform.

Environmental Protection Council (EPC):

Established in 1974, the EPC is charged with the responsibility for maintaining a sound environmental and ecological balance in Ghana. It coordinates environmental activities and education, conducts research and safeguards the environment during planning and execution of development projects. By reason of the nature of their mandate, the EPC has more opportunity to collaborate with other agencies than

Table 2.3: Summary Status of Political Will for Environmental Protection and Management

Condition	Status
Pressure on political leadership for economic development at the expense of the environment	Very intense. Proviso in legislation that environmental concerns should not compromise economic development
Executive Leadership	Strong, has potential for being translated into positive action on the environment
Use of institutional mechanisms	Extensive legal and regulatory framework
Administrative institutions	Mostly centralized. Decentralization policy has not decentralized some institutions that could coordinate environmental policy at the local level.
Policy Statements	Have not been reflected in national development plans as priority.
Public awareness	Public awareness marginal at best.

most. Yet its work is hampered for the same reason, for the lack of resources, the lack of coordination among governmental agencies and the lack of a stated environmental policy.

Council for Scientific and Industrial Research (CSIR):

The council has the overall responsibility for research organization in Ghana (C.S.I.R., 1973). It encourages research, initiates new projects, coordinates research and disseminates research information. The council is regarded as the scientific arm of government. A significant portion of research conducted under the auspices of the council are problems referred to it by various ministries and industries which do not have their own research facilities. The council supervises six major research institutions related to soils, forest and forest products, crops, food, industry, building and roads, and water. For the purpose of this study, the functions of soil, water, forest, and crops research institutes are discussed below.

Soils Research Institute:

The main activities of the institute include research into soil genesis, survey and classification of soils, soil chemistry and mineralogy, soil fertility, erosion control, soil conservation, soil microbiology and soil physics. As of 1980, the soil research institute had completed a survey of over 75% of the country and prepared maps showing soil associations, vegetation and present land use, and land capability determinations for agriculture (CSIR, 1973 and Dyasi, 1985).

Crops Research Institute:

The Crops Research Institute is the overall coordinating institution for experimental stations and crop specific research organizations. It also coordinates its activities with research being conducted in the universities. The institute conducts research on various aspects of crop production and disseminates research information through both the extension unit of the ministry of agriculture and publications.

Forest and Forest Products Research Institute (FPRI):

The general activities of the FPRI include research into silviculture and management, tree breeding and forest genetics, forest entomology, forest economics and, wood seasoning and preservation. Others include wood technology and anatomy and timber engineering and utilization. The Institute coordinates its activities with the departments of Forestry and Wood Technology in the University of Science and Technology.

Water Research Unit:

The Water Research Unit has the overall responsibility for assessing the water resources, both quantity and quality, of the country. It conducts water balance studies, and cooperates with the Institute of Aquatic Biology in water quality studies.

Ministry of Agriculture (MOA):

The Ministry is divided into 6 major departments: Division of Agriculture, Branch of Soil and Land Use Survey, Division of Animal Health, Division of Fisheries, Division of Mechanization, and Irrigation Development Authority. The Division of Agriculture is further divided into the Departments of Economics, Planning and Research and Agriculture. In general the Division of Agriculture implements fundamental, applied and technological research. The Branch of Soil and Land Use Survey was created on the Authority of the 1953 Ordinance which mandated the establishment of committees to preserve and reclaim land, protect water resources, and prevent soil erosion. The Branch coordinates its activities with those of the Soil Research Institute of the CSIR. The Branch of Soil and Land Use Survey is a small division and is not adequately represented at the local level.

Ministry of Finance and Economic Planning (MFEP):

The Ministry has fiscal and planning responsibilities at the national level. It has a two tier structure: Finance and Economic Planning. The Department of Economic Planning has responsibility for preparing national development plans and administering development projects. The Department's regional offices oversee central government projects at the local level. The Ministry supervises the activities of the Council for Scientific and Industrial Research, Environmental Protection Council, the Volta River Authority and such donor projects as the Onchocerciasis Control Program (discussed above). The department is also responsible for coordinating integrated rural development programs in various regions of the country.

One of the main issues related to the role of the Resource Planning Unit of the Department of Economic Planning is the centralized nature of the Ministry. In formulating the Local Government Act of 1971 the ministry successfully resisted decentralization to the local level. What this means is that the Ministry is not effectively represented in the district which now constitutes the basic unit of planning and implementation in Ghana.

Volta River Authority (VRA):

The Volta River Authority was established in 1961 to construct and manage the Akosombo hydroelectric project and the 8,730 sq km of lake that resulted from the construction of the dam. The Authority has since constructed a similar project at Kpong downstream of the original project. The VRA, among other things, conducts research to determine the quality of water in the lake.

NonGovernmental Organization

Ghana Academy of Sciences:

The Academy is a nongovernmental organization which coordinates research in the sciences. It maintains a number of research institutions among which are: Institute of Aquatic Biology, Soil Research Unit, and Water Research Unit. The Academy has responsibility for coordinating programs for the Scientific Committee on Problems of the Environment (SCOPE) and Man and Biosphere Program in Ghana.

Institute of Aquatic Biology:

The institute conducts general research in freshwater biology limnology of rivers, lakes, lagoons, and estuaries, pollution, and monitoring of inland waters with a view of controlling freshwater fishery, aquaculture, aquatic weeds, and vectors of waterborne diseases.

Soil Research Unit:

The unit conducts research similar to work done by the Soil Research Institute discussed above.

Working Group on the Environment:

In coordinating the activities of SCOPE, the Academy maintains a standing working group on the environment. This group consists of representatives from universities, research institutions,ministries, government departments, and the public.

Summary

The review of the environmental management system indicates that a significant number of laws and institutions exist to protect the environment of Ghana. Besides the Environmental Protection Act which provides the statutory basis for environmental protection, the Land Planning and Soil Conservation Act (35) provides the legal basis for the control of pollution from nonpoint sources. The legislation has, however, not been effectively implemented.

The review also raises the question of functional relationships between planning and management agencies. Inadequate coordination exists among the Branch of land Use Survey of the Ministry of Agriculture the research institutions under the C.S.I.R and the Environmental Protection Council, the resource planning units of the Ministry of Finance and Economic Planning to effectively implement the Land Planning and Soil Conservation Act.

The discussions of the existing environmental management and decision making system in this chapter provides the basis and the necessary information for the discussions that follow on the institutional arrangements for nonpoint source pollution control in Ghana.

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CHAPTER 3

ELEMENTS OF AN INSTITUTIONAL FRAMEWORK FOR NONPOINT SOURCE POLLUTION CONTROL IN GHANA

Introduction

The ability to document, quantify, and successfully manage control of nonpoint source pollution will depend on a strong and coherent administrative and regulatory framework. The institutional inadequacies (including a severe lack of coordination within the governmental structure, lack of review and enforcement of existing legislation, and the absence of the relevant agencies to plan and implement nonpoint source pollution control programs at the local level), discussed in previous chapters, suggest that an improved institutional framework which would be responsive to the needs of planning and management of nonpoint source pollution control is required. Institutional framework is defined broadly to include the administrative framework and statutory controls.

Conceptual Framework

In general, planning decisions regarding nonpoint source pollution must be viewed as constituting a functional responsibility within an area-wide planning decision-making complex. In Ghana, the Minister for Finance and Economic Planning and his staff play a major role in developing resource planning concepts. In theory, resource planning must be carried out using a holistic approach. This means incorporating environmental concerns into the planning process. The various roles within the decision making complex form a functional hierarchy. In a discussion of the political structure in Chapter one, mention was made of a decentralization program under which the districts form the basic unit of planning and administration. At the regional level, planning decisions are made within regional councils. A simplified regional planning decision making pattern is shown in Figure 3.1. Within the hierarchy, the highest decision-making in regional planning involve interactions among several sectors namely economic development, transportation, land use planning, environment, health, and several others not shown.

Under ideal conditions, the process of planning at both district and regional levels must be a continuing, iterative activity where changes at one level affect activity at the other levels. It has been mentioned that nonpoint source pollution, by its very nature, must be managed at the local level. For that reason, the new political structure in which the districts form the basic unit of planning and administration provides a rare opportunity to incorporate nonpoint source pollution control ideas, including modeling, into the existing planning process. Integrating environmental assessment and planning into the existing land use planning process is not a new concept. Both the United

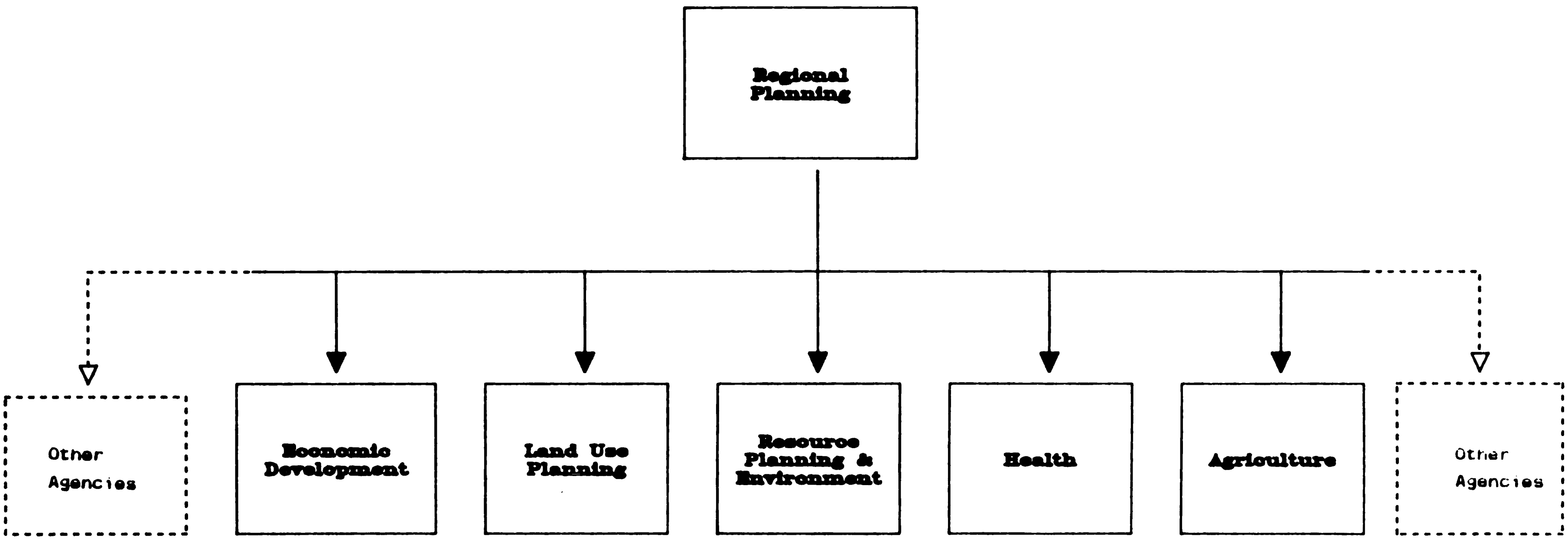


Figure 3.1 A Simplified Regional Planning Decision Making Scheme

Kingdom and Australia have a system where environmental planning and impact assessment review processes are integral to land use and resource planning (Lee, 1982, Westman, 1985). Ghana inherited an administrative and planning structure modeled along structures used in Britain. For that reason the proposal to include nonpoint source pollution control into the existing planning and administrative system has substantial merit and is based on a system that has been well tested.

The responsibility for resource planning which embodies, in theory, environmental management are concentrated at the national and regional levels. Thus the institutional system for nonpoint source pollution control in Ghana must be structured in order to assist the new units of planning at the district level. To further understand the potential roles that could be played by various levels of government, the following is a more detailed discussion of the national planning framework under the Local Government Administration Act (1974) [Sherwin, 1977].

The National Planning Framework

The local government structure outlined briefly in chapter two was designed to ensure the creation of strong integrated units of local government and the devolution of broader planning and administration responsibilities to the district level. At the national level, the National Economic Planning Council which consists of ministers of key economic ministries formulates the national development plan, allocates resources for plan implementation, and supervises efforts in planning and plan execution. The functional responsibilities of regional and district levels increased substantially with decentralization. Figure 3.2 illustrates the existing planning and development framework in Ghana. The goal of the framework illustrated in Figure 3.2 is to integrate administrative functions, development functions, and public participation in planning at all levels of government. Nine agencies which constitute development committees were set up as the development arms of both regional and district councils. The agencies include the ministries of agriculture, education, and, health. Others are: departments of Game and Wildlife, Parks and Gardens, Public Works, Town and Country Planning, and the Controller and Accountant General.

Nine regional Councils were established in 1977 under the decentralization system. The councils are made up of elected representatives and regional heads of decentralized ministries enumerated above. The council has three main functions described by Sherwin (1977) as follows:

> " - to act as agents of central government in planning and supervising national programs and development projects within the region; - to supervise and coordinate the functions of the district councils so as to ensure an equitable division of resources and efficient management of public services within the region; - to manage projects and services beyond the capacity of the district councils.

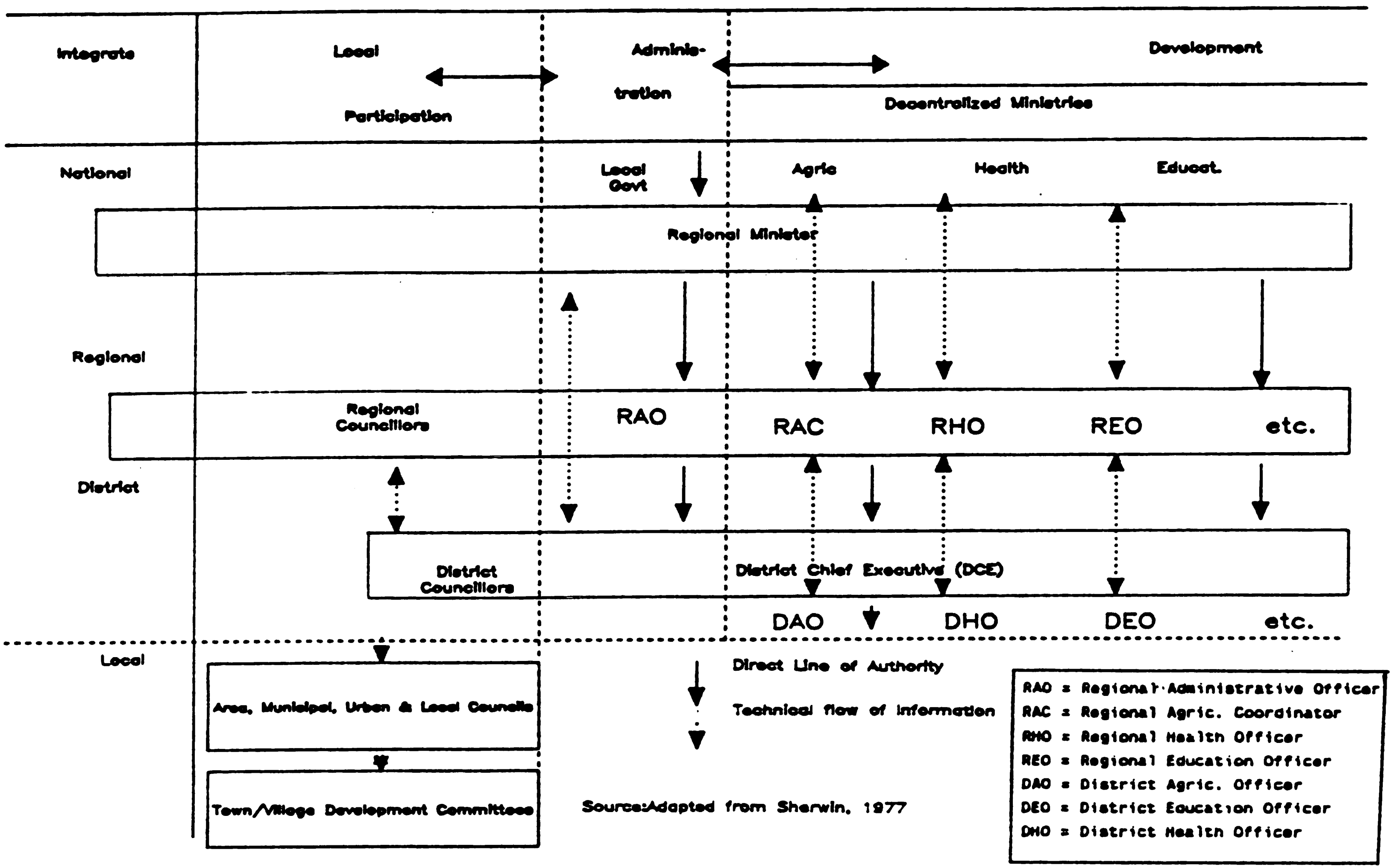


Figure 3.2 Planning and Administration Framework in Ghana

District Councils which were established in 1976 form the core of the decentralization program. The councils consist of elected representatives (councilors) and district heads of the decentralized ministries. The council is chaired by an elected representative. The heads of decentralized ministries form the district planning committee whose activities are coordinated by the District Chief executive. The functions of the council include: 1) acting as the sole taxing authority below the national level; 2) serving as the basic unit of planning and administration at the local level; 3) assuming primary responsibility for development of the area within the context of the national development plan. Prior to decentralization the vertical linkages shown in Figure 3.2 reflecting a top-down approach was the dominant influence in planning. The horizontal linkages indicated by the boxes incorporating the development agencies, elected councilors, and administration provide strong integrated development teams at the local level.

Area, Municipal, Urban and Local Councils are made up of representatives of local development committees. Their functions include: 1) serving as consultative groups to the district councils; 2) solve special administrative and social problems of the areas; and 3) stimulate and coordinate rural activities undertaken by Town and Village Development Committees.

The functions of the Town and Village Development Committees include: 1) organizing self-help development projects; 2) assist in revenue collection; 3) organize and supervise general sanitation.

The framework outlined above is significant for the management of nonpoint source pollution in two main respects. The planning system in Ghana 1) decentralizes authority and resources to the intermediate levels and 2) promotes "bottom-up" participation in development. By decentralizing resources and authority to intermediate levels planning initiatives in general and those relating to pollution from diffuse sources could be more readily implemented at the local level. The integrated nature of the planning functions prescribed for the regional and district councils suggests that implementation of management functions for agricultural nonpoint source pollution will be more effective if incorporated within the existing planning process.

The Potential Capacity of Various Levels of Government to Implement Nonpoint Source Pollution Programs

Responsibility for administration of water resource and environmental programs at the national level, as discussed in chapter two, has been divided between different agencies. Like land management programs where the authority to regulate the individual's use of land is reserved for national level institutions through the use of the police power and delegated to local government institutions, policies regarding nonpoint source pollution control must emanate from the national level with adequate statutory provision for implementation at the district level. There are several options for institutional development. Of these two seem to be most appropriate. 1) establish new agencies at all levels of government to manage nonpoint source pollution problems or 2) reorganize existing agencies and develop linkages among existing agencies.

The practice of establishing new agencies at all levels of government to meet special needs leads to functional fragmentation and duplication of roles. Further, the establishment of new agencies will require new overhead infrastructure making implementation of nonpoint source pollution programs an overly costly endeavour. Problems likely to arise from competition over scarce skilled manpower resources will be difficult to resolve. With current attempts to limit the size of the bureaucracies in Ghana, setting up a new agency to manage nonpoint source pollution will be counterproductive. An effectively designed process of reorganizing existing institutions will encourage detailed analysis of roles and functions of existing agencies in order to foster the necessary linkages and coalition among government agencies, define deficiencies in existing statutes, and define needs for manpower and financial resources.

On the premise that nonpoint source pollution is best controlled at the local level, national policy would need to address which agency would have ultimate responsibility for a nonpoint source pollution program. It would seem that the Local Government Administration Act has, in itself, provided the basis for establishing an institutional framework for nonpoint source pollution control. The district planning committees could constitute an appropriate oversight group. However, the secretariat for planning in the districts must be selected carefully.

From an institutional standpoint, the key to the success of any nonpoint source pollution program in Ghana would be the involvement of the resource planning units of the Ministry of Finance and Economic Planning (MFEP) and the Branch of Soil and Land Use Survey of the Ministry of Agriculture for the following reasons: 1) professional staff of the resource planning units have masters degrees in regional planning which has a strong component of environmental planning. With a very broad background, the resource planners are probably the single most qualified professionals to coordinate planning for nonpoint source pollution control; 2) the Branch of Soil and Land use Survey is a technical assistance agency with the mandate under Act 35 to provide soil and land use information relevant for planning water resources and agricultural projects. Other functions include provision of planning and management assistance in controlling soil erosion. The Soil and Land Use Survey in cooperation with the Resource Planning Units of MFEP will provide a strong institutional basis for developing agricultural nonpoint source pollution plans and implementing remedial measures to control the problem.

It is important to reiterate, at this point, that the MFEP is not represented at the district level. In order to assist the district planning efforts, however, district planners are being trained in the local universities through a cooperative venture by MFEP and USAID. The aim of the effort is to deconcentrate planning activities from the regional ministries to the district level. The establishment of district resource planning departments and close coordination and redirection of activities of the Branch of Soil and Land Use Survey will be essential to successful implementation of a rural nonpoint pollution program. Designating the district resource planning units as a coordinating agency for nonpoint source pollution control will not only give the program considerable visibility within government but also bring the EPC and the nonpoint source program under the same oversight agency - MFEP. Further, it will provide the technical expertise necessary for coordinating the nonpoint source pollution control effort. Table 3.1 summarizes the potential role of government levels in the control of nonpoint source pollution.

Institutional Linkages

Water quality improvements constitute one of the direct roles of the Environmental Protection Council. For that reason, and together with its general role as the agency

Table 3.1 Potential Role of Government Levels in the Control of Nonpoint Source Pollution.

Level	Information	Planning	Standards	Public Involvement
National (EPC)	Should asess national nonpoint source pollution conditions and provide technical advice to the regions. Establish national data storage system	Provide funding contigent on development of regional or district plans for control of nonpoint source pollution.	Establish standards at the national level to be incorporated into the regional and district planning processes. Provide strong support for enforcement of national standards	Provide information from national studies and data storage system to public.
Regional Level (Regional Economic Planning Ministry)	Establish and maintain a regional data base system to be into a national data system on water quality and present and projected land uses.	Develop and implement a framework for planning for nonpoint source pollution control at the district level. Provide funding and advice to district councils.	Adopt and enforce national standards. Set regional standards or regulations in the absence of national standards.	Provide a forum for public involvement in goal setting, standard formulation and strategies for control of nonpoint source pollution.
District Level (Resource Planning)	Establish district database system especially on specific watersheds to be linked into a regional data system.	Prepare and implement watershed management and landuse plans	Enforce national and regional standards and regulations.	Basic unit for gathering and diseminating information to public, involving them in planning process.
Local Level (committee for Soil and Water Conservation)	Assist in collection of basic information for planning at district level. Provide basic information to individual users.	Help implement district level plans.	Assist district staff in enforcing appropriate standards at local level.	Primary contact with individual citizens.

responsible for maintaining a sound environmental and ecological balance in Ghana, the EPC must assume a leadership role in nonpoint source pollution control. Its main responsibility will be to define a policy framework to be followed by both national and regional levels of government in formulating a nonpoint source pollution control strategy. The national policy framework to be formulated through a Task Force or a Committee of agencies shown in Figure 3.3 and other governmental or nongovernmental agencies determined as appropriate will articulate the objectives of nonpoint source pollution control, define roles and responsibilities of various levels of government, ensure implementation of national policy, and set up a process of evaluation. At the regional level the agencies will form the core of the planning committee for nonpoint source pollution which will define a regional framework for nonpoint source pollution control at the regional level. This framework will provide guidelines within which more detailed district plans will be formulated. Institutional linkages with other agencies will be required to ensure successful implementation of a nonpoint source pollution program in Ghana. In chapter two, the functions and role of the Council for Scientific and Industrial Research (CSIR) in environmental management was discussed. Given the fact that the CSIR through its research institutes (e.g. Water Research Unit, Soil Research Institute, the Institute of Aquatic Biology and Forest Products Research Institute) is the information arm of

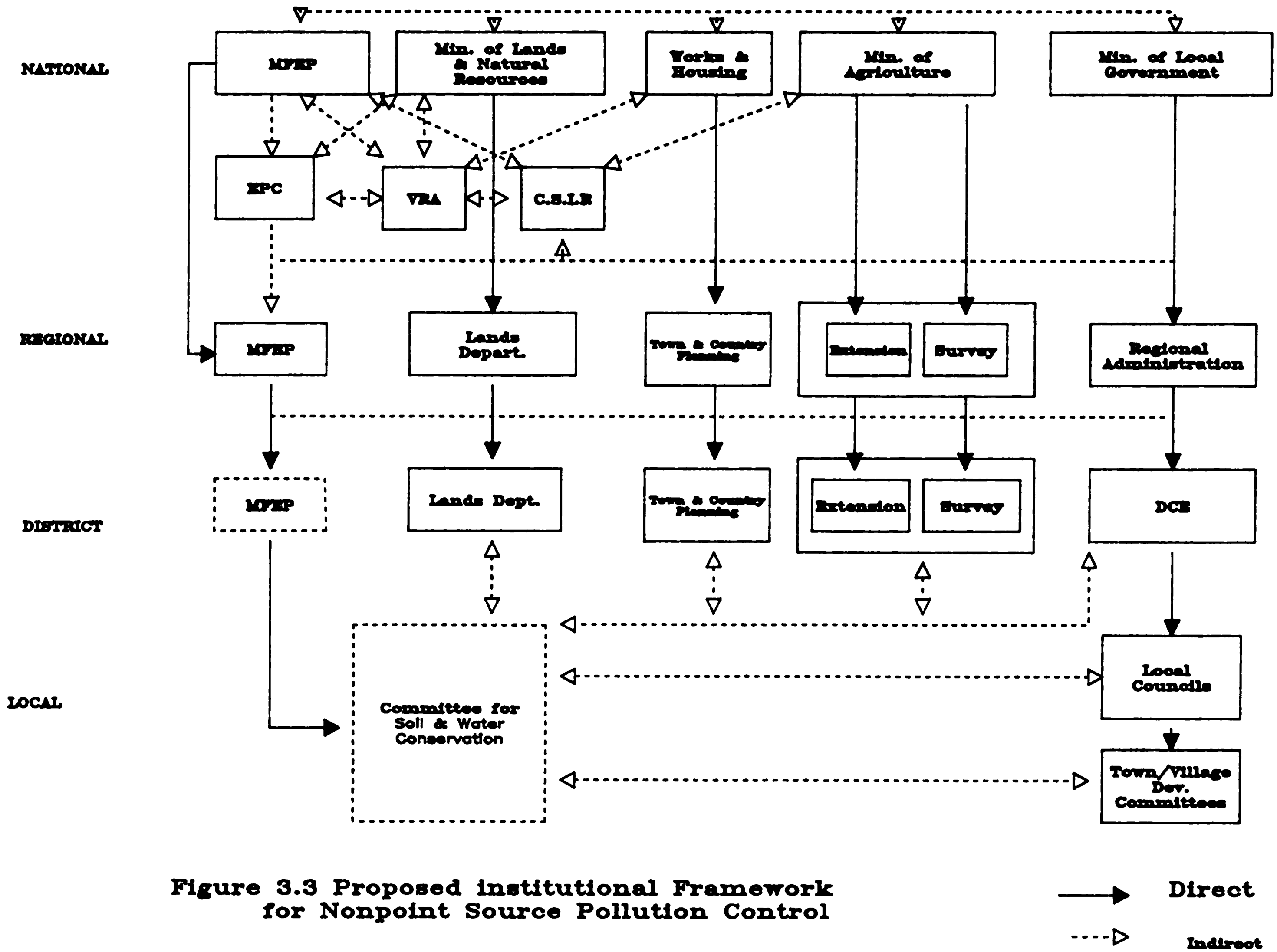


Figure 3.3 Proposed institutional Framework for Nonpoint Source Pollution Control

government on the environment of Ghana, cooperation of the designated planning secretariats with the CSIR will be crucial to planning nonpoint source control programs. The role of the universities, like the research institutions, will be in research for appropriate and cost-effective methods of controlling nonpoint source pollution. Further, such agencies as the Volta River Authority (VRA) which, at the moment, has an ongoing program of research into the effects of agricultural activities on the Volta Lake ecosystem must be given a visible role in the nonpoint source pollution control effort. The fact that the Volta River basin is, by far, the largest watershed in Ghana alone provides sufficient reason why involvement of the VRA in pollution control is crucial for success.

Timber exports constitute the second most important export product for Ghana. The use of heavy machinery for timber harvests has created considerable erosion and sedimentation problems currently not effectively regulated. The Ministry of Lands and Natural Resources which has traditionally had responsibility for regulating resource exploitation (e.g. timber and mineral concessions) must play a more active role in resource management and pollution control.

The planning and zoning ordinances (land use controls) administered by the Department of Town and Country Planning will become an asset in developing a mechanism, for example, for sediment control on a planning district basis. The statutory provisions in the Town and Country Planning Act require that a potential developer submit plans for development to the Department of Town and Country Planning for review and approval. These provisions could be extended to all development projects and should include a requirement for erosion and sediment control during plan preparation. With this provision, the need for technical experts to review the adequacy of proposed erosion measures will become apparent. It does seem that staff of the Branch of Soil and Land use survey who possess the technical skills might be best suited for the task of plan review.

The District Chief Executive's (DCE) Office will ensure that district nonpoint source pollution plans are prepared consistent with directives of the EPC through the Ministry of Finance and Economic Planning in the regions. The DCE's office will be responsible for setting up Planning Committees for Soil and Water Conservation at the district level. These committees must be formed in accord with the provisions of the Land Planning and Soil Conservation Ordinance (Act 35).

The Potential Role of Extension in Nonpoint Source Pollution Control

The traditional role played by extension in Ghana has been the dissemination of new research ideas and findings in agriculture through demonstrations and farmer education programs. Such research ideas as contouring and terracing with a high potential for erosion control, new and high yielding seeds, appropriate methods of cultivation, and proper use of agricultural chemicals have been under the purview of extension.

In Ghana the extension system has always been an integral part of the Ministry of Agriculture. Together with Private Voluntary Organizations (PVO) and the extension units of the quasi-government agencies involved in agriculture, the ministry has carried out extension activities since the early 1940's. At the local level, educational programs in cultivation methods have contributed to the goals of land use management and water conservation. Questions regarding the effectiveness of extension in the agricultural sector in Ghana have been asked and discussed extensively (see for example, Adu, 1982; Turner, 1980) and for that reason, do not constitute a subject matter of further discussion in this study. It is important to mention, however, that under ideal conditions extension will provide the most appropriate vehicle for environmental education in Ghana.

The future role of extension should, it would seem, be the continuation and improvement of its traditional roles in the diffusion of innovations in agriculture, forestry, and animal husbandry. Effective discharge of these traditional roles will, however, mean active involvement in efforts to control nonpoint source pollution through cooperation with EPC and other water quality agencies. Through their educational programs, extension can diffuse proven soil and water conservation innovations. Field extension agents and extension researchers could facilitate development and dissemination of information related to nonpoint source pollution and promote the development of nonpoint source pollution plans at the district level.

Information and Education

Pollution in general and nonpoint source pollution in particular has not been at the forefront of the development effort in Ghana. Together with a low literacy rate of about 50%, it is immediately apparent that the general level of understanding of the processes of pollution from nonpoint sources among the populace would be poor.

The approach to an information and education effort should, therefore, be predicated on limited knowledge and understanding of sedimentation and nonpoint source pollution. In order to develop the level of knowledge and understanding necessary to facilitate management of the problem an education program with particular emphasis on the process of erosion and sedimentation, movement of sediment and other contaminants, and runoff and its ultimate impacts on water quality must be designed at the national level.

On the premise that implementation of a nonpoint source management program will be facilitated by the development of adequate policy at the national level, the initial target audience must be policy makers at the national level. The official government attitude towards the environment reflected in the environmental protection legislation, indicating that environmental protection should at no time interfere with economic development, suggests that any attempt to convene meetings solely on nonpoint source pollution will not produce any meaningful results. The approach must involve presentations by staff of EPC at sessions convened for other purposes. A similar strategy would be implemented within the Regional and District Councils. This would be done with the hope that information would be diffused from elected officials to the general public.

In order to provide sufficient background to planners who would coordinate programs at both national and local levels, it would be necessary to develop linkages with universities and relevant post secondary institutions to incorporate land use and water quality modules into the school curricula. Programs which produce agricultural extension agents must be a primary target for this educational effort.

Linkages with other agencies like the Volta River Authority (VRA) and CSIR which are actively involved in extension, research, and dissemination of research information, would facilitate the design and implementation of the education and information effort.

Statutory Framework

One of the most important objectives of the EPC in relation to nonpoint source pollution control should be to determine whether existing legislation is adequate to facilitate nonpoint source pollution control especially at the district level. To that end, it would be necessary to conduct a comprehensive review of existing statutes and provide necessary revisions. The revisions should: 1) provide the necessary legal basis for the preparation and implementation of nonpoint source pollution plans at the district level; 2) mandate establishment of resource planning units of the MFEP to coordinate, among other things, nonpoint source pollution control planning efforts; and 3) designate the districts as the basic units of planning for nonpoint source pollution control.

Rural Nonpoint Source Pollution Ordinance

At the local level, an ordinance similar to the former Land Planning and Soil Conservation Ordinance (32) now Act 35 designed to control erosion and sediment from agricultural lands should be established. It is important to mention that the ordinance will incorporate new requirements. However, these new requirements will be developed within the existing statutory framework. For that reason, new legislative mandates will not be necessary. The new or revised ordinance must address several issues among which are the following: what statutes will form the basis of nonpoint source pollution control at the local level? what agencies will be responsible for planning and administration? what standards will be required? who will enforce the standards?

The issue of planning and administrative responsibility for nonpoint source pollution control was discussed in previous sections of this chapter. At this point, the question of standards which would be a particularly difficult one to resolve require some consideration.

Standards:

Several approaches to the establishment of standards for the control of nonpoint source pollution are possible. First, standards for sediment and nutrient levels in surface water bodies could be established. The problem of this approach is that high levels of nutrients and sediment in surface water do not point to the source of the pollutant. Under this strategy, therefore, control of the pollutant would require treatment of an entire watershed to reduce pollutant loading. Such a strategy will not only be cumbersome but extremely expensive to implement.

An alternative strategy would be to require all land uses likely to create sediment and nutrient pollution to develop sediment and nutrient control plans. The sediment and nutrient control plans would require each farm unit to develop conservation measures that would reduce excessive losses of sediment and nutrients from their fields. In Ghana this strategy will not only meet with political objection but is not capable of implementation for the following reasons. The economy of Ghana is predominantly agricultural. Over 50% of the population derive their livelihood from subsistence agriculture. The requirement to develop sediment control plans would place a substantial financial burden on the subsistence sector and create political tensions at the local level. Beyond the problem of planning, resource requirements for enforcement would be difficult. This is because numerous small scale farms of a subsistence nature must be inspected regularly to ensure that standards related to pollutant losses are being met.

A third approach would be to establish standards for individual land uses. This would require each developer (mostly farmers) to meet defined sediment and nutrient levels from their fields. The specific levels of losses permitted would be determined from studies using an acceptable and well tested model and would be incorporated into an ordinance that could be enforced. Given the subsistence nature of agriculture in Ghana, standards should be directed mostly at large scale agricultural activity. This argument is supported by the fact that mechanized agriculture has been shown to be the cause of increased erosion in tropical agriculture (Eckholm, 1976; Ahn, 1968; EL-Swaify and Dangler, 1976). The arguments raised against the general requirements for sediment and nutrient control plans are valid for the requirements for the attainment of specific standards on individual farms. Targeting of large scale mechanized agricultural activities should provide the basis for effective enforcement. The ordinance should prohibit harmful traditional practices such as indiscriminate removal of vegetative cover through burning and the use of pesticides like DDT that have been shown to be injurious to human health and the general environment. Also, standards for the proper levels of fertilizer application should be defined. Like other options discussed, enforcement mechanisms would be required to ensure compliance.

To provide a framework for implementation of nonpoint source pollution plans at the local level, the options discussed above, together with others to be formulated within the EPC and the resource planning units must be evaluated within the context of local circumstances and incorporated into the ordinance. At the national level standards would be developed within the EPC. The Council would study and evaluate information available from the CSIR, universities, and the scientific world in general. The standard would be studied within the EPC to ensure that issues related to surveillance and monitoring enforcement, cost-effectiveness, and potential impacts on other programs have been considered. The proposed standard would then be circulated among other agencies for review.

The specific details of the program will be formulated by the EPC in form of administrative regulations. These regulations will incorporate specific standards with very strong provisions for enforcement.

A Pilot Nonpoint Source Pollution Project

In order to test the feasibility of the ideas outlined above, it will be advisable to conduct a comprehensive study. This study will facilitate analysis of the potentially complex technical, social, economic, and institutional problems likely to arise in the implementation of a nonpoint source pollution program in Ghana. The following factors must be taken into consideration in selecting a watershed on which to base the pilot study: a) a nonpoint source problem must exist or at the minimum be perceived to exist, b) an ongoing water quality monitoring program must exist and, c) decision makers within the regional and district councils must demonstrate their willingness to solve the land use and water quality problems in the watershed. The specific goal of the pilot project would be to demonstrate the effectiveness of land use planning and control measures in improving the quality of water in the watershed and develop the necessary technical, manpower, institutional, economic, and political capacity to manage a nonpoint source pollution program.

Summary

The newly implemented program of decentralized development and decision making authority in Ghana provides a rare opportunity to incorporate planning for nonpoint source pollution control into the existing planning process. On the premise that nonpoint source pollution control is best carried out at the local level, decentralization of resources and decision making authority to local and intermediate levels will facilitate more effective planning and implementation. The planning team for nonpoint source pollution control will be formed from the regional and district planning committees. The Resource Planning Units of the Ministry of Finance and Economic Planning will be deconcentrated to the district level to coordinate economic and environmental planning. An education and information program designed to create awareness among policy makers, and the general public will be required. Further, modules related to land use and water quality management must be incorporated into the curricula of academic programs that produce planners and extension agents. A program for evaluating the adequacy of the existing regulatory framework for nonpoint source pollution control must be instituted. In order to test the adequacy of the suggested planning and administrative framework a pilot nonpoint pollution program must be carried out.

An important component of the pilot program would be the identification of an appropriate model which would be used to gain a better understanding, facilitate quantification of the magnitude and extent of the nonpoint source pollution problem, and determine standards that would be incorporated into a rural nonpoint source pollution ordinance. The next two chapters are devoted to the predictive technology (nonpoint source pollution modeling)

and the development of a criteria-based screening process for selecting among the potential models available for use.

CHAPTER 4

NONPOINT SOURCE POLLUTION MODELING AS A DECISION MAKING TOOL

The Status of Predictive Technology

Successful control of nonpoint source pollution depends on the understanding of the physical, biological, and chemical processes involved in the production, transport, and disposal of pollutants. It is, therefore, appropriate at this point to review the state-of-the-art of the analytic and predictive technology for the study of nonpoint source pollution phenomena.

Modeling is the most common and widely used form of predictive technology in the study of nonpoint source pollution phenomena. The reason for this popularity is not far fetched. The practice has found wide application because it provides the simplest and, probably, least expensive means of understanding nonpoint source pollution phenomena. The traditional method of monitoring is not only expensive and time consuming but is not a practical proposition over large geographical areas.

Types of Models

Nonpoint source pollution models have been classified into two broad categories namely: Screening (unit load) or planning models and hydrological assessment models (Barnwell and Krenkel, 1982). Screening models are simple tools designed to identify problem areas within a large watershed. These models are essentially functions that express pollutant generation per unit area over a given period of time for a specified land use. The unit loads are often expressed as tons/ha/yr or kg/ha/yr.

Hydrologic assessment models, on the other hand, are generally process oriented models that attempt to provide a better understanding of the various components of the hydrologic system and the movement of materials through both surface and groundwater systems. Chow (1972) identified several categories of hydrologic models. They include analog and scale models, simulation models, and abstract models. Analog and scale models are used to study fundamental and individual processes such as infiltration, soil-water movement, and adsorption-desorption of chemicals on soils. Simulation models attempt to represent the behavior of a hydrologic system. Abstract models represent the hydrologic system by replacing relevant features of the system by a set of mathematical relationships (Novotny, 1986). The abstract models are further divided into deterministic and stochastic types. Deterministic water quality models describe the hydrologic, rainfall, and runoff transformation process and pollutants associated with them (Novotny, 1981). Indeterministic models are statistical equations that express long-term pollutant loading related to land use and their attributes. Most nonpoint source pollution models are either simulation models or abstract- deterministic types.

Indeterministic nonpoint source pollution models are rare and still in their development stages (Novotny, 1986).

DeCoursey (1985), like Barnwell and Krenkel (1982), identified two classes of models: empirical and physical process or causal models. Empirical models, according to DeCoursey, are generally cause-and-effect models in which "a mathematical expression transforms a set of input variables into a description of the output without attempting to describe the processes taking place". Regression models are an example of empirical models. Causal models, on the other hand, attempt to describe the physical, chemical and biological processes in great detail. Several of the models reviewed in the next chapter fall within this class of simulation models.

It is important to note that empirical models are simple, require less data and, for that matter, are cost effective to use (DeCoursey, 1985). DeCoursey cautions, however, that empirical models are difficult to improve, cannot be extended beyond the range of data used to develop them, and are often easily misapplied.

Physical process models are capable of: predicting responses that are not necessarily observable; assessing the effects of environmental change; coordinating and structuring research; and defining ways in which empirical models, could be improved [DeCoursey, 1985). Physical process models, require large data bases for their development.

Uses of Nonpoint Source Pollution Models

The role of the water resource planner, besides preparing specific plans, involves analyzing strategies for managing water quantity and quality and making recommendations to policy makers. The task of planning, in both industrialized countries and LDCs is constrained by several factors, the most important being availability of time, money and personnel. It does seem that at the initiation of the planning process, a basic decision that needs to be made by the planner is whether the use of models will aid the preparation of water resource plans as well as the identification and analysis of alternative management strategies.

The value to the use of nonpoint simulation models lies in their ability to provide a tool for diagnosing a problem and providing a greater understanding of the pertinent relationships of the physical variables within the proposed system under study without having to make a physical examination. Shannon (1975) and Grimsrud et al. (1976) defined the uses of simulation models under three broad categories: systems simulation, prediction of performance, and model calibration.

Simulation of existing system (the most common use of simulation models) provides the planner with the necessary understanding of the interrelationships among the various elements of the system and among their attributes. This would enable the informed planner to identify problem areas. Another important use of nonpoint pollution models is their role in aiding an assessment of the effects of the loading of contaminants and changes in the nature and concentrations of effluent. Together with water quality criteria, nonpoint simulation models have been used to evaluate alternative plans, providing the planner a good understanding of the procedures and criteria for plan selection.

Constraints and Limitations of Model Development and Use

DeCoursey (1985), Shannon (1975), and Beasley et al. (1982) identified several constraints to model development. First, is the inordinate amount of time required to develop comprehensive models that span various disciplines. Often it is impossible for an individual, and in most cases, a group of researchers at one location to accomplish this feat. DeCoursey notes that with nonpoint source pollution models, testing is often the most difficult problem because the huge data bases required are often unavailable.

The problems associated with data generation, argued DeCoursey (1985), is perhaps the biggest constraint to the development of nonpoint source pollution simulation models. The models require several values for parameters related to soil characteristics, meteorological conditions, (including rainfall, air temperature, wind, solar energy etc) land cover data, channel cross sections, watershed dimensions, slope and aspect, nutrient, pesticide, and biological properties

(Novotny and Chesters (1981) and DeCoursey, 1985). Default values for parameters for which the model user does not have data, according to DeCoursey (1985), can result in "sizable error in simulated response". Beasley et al. (1982) note further, that model predictions are considered theoretical and often unreliable.

In spite of the problems discussed above, nonpoint source pollution models provide the most cost-effective means of understanding nonpoint source pollution phenomena and evaluating alternative control scenarios.

Approaches to the Design of Nonpoint Pollution Models

Modeling a real system requires that both inputs and outputs from the system be identified. The structure of the model is often a simplified representation of the interactions taking place within the real system (Beasley et al. 1982, Novotny and Chesters, 1981 and Shannon, 1975). In nonpoint source pollution modeling, watershed size, slope and roughness characteristics, erodibility, and soil texture are examples of systems parameters. Temperature and vegetative cover are examples of state variables. Input variables may include precipitation (dry and wet), and waste output.

Beasley et al. (1982) like Novotny and Chesters (1981) identified two basic approaches to modeling nonpoint source pollution. These include lumped parameter modeling and distributed parameter modeling. Lumped parameter models are characterized by high levels of spatial and temporal aggregation. Complete watersheds or large portions of it are treated as a unit with many individual characteristics lumped together. The interactions within the model are highly simplified. The systems parameters for each unit derived from the literature are often based on extensive field research information. The models are calibrated against field data and verified. These produce long term outputs which reflect different hydrologic conditions. Where changes in the systems parameters are required, there is a need to reestimate the input variables and coefficients. The distributed parameters approach, on the other hand, is characterized by a small level of spatial aggregation. Watersheds, for example, are divided into small homogenous units. These small spatial units are modeled separately, providing several outputs for the watershed. The sum total of the results of each unit produces the total output for the entire watershed.

Two direct consequences of distributed parameter modeling are high costs and increased requirements for computer facilities (Beaseley et al., 1982). Another common classification of watershed models is temporal. They are either long term or event oriented. Long term simulations can provide some understanding of, for example, overall loadings and net surface effects. An event oriented model has a shorter time span and describes the storm-induced response of the hydrologic system.

Structure of Nonpoint Pollution Models

Nonpoint pollution models are basically a description of hydrologic runoff transformations and their water quality characteristics (Novotny and Chesters, 1981). The following basic components are identifiable.

a) surface runoff generation component. This component is a description of the transformation of precipitation into runoff and surface flow. The importance of this component is to identify the origins of runoff and the size and magnitude of the flow.

b) the soil and groundwater component. This component describes the movement of water through the soil into aquifers. Several elements are characteristic of this component. They include: soil moisture, infiltration rate, evapotranspiration and water loss into deep groundwater zones;

c) the erosion component estimates quantities of soil loss from pervious areas.

d) the particle accumulation component describes the process of particle accumulation in urban areas and their removal by street clearing practices;

e) the soil adsorption and desorption component (not common to all nonpoint source pollution models) describes the distribution of adsorbed and desorbed portions of pollutants in soils.

Novotny and Chesters (1981) note that most nonpoint pollution models consider pollutants as sorbed components of particulate matter. Figure 4.1 is a description of the general components of nonpoint pollution models.

Application of Nonpoint Pollution Modeling for Management Decision Making

Plans designed to control nonpoint source pollution must involve a strategy aimed at identifying areas within a watershed responsible for most of the nonpoint source pollution, estimate the impacts of nonpoint source pollution, and determine the effectiveness of remedial actions. The Water Quality Board of the International Joint Commission (IJC) on the Great Lakes suggested a useful framework within which nonpoint source pollution decisions can be made. The initiation of the process shown in Figure 4.2 is the identification of impairments which restrict use of resources in the areas of concern. Impairments such as reduction in fish populations, eutrophication of lakes and rivers, sedimentation of lakes and rivers, tastes in drinking water, etc should be determined.

Next, potential causes of the impairments need to be identified. The nonpoint source pollution problem discussed in Chapter 1 indicated that sedimentation of reservoirs, reduction in aquatic flora and fauna in rivers and streams,

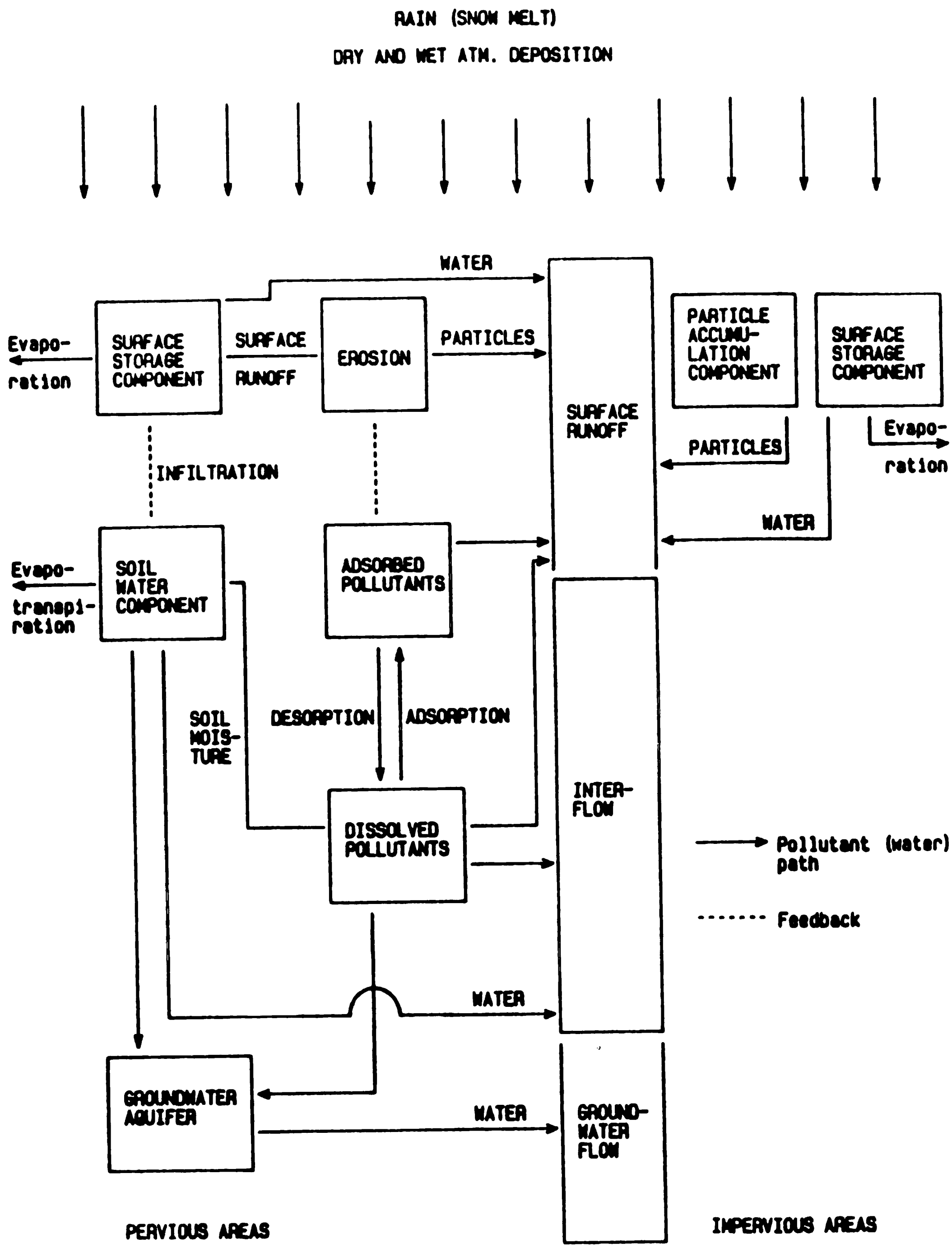


Figure 4.1 Components of Watershed Nonpoint Pollution Models
(Source: Novotny and Chesters, 1981)

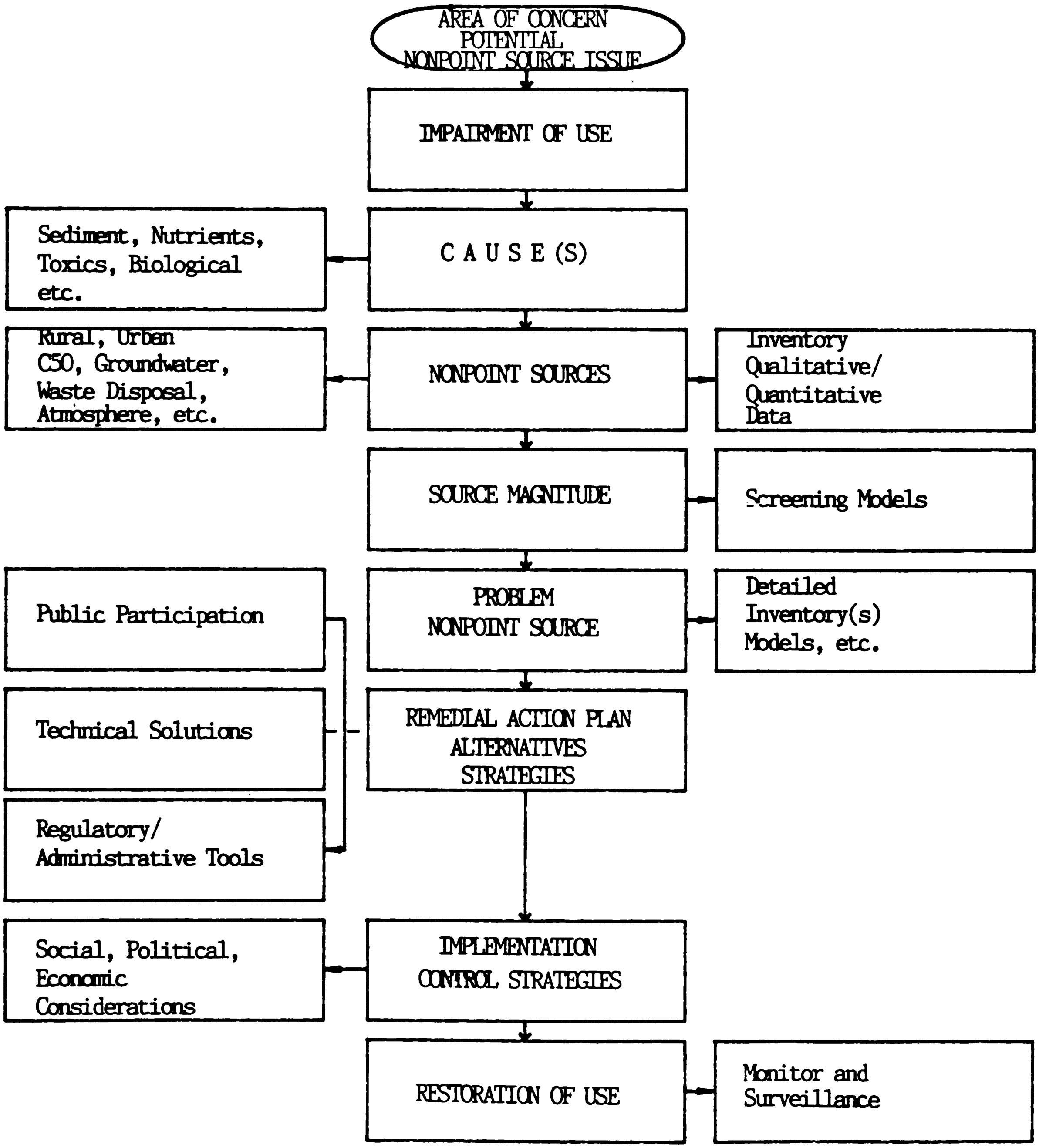


Figure 4.2 A Strategy to Identify and Estimate Impacts of Significant Nonpoint Sources.

Source: IJC Water Quality Board (1989)

and the presence of organic and inorganic substances in sources of water are of major national concern.

The third step involves identification of potential sources of nonpoint source pollution. The methods for evaluating potential sources include compilation of inventories, collection of qualitative and quantitative data, and the determination of unit area loadings. Having identified potential sources, the relative magnitude of various sources are determined. Screening models may be used, at this point, in assessing the relative magnitudes of sources.

Next, detailed investigations are conducted using hydrologic models to obtain a clearer definition of the problem and evaluate alternative cost-effective remedial programs. Remedial action plans including technical solutions, regulatory and administrative tools, and public involvement strategies are developed. Implementation and monitoring strategies are then formulated. The implementation strategy will consider the economic, social, political, and institutional issues that may affect implementation.

The framework discussed above suggests two distinct points at which nonpoint source pollution models may be applied; a) in determining source magnitudes (screening), and b) detailed analysis of the problem and testing of alternative remedial programs. Novotny (1986) suggested that modeling should proceed in two stages. Overview or screening modeling should identify problem areas to which detailed hydrologic modeling should be applied in the second step.

If a decision is made to use a model, one of two further decisions must be made: a) to develop a model, or b) use an existing model. Developing a new model does require expertise in modeling. Further, a new model requires several years of development and testing and are generally expensive. They can, however, be tailored to the specific problems within a given environment. On the contrary, the use of existing models will obviate the need for specific expertise in model development before models could be used, reduce time requirements for development and testing, and generally reduce cost. However, existing models, depending on their structure, may produce unrealistic results in a different environment.

The discussions that follow in the next chapter relate to the logical steps the should be followed in selecting an appropriate model for application to nonpoint source pollution problems in Ghana.

CHAPTER 5

CRITERIA FOR MODEL SELECTION AND USE

The preceding chapters of this study concerned the problem of nonpoint source pollution in Less Developed Countries in general and in Ghana in particular. In Chapter 4 it was noted that an objective assessment of nonpoint source pollution conditions and the development of alternative control scenarios will be facilitated by the use of models. Several models are available. For that reason the process of selecting a model with which to quantify nonpoint source pollution conditions is complex.

Commonly used criteria for model selection were derived from the literature. Secondly, criteria were developed from a survey of graduate students and professors in selected departments in Michigan State University. Weights for a selected set of criteria were the developed in order to determine their relative importance as a selection decision tool. This survey was based on a modified form of the ranked comparison technique discussed in Maranell (1974). A survey was required to resolve the wide divergence in opinion found in the literature regarding what constitutes the most important criteria for selecting an appropriate model. Similar studies carried out by Fedkiw and Hjort (1967) to determine the relative importance of research problems within the USDA and Kleine (1971) to evaluate users' views of discrete simulation languages provide a justification for using a survey to determine the relative importance for the selected criteria. The weighting of the criteria was based on a profile presented for Ghana (see appendix 1). The use of selected graduate students and professors in Michigan State University as surrogates of environmental planners and scientists in Ghana would introduce some judgmental errors into the determination of relative weights. This will result from lack of intimate knowledge of the conditions and environment in the country. For this reason, the survey was considered informal and the results used only to illustrate the logical processes involved in selection decisions.

Finally, a simple decision technique based on the weighted-criteria concept was used to design a criteria-based screening system for a list of the most prominent nonpoint source pollution models.

Literature on Model Selection Criteria

Nonpoint Source pollution model selection decisions are essentially an exercise in the evaluation of competing alternatives. The concept which has its foundations in multiattribute utility theory helps to determine relative weights of factors or criteria used to evaluate alternatives under consideration. Ranking, a method used for Evaluating Competing Alternatives (ECA), seeks to determine an order of the alternatives according to worth (Klee, 1988). The logical sequence of decisions defined as a simple ECA model will involve:

a) defining factors or criteria;

b) weighting the factors;

c) determining the value for each factor; and

d) computing a score for each alternative by multiplying the factor score for each alternative by each corresponding factor weight.

This sequence of decisions can be applied to the model selection process.

The literature on model selection criteria illustrate the considerable divergence which exists in opinion on what constitutes the most important criteria for selecting a model for quantifying nonpoint source pollution conditions. For example, Beasley et al. (1982) identified 3 primary factors for model evaluation and selection: They include: (1) availability and cost (both for data preparation and computer time); (2) applicability to pollutants of primary interest; and (3) the accuracy and sensitivity with which proposed treatment measures are simulated. Donigian and Beyerlein (1985) reviewing nonpoint pollution models for the EPA used 2 main criteria in screening the potential techniques and models for inclusion in their review. They are: (1) the techniques/models must be capable of estimating nonpoint source pollutant loads and/or concentrations in addition to runoff and sediment, and (2) the techniques/models must be operational through a demonstration of at least one successful application and the potential for similar applications. Also, there must exist sufficient documentation to enable a user to apply the model in another location. DeCoursey (1985) discussing mathematical models for nonpoint source pollution control identified several criteria for model selection. They include, among others: cost, accuracy, applicability to water body and pollutant, and availability of data. Dearth (1985) writing on irrigation water management modeling in Sri Lanka discussed several criteria for model applications in optimizing irrigation water use. They include: cost, data availability, and manpower availability. Several criteria were used in selecting water quality models in Grimsrud et al. (1976). They include: application to waterbody of concern, cost, model availability and accuracy, ease of model application, and availability of data for model inputs, outputs and calibration.

Among ten criteria for the selection of models for lake quality management planning listed by Reckhow and Chapra (1983) are precision, costs, data availability, simplicity, and sensitivity. Leonard and Knisel (1986) discussing the selection and application of models for nonpoint source pollution and resource conservation argued that model users should carefully consider attributes of different models relative to the specific problem. Some considerations they enumerated include model purpose, representation, data requirements and availability, ease of parameter estimation, and both ease and cost of simulation. Wilson et al., (1986) identified six criteria for selecting a modeling approach. They are: proposed use of the model, potential for adaptation of the algorithm, availability of input parameters, sophistication of potential users, and the computational time required for solution of the algorithms. Singh et al. (1985) identified insufficient data as the most important limitation for developing a new predictive model for estimating soil loss and sediment delivery to surface waters in India. Discussing soil erosion and its control in developing countries, Hauck (1985) noted shortage of trained staff for supportive research and lack of comprehensive data for research among the most important problems. In Southwestern Nigeria, Lal (1985) modeling erosion- productivity relationships of tropical soils identified insufficient data as the most important problem in developing a predictive model.

Based on the review of model selection criteria nine generic criteria were isolated for the study of opinions on what constitutes the most important criteria for model selection in a hypothetical LDC. They include:

a) the applicability of the model to the nonpoint source pollution problem,

b) availability of the relevant parameters within the candidate model,

c) the level of data availability,

d) cost of the model,

e) accuracy of the model,

f) availability of qualified manpower to apply the model,

g) the ability of the model to generate realistic outputs,

h) simplicity of the model,

i) ease of application.

Similar criteria identified in the review of literature were combined to generate the list of criteria enumerated above (see Figure 5.1).

Survey

A stratified random sample of fifty respondents was selected from six departments. The departments are: Agricultural Engineering, Crops and Soil Science, Environmental Engineering, Resource Development, Forestry, and Fisheries and Wildlife. The respondents were asked to weight the nine criteria on a Likert-type five point scale from extremely important (3 points), very important (2 points) important (1 point) neutral (0 points) and unimportant (-1 point) [see Appendix A]. The political, social, and economic profile provided for the country closely mirrowed those published for Ghana.

Results and Discussion

Of the 33 respondents, 24.2% were citizens of LDCs. The remaining 75.8% were citizens of industrialized countries.

Figure 5.1: Summary of Criteria and Sources

CRITERIA AUTHORS	Data Needs	Parameters Modeled	Applicability of Model	Model Costs	Availability of Qualified Manpower	Ease of Application	Simplicity	Realisitc Model Outputs	Accuracy
Beasely et al. (1982)	X		X	X					X
Donigian and Beyerlein (1985)		X							
DeCoursey (1985)	X		X	X					X
Dearth (1985)	X			X	X				
Grimsrud et al. (1976)	X		X	X					X
Reckhow Chapra (1983)	X	X		X			X	X	X
Leonard Kinsel (1986)	X	X		X		X			
Wilson et al. (1986)	X	X	X		X	X	X		
Singh et al. (1985)	X								
Hauck (1985)	X				X				
Lal (1985)	X								
Reckhow et al. (1985)	X	X		X			X	X	X

X = enumerate by author

Sixty-eight percent of the sample indicated a lack of exposure to simulation modeling in less developed countries. Sixty-seven percent of the respondents are currently working in the water resources profession. The distribution of number of years of experience in the water resource profession is represented in Table 5.1 below.

Opinions on how the various criteria ranked relative to each other were required to design a screening system for selecting among the large number of nonpoint source pollution models potentially available. Responses were based on a scale of -1 to 3, with -1 representing unimportant, 3 representing extremely important, and zero representing neutral. The response scale contains relative values. For that reason, complete interpersonal comparison was not possible.

Summary statistics of the results of the ratings are shown in Table 5.2. The mean responses for all respondents indicate that data requirements were was assigned the highest aggregate rating of 2.531 followed by parameters modeled (2.424), applicable situations (2.364), model costs (2.031) and availability of manpower (2.000). Those ratings on the measurement scale are relatively high ratings. Others are: ease of application (1.939), simplicity of the model (1.909), realistic model outputs (1.758), and model accuracy (1.515).

Comparative analyses were done to determine whether significant differences existed in the ratings assigned by respondents from LDCs and other respondents, respondents with simulation experience in LDC and those without, and

Table 5.1 Level of Experience and Composition of Sample

Number of Years in Profession	No. of Respondents	% of Total
25+	2	6.1
21 - 25	1	3.0
16 - 20	2	6.1
10 - 15	1	3.0
6 - 9	4	12.1
1 - 5	17	51.5
Less than 1	6	18.2
Total	n = 33	100.0

Table 5.2: Mean Scores (All Respondents)

Criteria	Mean Weight	Std Dev	Std Error	Range	Total no of cases (n)
Data Needs	2.531	0.671	0.119	2.000	33
Parameters Modeled	2.424	1.001	0.174	4.000	33
Applicable Situations	2.364	0.895	0.156	4.000	33
Model Costs	2.031	1.121	0.198	4.000	32*
Availability of Qualified Manpower	2.000	1.225	0.213	4.000	33
Ease of Application	1.939	1.088	0.189	4.000	33
Simplicity of the Model	1.909	1.909	1.100	4.000	32*
Realistic Model Outputs	1.758	1.001	0.174	3.000	33
Model Accuracy	1.515	1.121	0.195	4.000	33

* = n-1

respondents currently working in the water resources profession and those in other professions. The results are presented in Tables 5.3, 5.4, 5.5 as mean ratings, standard deviations and t-values and probabilities for the nine criteria.

Both the T-Test and chi-square (in appendix) statistics were used to test the hypothesis that the mean ratings generated by respondents from LDCs and other respondents are the same. Similarly tests were done to determine if there were any significant differences between respondents with simulation experience from LDCs and those without simulation experience in LDCs. Further analysis of differences in the mean responses between respondents currently working in the water resources profession and those working in other professions was done. At a 95% confidence level both the t-test and chi-square test do not show evidence of significant differences in the mean ratings generated between the different groups mentioned above. It is important to mention that the inability of the test statistics to detect significant differences in the ratings may have been due to small size of the sample which resulted in a significant loss of information. The T statistic is more effective in detecting differences between two means with larger samples. Testing at a 90% level, there is evidence of a significant difference between the mean ratings of respondents with exposure to simulation modeling in LDCs and those without

Table 5.3: Differences in Responses Between LDC Respondents and other Respondents

Criteria	LDC (mean) n=9	Other (mean) n=24	T-value	DF	2-tail Prob.
Data Needs	2.2857	2.6000	-1.00	8.61	0.343
Parameters Modeled	2.3750	2.4400	-0.15	11.31	0.881
Applicable Situations	2.5000	2.3200	0.66	22.75	0.517
Model Costs	2.2500	1.9583	0.55	9.77	0.593
Availability of Qualified Manpower	2.5000	1.8400	1.76	21.26	0.093
Ease of Application	2.1250	1.8800	0.65	16.59	0.524
Simplicity of Model	2.1250	1.8400	0.75	16.80	0.461
Realistic Model Outputs	1.8750	1.7200	0.43	14.95	0.676
Model Accuracy	1.1250	1.6400	-1.05	10.56	0.317

Table 5.4: Differences in Responses Between Respondents with simulation Experience in LDCs and Respondents Without

Criteria	Experience With (mean) n=10	Experience Without (mean) n=13	T-value	DF	2-tail Prob.
Data Availability	2.8000	2.4091*	1.90	28.06	0.068
Parameters Modeled	2.3000	2.4783	-0.41	13.21	0.690
Applicable Situations	1.9000	2.5652	-1.65	11.47	0.125
Model Costs	2.1000	2.0000*	0.26	24.16	0.796
Availability of Qualified Manpower	1.8000	2.0870	-0.61	17.34	0.547
Ease of Application	1.8000	2.0000	-0.45	14.93	0.660
Simplicity of Model	1.8000	1.9565	-0.33	13.94	0.743
Realistic Model Outputs	1.7000	1.7826	-0.19	13.25	0.853
Model Accuracy	1.8000	1.3913	0.95	16.95	0.353

* = n-1

Table 5.5: Differences in Responses Between Respondents Currently working in the Water Resource Profession and Those in Other Professions.

Criteria	Water (mean) n=22	Other (mean) n=11	T-value	DF	2-tail Prob.
Data Availability	2.5455	2.5000*	0.20	24 03	0.845
Parameters Modeled	2.4091	2.4545	-0.13	22.44	0.091
Applicable Situations	2.4091	2.2727	0.47	23.80	0.642
Model Costs	2.0952*	1.9041	0.41	16.93	0.687
Availability of Qualified Manpower	1.9091	2.1818	-0.69	23.98	0.495
Ease of Application	1.8636	2.09009	-0.63	27.57	0.532
Simplicity of Model	1.9091	1.9091	0.00	17.83	1.000
Realistic Model Outputs	1.7727	1.7272	0.12	17.98	0.909
Model Accuracy	1.5909	1.3636	0.57	22.85	0.575

* = n-1

exposure for the criteria "data availability". While respondents with simulation backgrounds in developing countries rated data availability at 2.8000 those without simulation backgrounds rated it at 2.4091.

Summary of Findings

In general, the survey of opinions on what constitutes the most important criteria seems to suggest that respondents are in agreement with the available literature on the factors that should be considered for selecting a model for simulating nonpoint source pollution conditions. For example, the summary of criteria for model selection shown in Figure 5.1 indicates that data needs is the most frequently identified criterion for model selection. This survey also identified data needs as the most important criterion for model selection. Following data needs the determination of whether the relevant parameters were modeled was the second most frequently identified criteria. The weights derived from the survey also identified parameters modeledas rating next in relative importance to data needs and availability. There appears to be no statistically significant difference in weights attached to the various criteria between respondents from LDCs and those from other countries. In general respondents with simulation experience in developing countries seemed to regard data needs for simulation studies as of more concern than those without simulation experience. No significant differences were observed between respondents currently working in the water resources profession and those working in other professions.

The primary intent of the study was to determine the relative importance and weights for the set of criteria discussed above. The mean ratings assigned to the different criteria seem to be consistent with the frequency with which the criteria were enumerated by different authors shown in Figure 5.1. The ratings shown in Table 5.2 constitute the weights required for developing a criteria-based screening process for selecting nonpoint source pollution models. The sections that follow provide a discussion of the process.

The Criteria-Based Screening Process

Two main processes were examined in this study. The first process involved subjecting the models to analysis using all nine criteria. Scores are allocated by applying the list of nine criteria to available knowledge on the models. Generally, a score of 1 is assigned to the model factor if the factor conditions are met. If the factor conditions are not met a score of 0 is assigned. Where the criterion (e.g. data requirements) involves relative magnitudes, a score 0.3 is assigned to high, 0.6 to moderate and 1.0 to high respectively. The weights generated for the individual criteria are used to adjust the impact of each factor rating. For each model, the overall adjusted rating would be defined as a summation of the products of the factor ratings and criteria values or weights. This can be computed by the equation:

$$WR = a_1 b_1 + a_2 b_2 + a_3 b_3 + \ldots + a_n b_n$$

where:

WR = total rating
a = factor values
b = factor weight

Where there is insufficient information to assign a rating, the planner must decide the relative importance of the factor by matching it against the weighted criteria. If the factor is of major importance, the necessary information must be obtained. The general procedure for determining total ratings for each model is shown by the flowchart in Figure 5.2.

The second approach involved subjecting the models to the criteria using a decision flow chart. The flow chart (Figure 5.2b) essentially poses series of questions for which responses are obtained from the summary of model review. Criteria that could not be evaluated against the models either because of general lack of knowledge on the subject or lack of data were not included in the screening system. The initiation of the process is the determination that a candidate model is applicable to a particular nonpoint source pollution problem. All candidate models are subjected to the applicability test. Testing is done by determining that the models consist of algorithms appropriate to the concerns of planners. For example, a model designed to simulate

Figure 5.2 Decision Guidance for Model Screening.

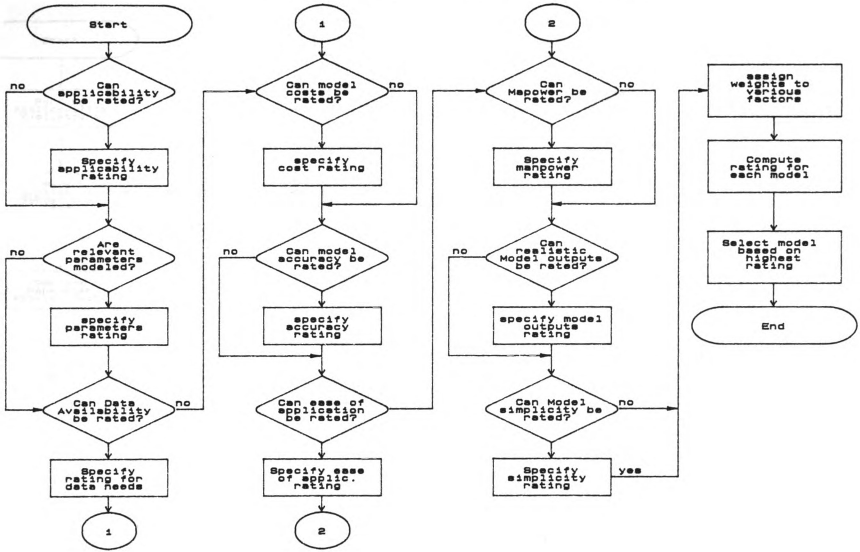
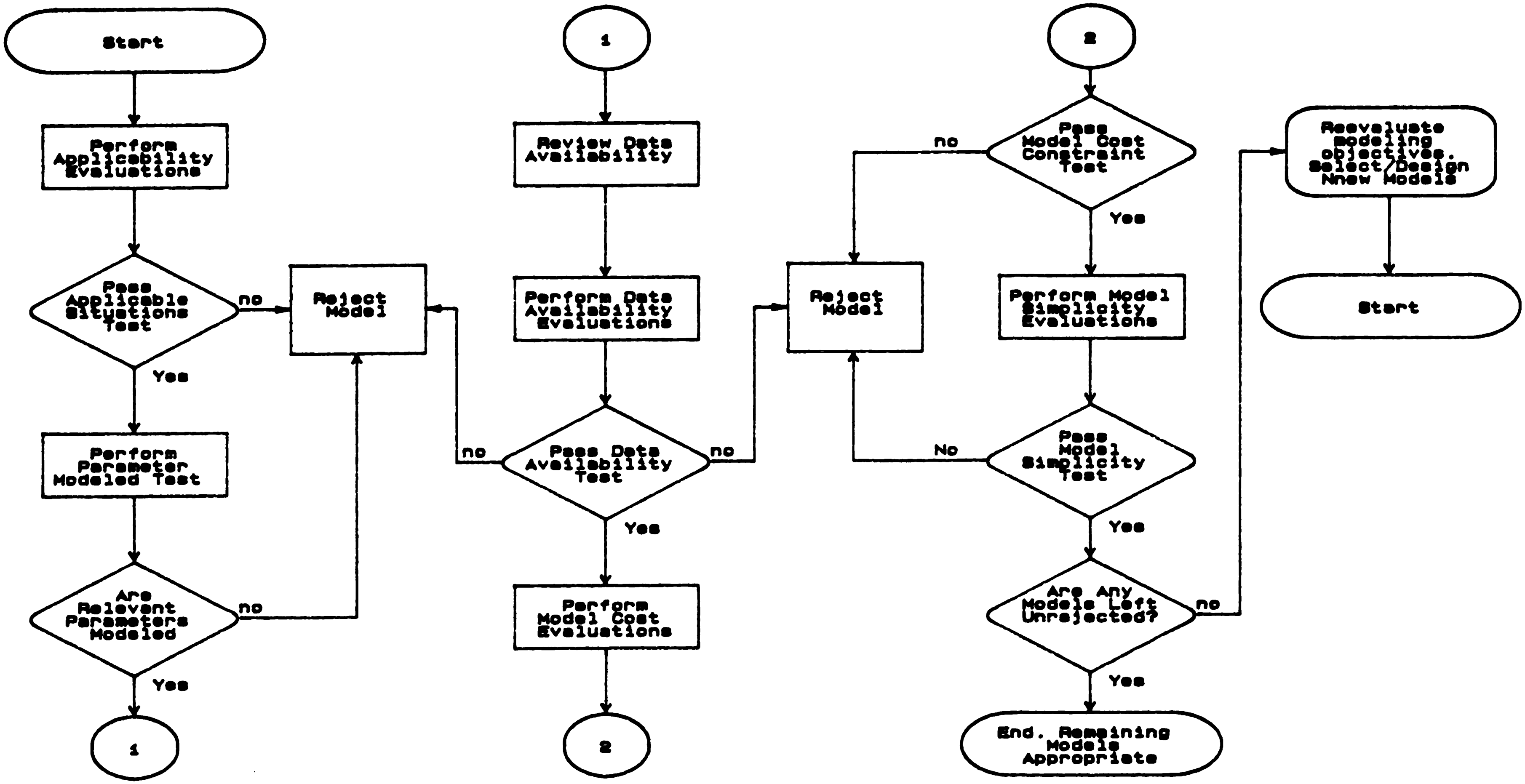


Figure 5.2[illegible]: Decision Guidance for Model Screening.



pollution conditions in estuaries will not be appropriate pesticide and nutrient losses from agricultural fields. An inappropriate model is rejected and removed from further consideration. If a model passes the applicability test it retained for further testing.

Closely associated with the decisions regarding applicability of the models is the determination that the relevant parameters are simulated by the candidate models. The models are assessed against a list of parameters of interest. In Ghana, for example, the parameters of interest will include nutrients, sediment, and surface runoff. These parameters were identified in the problem statement as pollutants of concern to planners. Models that fail the parameters modeled assessment will be removed from further consideration. Models that simulate the parameters of interest are retained for further testing in the next step.

Cost and data requirements are intricately linked. This is because data costs are the most important cost components of model application. The candidate models are subjected to data evaluations. First, a review is done to determine whether input data is available. If input data is not available, a determination is made regarding whether data can be collected within the budget constraints. If not, the model is rejected from further consideration. If resources are available the model is retained for further screening for cost. Given the lack of information on the cost of nonpoint source pollution models, cost evaluations in the screening process are determined subjectively as low, moderate and high. Models that fail the cost constraints test are removed from further consideration. The remaining models are retained for further testing for simplicity and the ease with which the models could be applied. Any candidate models remaining are potentially appropriate for application. In cases where all models fall out during screening, modeling objectives must be reexamined and new candidate models selected. The process will be repeated for the new list of candidate models. The remaining criteria including realistic model outputs, accuracy could not be reasonable evaluated with the available information. For that reason they were removed from the screening process. Ease of application was equated to simplicity.

A Review of Selected NonPoint Source Pollution Models

This section provides a general description of selected nonpoint simulation models. All the models in this text have been selected based on the availability of descriptive data and their capability for simulating such basic parameters as sediment, nutrients and, pesticides. Given the fact that the nonpoint pollution problem in Ghana is primarily agricultural in nature the selection of the three parameters as decision criteria is defensible. The models selected for review are the most prominent models currently in use for simulating nonpoint source pollution phenomena (Novotny, 1986).

<u>**Agricultural Chemical Transport Model**</u> **(ACTMO).**

Developed by the U. S. Department of Agriculture and the Agricultural Research Service, ACTMO was designed to simulate transport of organic chemicals from agricultural lands. The model consists of three main components: hydrologic, erosion-deposition, and chemical transport. The spatial dimension of the submodel is defined as a zone. A zone is constructed by grouping together major soil types or land use classes or any physical features considered important. Soil topographic maps are used to determine the proportion of each zone overflowing unto a lower zone. Soil moisture is estimated by determining infiltration rate, evapotranspiration, and seepage into lower soil layers. Infiltration and runoff are computed for each zone. Runoff is routed across each zone and the overflow is distributed on adjacent soil segments. Groundwater recharge rate which is an input into the model is derived from average annual evapotranspiration, and average annual stream flow.

The second subsystem, the Erosion-Deposition, subsystem, predicts soil loss by applying a modified version of the USLE. The modified USLE is capable of estimating particle size distribution and calculating clay enrichment ratios.

The third major subsystem modeled in ACTMO is the organic chemical transport subsystem. This submodel traces the flow of a single application of an agricultural chemical within a defined watershed. Elements of the chemical transport system simulated by the submodel include: sorption and desorption processes; and chemical decomposition and dispersion. A special option of the chemical transport component of the model is designed to simulate nitrogen movements and transformations. The model is limited by the requirement that only one rain gauge input is allowed. For that reason a farm size watershed is the recommended spatial unit for simulation. The disadvantages include: minimal data management capabilities; assumption of sloping terrain (may not apply to flat terrain); and the model allows for only one chemical and one application per simulation. The primary advantage is that a wide range of agricultural applications is possible.

Hydrocomp Models

Hydrocomp Models are a set of models developed from a Standford Watershed Model IV by Hydrocomp, Inc., Palo Alto, California. One of the most recent is the Hydrocomp Simulation Program (HSP). The Hydrocomp Simulation Program has been modified into several models which can be found in the public domain. They include: the Nonpoint Simulation Model (NPS) and the Agricultural Runoff Model (ARM). These are discussed below. The HSP has 3 basic components: LIBRARY, LANDS, and CHANNELS. The water quality model (QUAL) is a separate model used with any of the three component systems mentioned above. A flowchart for QUAL is described in Figure 5.3.

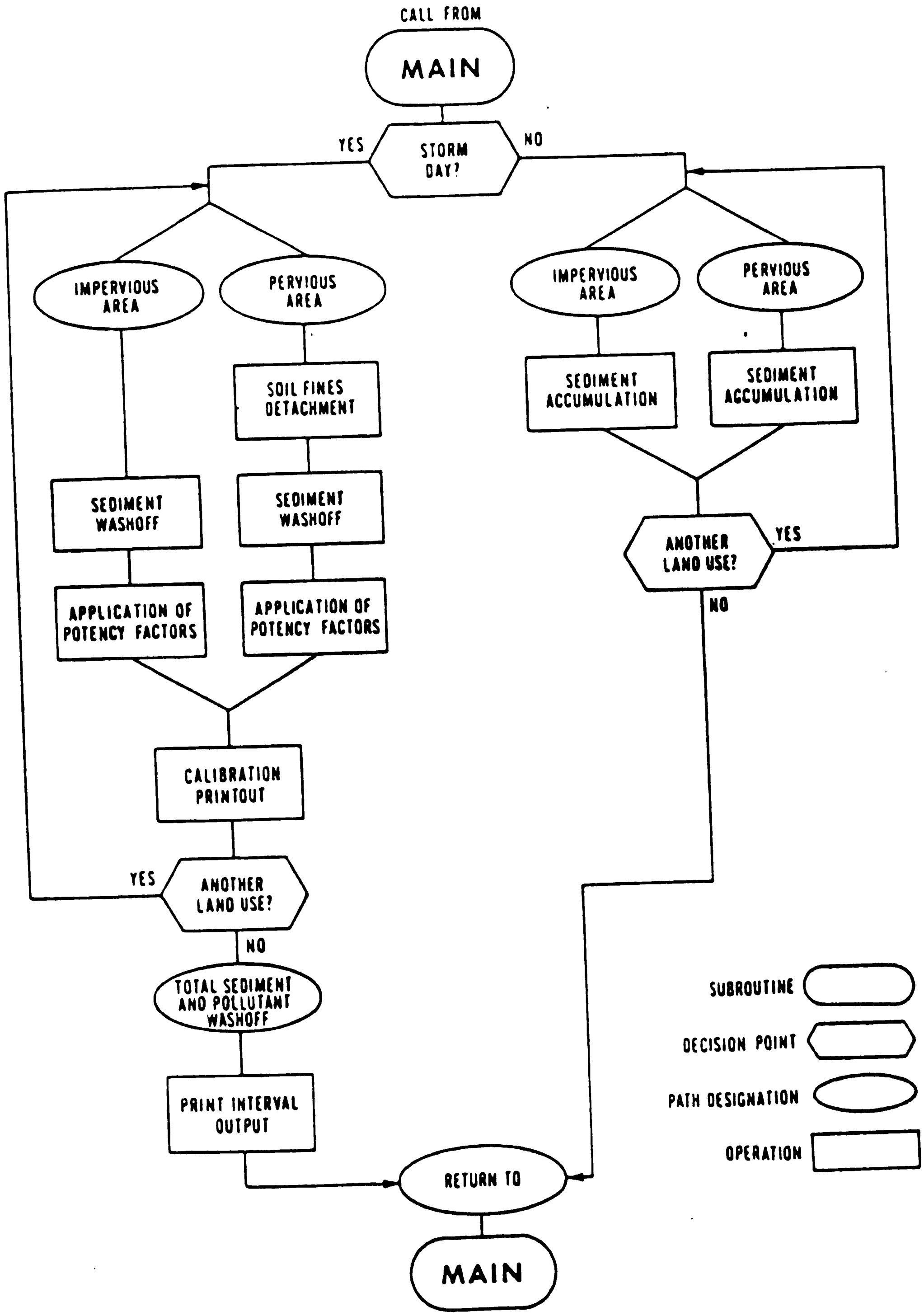


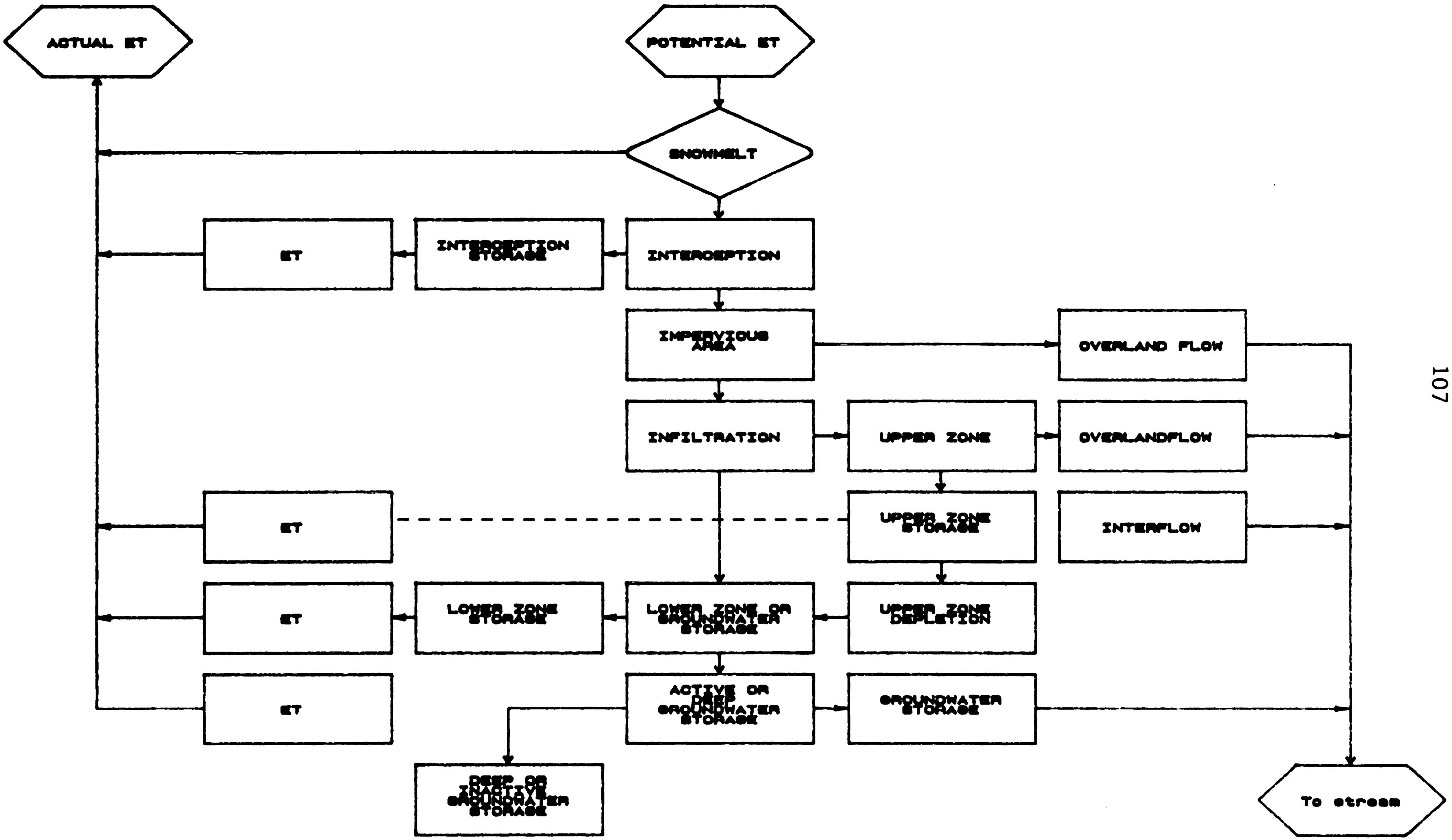
Figure 5.3 Functional flowchart of the QUAL subroutine

Source: Donigian & Crawford (1976)

LIBRARY is the master program and serves as a data- file handling component of the model. LANDS, on the other hand, is a flow-generating submodel which estimates overland inputs into channels from meteorological sources and overland flow characteristics.

The structure of LANDS is described in Figure 5.4. Input data include: precipitation (which can be input at between 5 min to 6 hrs), daily information on potential evapotranspiration, slope of the overland flow, imperviousness of the watershed, soil moisture, saturation and permeability of soils, storage and other physical and meteorological variables. The model is calibrated against measured hydrologic flow data in order to determine parameters related to soil and groundwater flow. Excess rainfall in the model is computed by reducing precipitation by hydrologic losses, infiltration, and Surface Storage. A snowmelt component determines heat inputs and losses from accumulated snow pack. Runoff in the model is computed by reducing precipitation by surface storage. Overflows onto adjacent pervious areas are not accounted for. This implies that runoff volume from an impervious area is added to the water balance in a pervious area. The soil storage parameter in LANDS is determined by calibrating the model. Soil Storage in the model has two components: <u>upper zone soil storage</u> and <u>lower zone soil storage</u>. The upper soil storage represents

Figure 5.4 LANDS Simulation. (Replotted from Donigian & Crawford, 1976)



water storage in the upper zone which are affected by evaporation and transpiration. The lower zone storage is moisture in the zone of aeration to the bottom of the root zone.

Interflow is another component simulated by LANDS. This is estimated by an equation which relates lateral movement of soil water to the exhaustion of the lower zone storage. Surface runoff is routed overland to the receiving channel. The groundwater component of precipitation is the difference between seepage from the lower soil zone and deep percolation.

The CHANNELS submodel is determined by kinematic wave approximation especially in the more recent models.

The QUALITY model utilizes the Negev model to estimate erosion from pervious areas. Additionally, street dust and dirt accumulation and washoff from impervious surfaces is simulated by a concept developed by a simple mass balance of the dirt accumulation process.

The Hydrocomp Simulation Program is large. It requires extensive data bases and large computer hardware [Novotny and Chesters, 1981]. The input parameters used however have to be lumped making them less efficient in simulating watersheds with changing physical characteristics.

The Nonpoint Simulation Model (NPS)

The NPS is one of the simplified versions of the HSP applicable to nonpoint pollution put out by Hydrocomp, Inc.

on the request of the U. S. EPA. The model simulates nonpoint pollution from five land use categories. Runoff, water temperature, dissolved oxygen and sediments are the basic watershed characteristics simulated by the model. Besides the characteristics mentioned above the design of the model allows the user to specify up to five pollutants from each land use category.

Three major components of the model are identifiable. They are MAIN, LANDS and QUAL. Both the LANDS and QUAL components of the model are similar to those in the proprietary model (HSP) described above. The LANDS and QUAL segments are designed to operate at 15 minute intervals during storm events. During rain storm periods, a combination of 15 minutes, 1 hour and 24 hour intervals is used to simulate evapotranspiration and soil water percolation.

MAIN is the master program. Like the HSP model, the QUAL submodel in NPS computes erosion by the Negev model. A mass balance system is used to compute dust and dirt accumulation. Figure 5.5 describes a flow diagram of the NPS model.

The Agricultural Runoff and Management Model (ARM)

The ARM model is another version of the Hydrocomp simulation models. The ARM model simulates runoff, sediment, pesticide and nutrient loading to surface waters from both surface and subsurface sources. The model comprises six components, namely: LANDS; SEDT; ADSRB; DEGRAD; NUTRNT; and

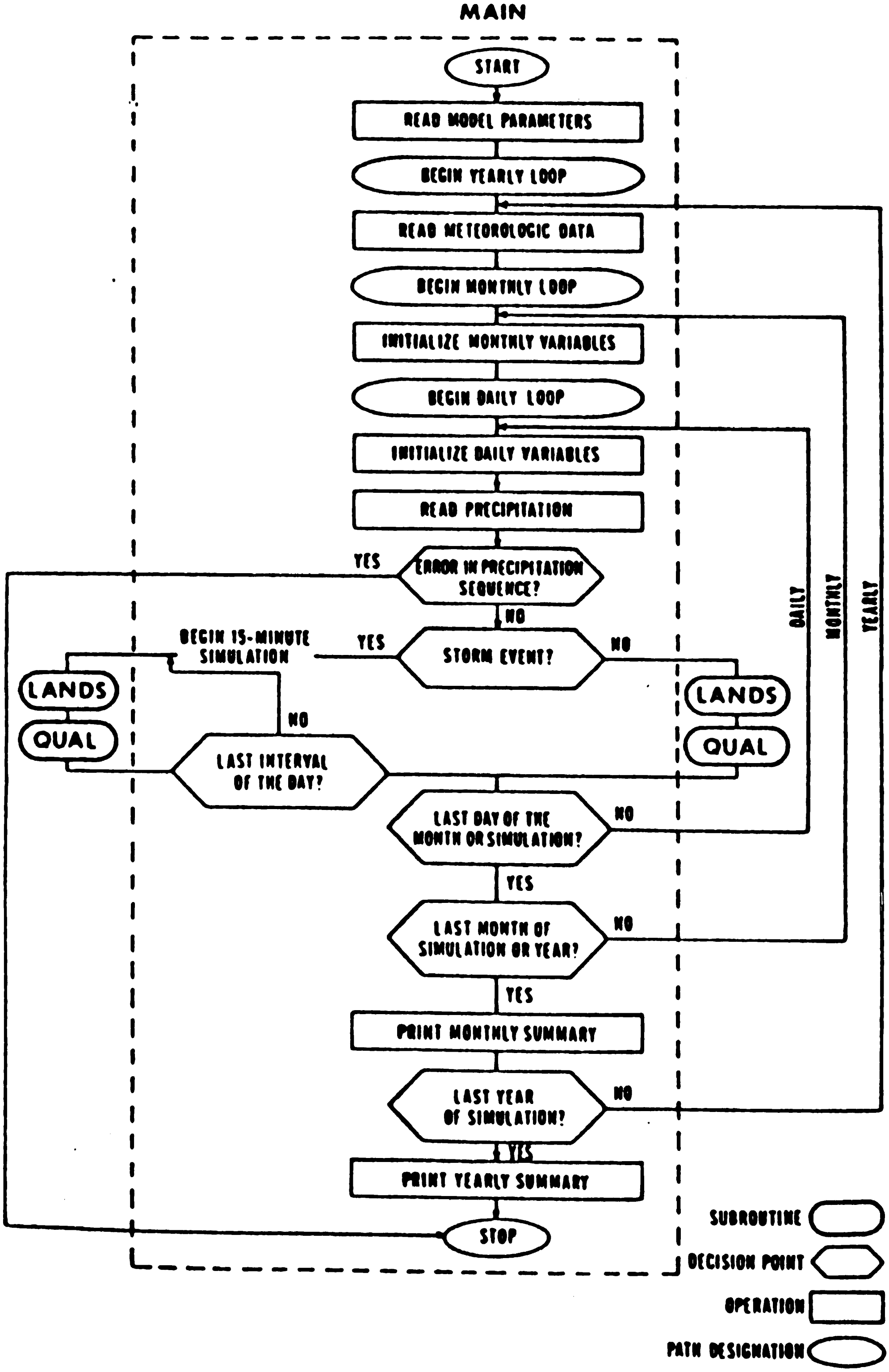


Figure 5.5 NPS model structure and operation

Source: Donigian & Crawford (1977)

MAIN which is the master program. LANDS is the hydrologic component, SEDT is the sediment production component, ADSRB is the pollutant adsoption/desorption component, DEGRAD is pesticide degradation, and NUTRNT the nutrient transport component.

Again the LANDS submodel is similar to those in the HSP and NPS models, and the SEDT component uses the Negev sediment model mentioned above. The adsorption/desorption component assumes instantaneous activity.

Pesticide volatilization is simulated in the model. Combined pesticide degradation is estimated by determining volatilization and microbial decomposition.

The processes simulated in the nutrient transformation model include plant uptake, adsorption/desorption, nitrification/denitrification, mineralization and immobilization.

Continuous and event simulations are possible with the ARM model. However, only relatively small watersheds can besimulated with some degree of success. The structure of the model is shown in Figure 5.6.

The Universal Soil Loss Equation (USLE)

The USLE is probably one of the most familiar and widely used models in the area of nonpoint pollution [Foster et al. 1984, 1985; Wischmeier, 1978; DeCoursey, 1985]. The equation was designed to predict soil loss from sheet and rill erosion. The equation, according to Wischmeier (the author),

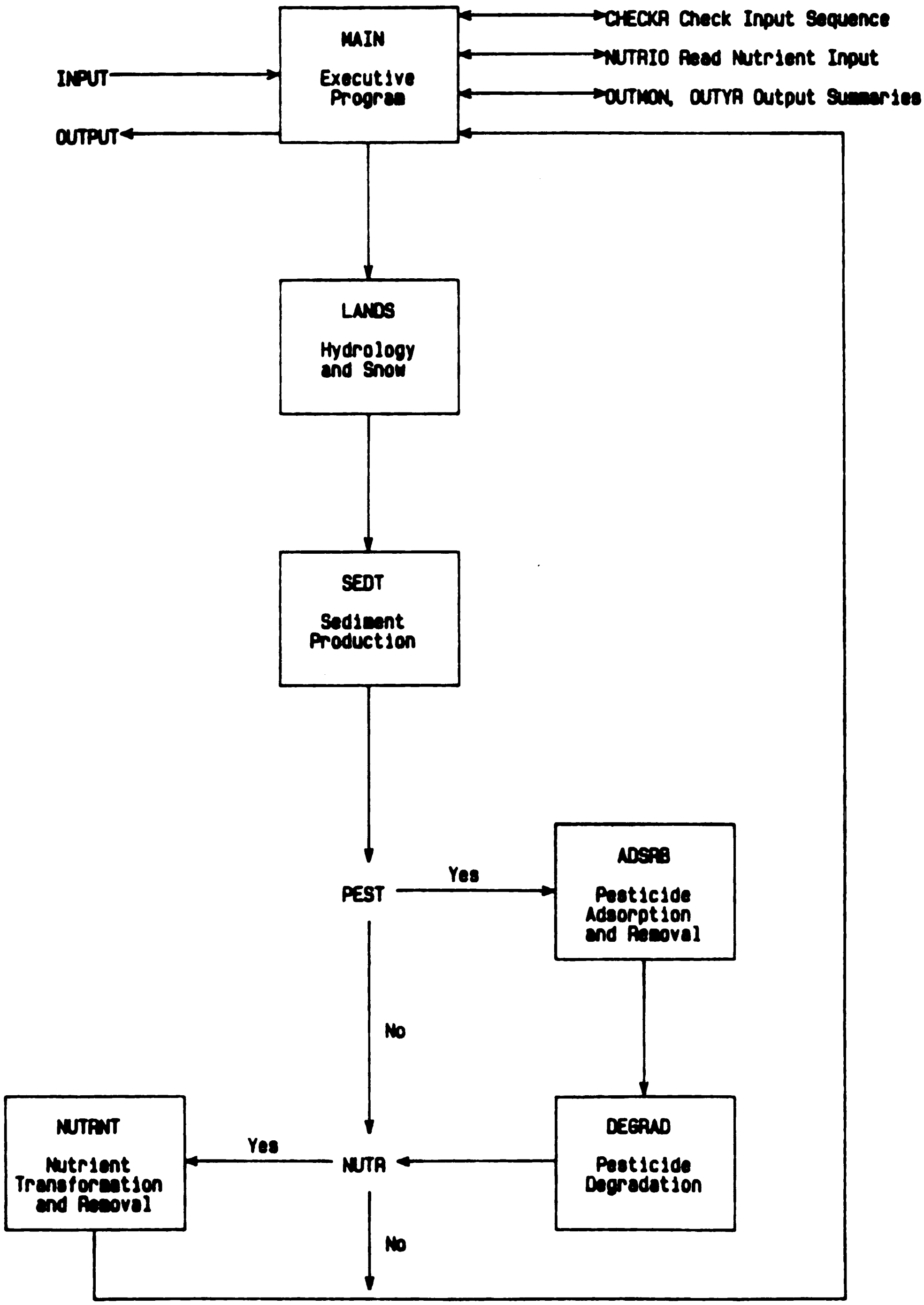


Figure 5.6 ARM Model Structure and Operation
Source: Donigian et al., 1977

does not account for deposition of eroded material. Procedures for estimating erosion are, besides their predictive capability, useful in selecting practices to control site specific erosion and nonpoint source pollution [Foster et al., 1984]. The interaction of several variables are represented in the regression equation used to calculate long-term average annual soil loss from small areas. The universal soil loss equation groups the variables under six erosion factors to produce:

$$A = (R)\ (K)\ (L\ S)\ (C)\ (P) \qquad (1)$$

where A is the average soil loss for the time interval R expressed in the factor K as tons/acre. R is a measure of the erosive forces of rainfall which is often equal to the erosion index (EI) rainfall parameter. K is a measure of the erodibility of a particular soil. L and S are adjustment coefficients for effects of length, steepness and the storage of the field slope. C determines the effect of different cropping practices and management systems on soil loss. P reflects the benefits of supporting management practices on soil loss. The USLE was initially designed to guide the selection of conservation practices for specific sites. The product of R, K, L, and S determines the basic soil loss index. C, as mentioned earlier, determines the effect of cropping practices and P, the benefits of such supporting practices as contouring and strip cropping.

The USLE can be and has been used to estimate total average annual soil loss from sheet and rill erosion within a defined watershed. For the prediction of nonpoint source pollution the USLE has been modified to a very large extent. In order to improve its use for estimating erosion from single storms, a soil loss ratio which is appropriate for the crop and soil conditions on the day of the storm is often used instead of a general value for the crop stage [Foster et al., 1984]. Also, a runoff component is added to the USLE erosivity factor. This modification known as the Modified Universal Soil Loss Equation (MUSLE) is used to estimate sediment yield and obviated the need for sediment delivery ratios required in the USLE for the estimation of sediment yield.

Another modification, the Onstad and Foster (1975) modification, includes the USLE erosivity factor, storm energy times a 30-minute intensity plus a runoff term based on the peak runoff rate and the volume of runoff [Foster et al. 1984]. This modification is an attempt to include runoff and erosivity effects in the estimation.

The third modification to the erosivity factor by Foster et al. (1977) attempted to separate rill from interril erosion. This modification combines the erosivity factor in the USLE for a single storm event with terms that represent the interril erosion and the runoff erosivity factor of Onstad and Foster (1975) which define slope lengths and steepness factors thought to represent rill erosion. This modification is the one used in CREAMS described later.

These erosion prediction equations together with hydrologic modeling permit the use of the USLE in nonpoint pollution modeling and are reflected in several nonpoint pollution models.

<u>Chemical Runoff and Erosion from Agricultural Management Systems</u> (CREAMS).

CREAMS was developed by the Agricultural Research Service of the U.S. Department of Agriculture (Knisel, 1980 and Leonard and Knisel, 1984 and Ferreira, 1984). It was designed principally for evaluating agricultural best management practices (BMPs) for pollution control. The original model has been modified to combine the hitherto separate hydrology, chemical, and erosion submodels.

CREAMS is capable of simulating several variables. Runoff volume, infiltration, evapotranspiration, soil water content, and percolation are computed on daily basis (Leonard and Knisel 1984). Erosion and sediment yield are estimated. Plant nutrient and pesticides as well as storm load and average concentrations of dissolved chemicals and sediment are also simulated.

The primary advantages of the model enumerated by Donigian and Beyerlein (1985) include: reasonably accurate representation of soil processes, continuous simulation, and the ability to evaluate different BMPs. Further, the model can simulate twenty pesticides at a time. The disadvantages are: small size of simulation area, limited data management and handling capabilities, and small temporal aggregations (daily time-step simulation).

<u>Agricultural Nonpoint Source Pollution Model</u> (AGNPS).

AGNPS is a product of a coordinated effort between four state and federal agencies in Minnesota. The single event model was designed to evaluate nonpoint source pollution from agricultural watersheds of between 200 to 9,300 acres. It analyzes sediment and nutrient transport and provides a means of comparing different watersheds. The model is also capable of evaluating various conservation alternatives.

From the headwaters of the watershed to the outlet, AGNPS routes sediment and nutrient in a step-wise fashion to facilitate an examination of flows at any point in the watershed. During a storm event, runoff (including sediment and nutrient) is routed downslope through a watershed. The watershed is divided into several cells of four hectares only each.

The model comprises several subsystems. These include: RUNOFF, CHANNEL FLOW, EROSION, SEDIMENT TRANSPORT, and NUTRIENT TRANSPORT. Overland runoff is computed using the Soil Conservation curve number method (Bosch et al. 1983). Channelized flow is estimated with the equation from CREAMS (Bosch et al., 1983). The Modified Universal Soil Loss Equation (MUSLE) estimates upland and sheet erosion from single storms. Estimates for erosion and runoff provide the basis for routing sediment through the watershed. The routing method was derived from a steady-state continuity equation described in Bosch et al., 1983. The nutrient portion of the model computes nitrogen and phosphorus transport throughout the watershed. The method used is from CREAMS. Modifications made to AGNPS accounted for the effects of soil texture (Bosch et al., 1983).

The primary outputs of AGNPS include: volume and peak runoff, sediment generation, and nutrient loadings. Inputs include: precipitation, erosivity, peak flow rates, fertilizer application, soil type, land use, and runoff volume. The principal advantages of the model are: its flexibility and simplicity, minimal inputs which are obtainable from existing records and visual reconnaissance, and its capacity to estimate water quality variables at intermediate points throughout the watershed.

A REAL NONPOINT SOURCE WATERSHED ENVIRONMENT RESPONSE SIMULATION MODEL (ANSWERS)

The ANSWERS model, developed in Purdue University was designed to simulate sources, flows and repositories of sediment and nutrient. The model is based on the distributed parameter concept. Watersheds are divided into small areal elements of between 1 to 4 hectares each. The structure of the model consists of a hydrologic model, a sediment detachment/transport model, and components which describe overland flow, infiltration, surface storage, channel flow, and subsurface flow. The model is event oriented. The ANSWERS data files are designed to use readily available sources of information such as soil surveys, topographic maps, and crop and management surveys.

The primary advantages of the model include: a) the ability to evaluate alternative erosion control and management practices (Beasley et al., 1980; Donigian and Beyerlein, 1985), b) the modularity of the program structure enabling modifications to the existing program and additions of new algorithms, and c) the large dependence of data files on secondary data sources. The disadvantages include a) complexity of preparing data files, b) the storm-event nature of the model which fails to allow long term simulations, c) its inability to simulate pesticide processes,and d) the requirement for large computers for simulating large watersheds.

Summary of Model Review

This review has covered the most prominent nonpoint source pollution models currently in use. The models vary widely in structure, parameters represented, complexity, and ease of application. The models are presented both as examples of the state-of-the-art of available in nonpoint source pollution modeling and to aid in identifying the parameters and attributes of the various models summarized in Figure 5.7 below.

From the review of the of the models, a number of important observations can be made. First, most of the models

MODEL	Hydrology		Loading Sources					Space Scale		Water Quality			Data Needs			Time Scale			Model Costs			Accuracy		Simplicity		Ease
NAME / Attributes	Surface Runoff	Subsurface Flow	Urban	Agricultural	Forest	Precipitation	Chemical Application	Multiple Catchment	Single Catchment	Sediment	Nutrient	Pesticides/Toxics	Extensive	Moderate	Minimal	Annual Loads	Event Loads	Continuous	Equipment Costs	Data Costs	Manpower Costs	Representation	Sensitivity to inputs	Easy to Understand	Easy to Operate	Ease of Modification
NPS	X	X	X	X	X			X	X	X	X		X				X	X	M	H	H			O	O	
ARM	X	X		X			X		X	X	X	X	X				X	X	M	H	H			O	O	
AGNPS	X	X		X				X	X	X	X				M	X			M	M	M			X	X	
CREAMS	X			X	X		X		X	X	X	X	X				X	X	M	H	H			X	O	
ANSWERS	X	X		X	X		X		X	X	X		X				X		M	H	H			X	O	
USLE	X		X	X			X		X	X					X	X			L	L	L			X	X	
HSP	X		X	X				X	X	X	X	X	X				X	X	M	H	H			O	O	
ACTMO	X			X				X	X	X	X	X	X				X	X		H	H			O	O	

FIGURE 5.7: MODEL SUMMARY

X = Available/Ease
M = Moderate
H = High
L = Low
O = Difficult

described above are large and complex models which require large data bases for their operation. These characteristics have important ramifications for their selection and use in the context of a developing country. The review seems to reveal a large dependence on the USLE to estimate erosion. Of the seven models discussed besides the USLE, three (AGNPS, ACTMO, and ANSWERS) use the USLE as the basic algorithm for simulating erosion and sedimentation processes. Two others (NPS and ARM) like their proprietary model - HSP use the Negev model to estimate erosion. For the purpose of this study, the USLE is remove from the list of candidate models. This is because taking the USLE through the screening process would mean comparing the model against itself.

Application of Criteria-Based Screening Process

To illustrate the screening process, the seven commonly used nonpoint source pollution models described above were screened. The USLE was removed from further consideration for reasons discussed above. The task was to select appropriate models for quantifying the magnitude and extent of the nonpoint source pollution problem in Ghana. In particular, the objective was to determine the magnitude of runoff, sediment, and nutrient losses from agricultural lands.

To provide the means for making informed judgments and decisions on the models, several model attributes were defined in form of a worksheet (shown in Figure 5.7 above) to be used in conjunction with the decision flow chart.

It is important to note at this point that decisions regarding such attributes as data needs, model costs, and simplicity involve value judgments. A system that provides easy access to decision models in order to support decision tasks must deal with subjective judgments. These judgments were , however, based on information available in the literature. Further, the problem of lack of data is real. For example, no studies are currently available which compare costs of applying nonpoint source pollution models. The problem of what is considered high costs or low cost may be relative. Even if the screening system ensures that those who make decisions relative to the model elements and their attributes have a large store of knowledge and experience, ultimately, subjective judgments must form part of the decision process. The algorithm defined above will ensure that factors considered in selecting a model are explicitly stated and consistently applied.

In order to apply the decision flow chart in Figure 5.2 the eight models were evaluated for the elements defined above. The flowchart must be used in conjunction with Figure 5.7.

The determination of the level of data needs was based on previous evaluation of the candidate models for the International Joint Commission on the Great Lakes by Donigian and Beyerlein (1986). Based on that determination (also shown in Figure 5.7.). AGNPS was assigned a rating of 0.6 points for moderate data requirements and the other six candidate models a rating of 0.3 for high data requirements. The determination of the applicability of the models for quantifying pollution from agricultural systems was done from Figure 5.7 under loading sources. All the models under consideration are capable of simulating pollution conditions on agricultural lands. The model attributes identified under hydrology and water quality provide the required information to determine whether the parameters of interest have been modeled by the candidate models. All output parameters (surface runoff, sediment, and nutrients) required under the scenario are simulated by all candidate models. Each model is assigned a rating of 1.

The cost ratings, like the preceding criteria, were based on information obtained from the literature (see Figure 5.7). The literature reviewed above indicate that six of the seven models namely; HSP, CREAMS, ANSWERS, ACTMO, ARM, and NPS require large quantities of data skilled manpower, substantial amounts of time for their operation. According to Reckhow et al. (1985) there is an implicit concern for cost as a constraint once data limitations are identified. For that reason high data requirements constitute a basis for subjectively rating the models as low cost, moderate cost or high cost. The six models listed above were therefore rated as high cost models and assigned a rating of 0.3 each.

The manpower availability ratings were done simultaneously with model simplicity and ease of application ratings. A complex model requires highly skilled manpower to understand and operate. Again the simplicity ratings were based on previous reviews of the candidate models. The HSP, CREAMS ANSWERS, ARM, ACTMO, NPS were determined to be complex models requiring skilled manpower for their operation. The models were therefore rated 0.3 each for manpower availability, ease of model application, and model simplicity. AGNPS was rated as simple 1.0.

Model accuracy is generally not known. Often, models are tested for precision rather than accuracy. For this reason, model accuracy was dropped as an evaluation criterion. The ability of the models to simulate results that are socially and politically sensitive was difficult to determine. For that reason the realistic model outputs as a model selection decision criterion was not rated. The weights assigned to each criterion was multiplied by the rating and then summed up to obtain a total rating for each model. The model with the highest total rating is the most preferred model given the resource constraints on which the value weights were determined (see Table 5.6). The application of the system indicates that among the candidate models evaluated, AGNPS has the greatest utilization potential in Ghana.

The criteria-based screening system as applied is capable of differentiating between different spectra (eg.

Table 5.6: Results of Model Screening

Criterion / Model	RATING Data Needs (b=2.531)	Parameters Modeled (b=2.424)	Applicability (b=2.364)	Model Costs (b=2.031)	Manpower Availability (b=2.000)	Ease of Application (b=1.939)	Simplicity (b=1.909)	Total Rating (WR)
ACTMO	0.3	1.0	1.0	0.3	0.3	0.3	0.3	7.89
ARM	0.3	1.0	1.0	0.3	0.3	0.3	0.3	7.89
AGNPS	0.6	1.0	1.0	1.0	0.6	0.6	1.0	11.77
ANSWERS	0.3	1.0	1.0	0.3	0.3	0.3	0.3	7.89
CREAMS	0.3	1.0	1.0	0.3	0.3	0.3	0.3	7.89
HSP/HPSF	0.3	1.0	1.0	0.3	0.3	0.3	0.3	7.89
NPS	0.3	1.0	1.0	0.3	0.3	0.3	0.3	7.89

b = Weight of Criteria
WR = Weighted Rating

large/complex, moderate, simple) of nonpoint source pollution models. However, it is insufficiently sensitive to choose among models that fall within one spectrum. For example it is extremely difficulty through this rating system to discriminate among various levels of applicability or ease of application or cost where quantitative data on cost is unavailable. For this reason, the large and complex models which constitute the bulk of the models subjected to screening produced the same results. Given this shortcoming this approach was rejected in favor of the more subjective system using flow charts to guide selection decision.

In order to apply the decision flowchart in Figure 5.2b the seven models were evaluated against the elements defined in Figure 5.7. The determination of the applicability of the model for quantifying pollution from agricultural systems was done from Figure 5.7 under loading sources. All the models under consideration are capable of simulating pollution conditions on agricultural lands. The model attributes identified under hydrology and water quality provide the required information to determine whether the relevant parameters (surface runoff, sediment, and nutrients) required under the scenario are simulated by all candidate models. The seven models are then subjected to the data availability criterion. The literature reviewed indicate that six of the seven model reviewed above namely; HSP, CREAMS; ANSWERS; ACTMO; ARM; and NPS require large quantities of input data for their operation. Since large data requirements imply high model application costs the models fail on data and cost constraint test. Given the resource constraints identified in Chapter 2, the models are rejected from further consideration. If sufficient funding was made available, the models would be retained and subjected to further testing. AGNPS at this point emerges as a potentially useable model for application in Ghana.

An Examination of AGNPS as a Potential Nonpoint Source Pollution Model for Planning Applications in Ghana

AGNPS, as discussed earlier in this chapter, was designed to simulate surface runoff, erosion and sediment loss, and nutrient primarily from agricultural fields. The model works on a cell basis. In order to apply the model in Ghana, several modifications will be required.

Runoff

The basic algorithm used for estimating runoff is the Soil Conservation Service (SCS) curve number method based on the equation:

$$Q = (P - Ia)^2 /(P - Ia) + S \qquad (2)$$

where Q = runoff (in)
P = rainfall (in)
S = potential maximum retention after runoff begins (in)
Ia = initial abstraction (in)

The initial abstraction is an estimate of losses before runoff begins. These losses which include water retained in depressions, water intercepted by vegetation, evapotranspiration, and infiltration vary considerably from place to place. Studies that defined the empirical equation Ia = 02S used to define curve numbers were conducted on many small watersheds in the United States. S is related to soil and cover conditions of the watershed through the curve number (CN) as follows:

$$S = 1000/CN - 10 \qquad (3)$$

The Hydrologic Soil Groups (HSG), land cover types, treatment, hydrologic conditions, and antecedent runoff conditions are the basic determinants of runoff curve numbers.

Given the wide variations in infiltration rates of different types of soils, the application of a CN generated based on studies in watersheds in the United States to Ghana will produce erroneous runoff results. This means that a relationship other than the empirical equation Ia = 02S must be used to estimate runoff. This would require redeveloping the SCS equation:

$$Q = (P - 02S)^2 / (P + 0.8S) \qquad (4)$$

obtained after substituting the empirical relationship developed for initial abstraction into equation (2). Original rainfall-runoff must be obtained in Ghana to establish a new empirical relationship for the potential maximum retention parameter (S) for various soils and cover types.

Peak flow within channels is estimated using an equation from CREAMS as follows:

$$Q = 3.790\ A^{0.7}\ CS^{0.159}\ (RO/25.40^{\ 0.903A\ LW0.0166})\ -0.187 \quad (5)$$

where Q is peak runoff in m^3/s; A is the drainage area, CS is channel slope in m/km; RO is runoff volume in mm 2 and LW is the length-width ratio approximated by L/A where L is the length of the watershed and A is size of drainage area. This relationship needs to be tested to determine whether estimated peak flows using equation (5) approximate observed peak flows in a realistic manner.

Erosion

Soil erosion is estimated by AGNPS using the USLE. The original regression equation discussed above in equation (1) was modified by a slope shape factor (SSF). The attractiveness of the USLE as a basis for estimating soil erosion is that the model is well tested, it is simple, and has a large body of well developed literature to support it.

For practical applications in a tropical environment however, several factors need to be adjusted. Of particular interest are the storm energy-intensity factor (EI) and the Soil erodibility factor (K). Isoerodent maps are often used to select storm energy -intensities of 30-minute durations for various locations in the United States. In order to develop isoerodent maps using standard USLE procedures extensive data and calculations will be required (Lo et al., 1983). For each station with a rain-gauge, yearly summation of EI for erosive storms are averaged over 20 year periods to determine unbiased EI values.

Given the difficulties inherent in developing isoerodent maps using conventional USLE methods a simpler method requiring daily, seasonal and annual rainfall have been used successfully. Simple indices like the Fournier index (p^2/P) where p is average rainfall during the wettest month and P is average annual rainfall or the Modified Fournier index (pi/P) where pi is mean monthly rainfall and P is mean annual rainfall can be used to estimate EI. From a regression analysis, average annual rainfall has been determined as the best estimator of EI. This method could be applied to the existing rainfall data in Ghana to generate isoerodent maps for the entire country.

Soil erodibility (K) is determined primarily by the inherent characteristics of various soil types where slope, rainfall, vegetative cover, and soil management practices are equal. Given the wide variation in soil types, erodibility values for various soil types need to be determined for soils in Ghana. Previous studies (CSIR, 1976; Quansah, 1983; Boffoe-Bonnie and Quansah, 1975; and Ahn, 1968) provide the basis for uniquely applying erodibility values for selected Ghanaian soils. Also, systematic studies are required to determine the relationship between slope length and soil loss for various soils and climatic regions in Ghana.

Sediment Transport

The method used for routing runoff and sediment through the watershed was derived from the steady state continuity equation discussed in Young et al. (1983):

$$Qs(X) = Qs(O) + Qsi\ X/L - \quad D(x)\ w\ dx \qquad (6)$$

where Qs(X) is the sediment discharge at the stream end of the channel reach; Qs(O) is the discharge at the upstream end of the channel; Qsi is the lateral inflow rate of sediment; x is the downstream distance; w is the width of the channel; L is the reach length; and D(x) is the deposition rate. The derivation of the basic routing equation for sediment loads in the model is discussed in greater detail in Young et al., 1983.

The use of the steady state equation requires the determination of soil texture and roughness coefficients. Previous investigations of the microaggregation of soils in Ghana (Ahn, 1968) should provide the necessary information and the basis for determining soil texture and roughness coefficients.

Nutrient Transport

The nutrient component of the model estimates the transport of nitrogen (N), phosphorus (P), and chemical oxygen demand (COD) throughout a watershed. COD which is the measure of the amount of oxygen required to oxidize organic and oxidizable inorganic matter in water was included in the nutrient component to provide an indication of the level of pollution in runoff.

The nutrient transport calculation in the model was divided into two parts. One deals with the sediment- attached (adsorbed) nutrients and the other with soluble nutrients. Nutrient associated with sediment is estimated for each cell using the equation:

$$Nut(sed) = Nut(si) * SY * ER \qquad (7)$$

$$ER = A * Qs * * B * T(f) \qquad (8)$$

where Nut(sed) = N or P transported by sediment, Nut(si) is N or P content of soils in the field; Qs is sediment yield predicted by the sediment transport equation; ERis an enrichment ratio for N or P. Factors A and B are constants which equal 7.4 and -0.2 respectively. T(f) is a correction factor for soil texture.

Soluble nutrient in runoff is estimated by the equation:

$$N(sol) = C(RO) * N(ext) * Q * 0.01 \qquad (9)$$

where N(sol) is the concentration of soluble N in runoff C(RO) is the concentration of soluble nitrogen in soil surface during runoff, N(ext) is the extraction coefficient for movement into runoff, and Q is total runoff. Soluble P is similarly estimated within the soluble nutrient algorithm.

COD is assumed to be soluble. The estimates are based on runoff volume and the average concentration of COD in runoff. Background concentrations for COD in runoff for various landuses are obtained from the literature.

Summary

Planners need nonpoint source pollution models to evaluate the magnitude and extent of the nonpoint source pollution problem in Ghana. Several nonpoint source pollution models have been developed over the past two decades. Given the wide array of models currently available, planners must carefully consider the elements of the various models and their attributes relative to a given nonpoint source pollution problem in order to select an appropriate model. In this chapter, a criteria-based screening process was developed for selecting a model to evaluate nonpoint source pollution problems. An example application of the screening process indicates AGNPS will be an appropriate model to be used for planning applications in Ghana. The model is relatively simple. the data requirements, manpower requirements and costs of application are moderate. Previous applications indicate that it produces relatively precise results. To be applied realistically, however, several modifications (discussed above) are required.

The next chapter summarizes the research, outlines the major conclusions and discusses recommendations.

CHAPTER 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The final chapter of this study is divided into three main sections. They include: 1) a summary and conclusions of the research; b) limitations of the study; and d) a discussion of recommendations and areas of further inquiry.

Summary and Conclusions

Nonpoint source pollution, as shown, is an environmental problem in LDCs. In terms of mass, sediment constitutes the major pollutant from agricultural activities. Soil loss affects not only productivity of the land but also the quality of lakes and rivers into which soil flows. The costs of nonpoint source pollution are reflected in loss of crop productivity, increased fertilizer use, and losses resulting from the adverse effects of pollution of water resources on aquatic flora and fauna. While chemical pollution has been the main focus of water quality research in most industrialized countries, erosion and river sedimentation are the most critical water quality problems in most developing countries. Nevertheless, the increasing use of agricultural chemicals and increased industrialization pose a potential threat to water resources from chemical pollution in LDCs.

The major concerns for pollution from fugitive sources in most developing countries relate to the adverse effects of erosion and chemical transport on both ground and surface water resources. In order to mitigate the adverse effects of erosion on productivity of the land, many developing countries have significantly increased consumption of agricultural chemicals.

Ghana is predominantly an agricultural country. Between 1970 and 1980 fertilizer consumption per hectare of arable land increased by 770%. Along with fertilizer, pesticide consumption has increased substantially. Erosion and siltation have been recognized as constraints to resource development.

Of the positive aspects of environmental protection which emerged from this research, the most important seems to be the general awareness within the government of Ghana of the problems of the environment and the extent of the initiatives taken to protect the environment. The literature reviewed on the environment of Ghana seems to reveal that a significant number of laws and institutions exist to protect the environment of Ghana. Further there seems to be awareness of the fact that policy changes are necessary to improve management of the environment. The Land Planning and Soil Conservation Act (35), for example, provides the legal basis for the control of pollution from sediment and agricultural chemicals. A general survey of potential soil hazard areas has been done. However, only limited studies attempt to define, in a quantitative way, nutrient and sediment losses from agricultural fields and develop strategies to solve the problem.

In addition to the awareness of the environmental problems and the existence of a management structure for pollution control, Ghana has considerable potential for growth. The fertile basin of the Volta, Volta Lake with its substantial irrigation potential, and the timber and mineral resources provide the basis for economic growth. Growth will not only provide the needed resources for development but also create the conditions for increased pollution of the nation's environment. Over the past three years the downward trend in the economy of Ghana has been reversed to a current growth rate in GNP of 6%. A substantial restructuring of the productive sectors of the economy is taking place with substantial investments coming from bi-lateral and multi-lateral sources. These investments provide a rare opportunity for strengthening the environmental management system.

The main objectives of this study have been: a) to examine the existing decision making complex for pollution control in Ghana; b) to develop an improved decision framework for managing agricultural nonpoint source pollution in Ghana; and c) to develop a framework for the selection and use of nonpoint source pollution models for decision making in Ghana.

The ability to quantify and develop alternative control strategies will depend on a strong and coherent administrative framework. To that end, chapters 2 and 3 were devoted to examining the existing planning and institutional framework in Ghana with the aim of suggesting an institutional framework within which nonpoint source pollution decisions can be made in Ghana. In chapter 3 the main elements of an institutional framework that will aid planning and control activities were defined. Other important issues like the role of information and education, standards, and pilot studies for the control of nonpoint source pollution were explored.

Effective control nonpoint source pollution will depend on a good understanding of the physical, social, economic, and institutional factors affecting the problem. To gain a good understanding of the problem, planners need a model of the system. The literature on nonpoint source pollution modeling as a decision making tool indicate a wide proliferation of models developed over the last two decades. In order to gain an understanding of the range and capabilities of models available a review was done of the current status of nonpoint source pollution modeling technology and commonly used nonpoint source pollution models.

The review revealed that most of the models in common use are large and complex models which require large data bases, skilled manpower, and substantial financial resources for their operation. To date there are no studies available that compare, in a comprehensive way, the costs of operation of these models.

The wide proliferation of nonpoint source models suggests that planners must carefully select a model which best represents a given nonpoint source pollution condition and has the capability to identify an optimum control scenario while minimizing complexity and costs. On the premise that resources are severely limited in Ghana, some criteria must be established for model selection. In chapter 5, a review was done of the literature to identify criteria for model selection and use. survey the criteria were presented to graduate students and faculty (in the capacity of surrogates) in selected departments at Michigan State University to obtain opinions and a relative ranking of what constitutes the most important criteria for model selection. The rankings were based on a scenario of an LDC. The survey seems to be consistent with what is identified in the literature as the most important criteria. No statistically significant differences were observed in the relative ranks generated between the various groups of respondents identified in the survey. Following analysis of the survey, a decision flow chart was developed based on the rankings generated by respondents from LDCs to be used as a tool for identifying potential models given specific problems. The analysis in chapter 5 indicates that as a result of lack of quantitative information it is not feasible to develop a quantitative rating system base on the rankings generated based on relative importance of the criteria. However, it is feasible to develop an objective system using expert opinions found in the literature. The application of the screening system identified AGNPS as model that could be used planning and decision making in Ghana. Proposals were also made adaption of the model to Ghanaian conditions.

Limitations

Because of lack of resources, it was not possible to conduct a formal study of environmental planners, engineers, and other scientists in Ghana to determine the relative importance of criteria for model screening and selection. For that reason, professors and graduate students were used as surrogates. The result of the survey is, therefore, illustrative only and cannot be accepted as totally representing the ranking that would otherwise have been obtained from Ghanaian professionals.

There are no studies currently available that compare costs of operating nonpoint source pollution models. The determination of what constitutes low cost or high cost in the screening process is indirectly determined from the size of data requirements for the model and opinions expressed by experts derived from the literature. Data cost may vary from project to project depending on what level of baseline information is available. For that reason, data cost may not necessarily provide an objective indication of model costs.

Recommendations

The recommendations discussed below are directed at solving the problems outlined above. The recommendations will be implemented at both national and local levels.

1) The first recommendation~~s~~ is directed at establishing a coherent national policy on the environment of Ghana. In spite of the existence of a coordinating agency (EPC), it is clear that the environmental management system suffers from the absence of a national policy. The Government of Ghana (GOG) should develop such a policy and specifically publish it in the next national development plan. The national policy on the environment which will incorporate a section on pollution from diffuse sources will provide guidelines and a framework for pollution control activities both at the national and local levels. A stated national policy in a national development plan will make apparent the government's intention to aggressively pursue a strategy of controlling pollution. Given the relative importance of agriculture to economic development, an aggressive policy to reduce erosion and protect water resources will be consistent with the goals of increasing food production and protecting the health of the people of Ghana.

2) A pilot program should be implemented in a small watershed (preferably one in which water quality

monitoring is taking place) to examine the adequacy of the existing economic, social, institutional and policy framework for nonpoint source pollution control. This study should define the technical, resource, and manpower requirements for implementing a national program for nonpoint source pollution control.

3) The government should develop a major study program to quantitatively assess the magnitude and extent of nonpoint source pollution in Ghana. Based on the application of the criteria-based screening system developed in this study, AGNPS is recommended as a good screening and planning model to be used as a basis for the study program.

4) A more thorough evaluation should be conducted, through a pilot study, of the institutional structure for environmental and natural resources management with the aim of suggesting ways of coordinating government activities and programs. To that end the proposed framework outlined in Chapter 3 of this study would form the basis for implementing the pilot program. In particular, the role of the EPC in coordinating a national program for controlling nonpoint source pollution should be defined in greater detail. The study should evaluate the problem of overlapping responsibilities and gaps in institutional coverage.

5) The Government of Ghana (GOG) should immediately deconcentrate activities of the MFEP to the district level. The Resource Planning Units of MFEP at the district level should assume responsibility for coordinating planning and implementation activities related to nonpoint pollution.

6) The statutory basis for nonpoint source pollution control should be reviewed. The objective would be to determine whether sufficient authority exists within existing legislation to control the problem. If found inadequate to determine whether new authorizing legislation is required. This review is required to give effect to the environmental policy.

7) An assessment of how effectively technical standards will promote the goals of nonpoint source pollution must be done.

8) The battle against nonpoint source pollution in rural areas will be lost or won on farms. Reduction of erosion from agricultural lands may be achieved through better management of croplands. To that extent, an effective educational program must be launched through extensive extension activity, seminars and presentations, and inclusion of modules related to the subject in school and college curricula.

APPENDICES

Appendix A: Survey

RESPONDENT INFORMATION

1. Area of Expertise____

2. Are you currently a citizen of a Less Developed Country?

   Yes No

3. For how many years have you worked on water-related projects?

   Less than 1 year
   1 - 5 years
   6 - 10 years
   10 - 15 years
   16 - 20 years
   21 - 25 years
   above 25 years

4. Are you currently working in the profession?

   Yes No

5. Have you worked with simulation models in a developing country?

   Yes No

Scenario - Country (A) Profile

Country A is a lower middle-income country with a GNP per capita of $860.00 . It has a population of 21 million people. In addition to universities, a few institutions related to agricultural and water research are available for resource and environmental planning. Research into nonpoint source pollution is only beginning. Systems analysts and computer programmers are available in small numbers. Environmental research has to compete with industry for such manpower resources. The political climate is not exactly stable - shifting between democratically elected governments and military dictatorships. Data storage and retrieval systems, especially for environmental research, are not very well developed. However, basic data can be obtained from various departments.

Using the information provided as a guide, please rank on a 5-point scale (from a - e), the relative importance of each criterion. Place an (X) corresponding to the ranking you select for the country A scenario.

<u>Criteria</u>

1. <u>Parameters Modeled</u>: a model which simulates physical factors such as, surface runoff quantity and quality, sediment loss, solar radiation, landuse, DO, BOD, nutrients, pesticides, e.t.c.

	<u>country A</u>
a) Extremely important	________
b) Very Important	________
c) Important	________
d) Neutral	________
e) Unimportant	________

2. Applicable Situations: the ability of a model to simulate the correct type of nonpoint pollution problem. For example, impacts of nutrients from agricultural lands on water bodies, effects of soil loss, e.t.c.

	Country A
a) Extremely important	________
b) Very Important	________
c) Important	________
d) Neutral	________
e) Unimportant	________

3. Data Requirements for model inputs, outputs, calibration and verification. For example, physical factors such as water quality, effluent, e.t.c. and social factors such as agricultural production systems.

	Country A
a) Extremely Important	________
b) Very Important	________
c) Important	________
d) Neutral	________
e) Unimportant	________

4. <u>Model Costs</u>: including model acquisition costs; equipment requirements; machine costs; data acquisition costs; and manpower costs.

	<u>Country A</u>
a) Extremely important	________
b) Very Important	________
c) Important	________
d) Neutral	________
e) Unimportant	________

5. <u>Model Accuracy</u>: For example 95% confidence that a model will simulate the relevant water quality processes it attempts to account for. These include simplifying assumptions and their effects on water quality predictions.

	<u>Country A</u>
a) Extremely important	________
b) Very Important	________
c) Important	________
d) Neutral	________
e) Unimportant	________

6. Ease of Application: sufficiency of documentation; updatability; and ease of modification.

	Country A
a) Extremely important	________
b) Very Important	________
c) Important	________
d) Neutral	________
e) Unimportant	________

7. Availability of Qualified Manpower. For example, computer operators, programmers; and systems analysts.

	Country A
a) Extremely important	________
b) Very Important	________
c) Important	________
d) Neutral	________
e) Unimportant	________

8. Realistic Model Outputs. For example, are the results of the model socially and politically sensitive?

	Country A
a) Extremely Important	________
b) Very Important	________
c) Important	________
d) Neutral	________
e) Unimportant	________

9. Simplicity of a Model: A model which does not require an inordinate amount of time and skills to understand and operate.

	Country A
a) Extremely important	________
b) Very Important	________
c) Important	________
d) Neutral	________
e) Unimportant	________

Of all the criteria listed above, which ones in your opinion are the 3 most important. List by question number in order of importance in the spaces provided below.

Country A

____

____

____

Please return to Segbedzi W. Norgbey, 330D Natural Resources Building by November 5, 1987. If you have questions, call me at 355-0859 (Home) or 355-8524 (Office) or 355-3346 to leave a message.

THANK YOU!

APPENDIX B: CHI-SQUARE TEST RESULTS

Appendix B: Chi-Square Results

Table 5.3b: Differences in Responses Between LDC Respondents and other Respondents

Criteria	LDC (mean) n=9	Other (mean) n=24	Chi-square	DF	Signi-ficance	No.of cases
Data Needs	2.2857	2.6000	1.47505	4	0.4783	32
Parameters Modeled	2.3750	2.4400	1.06464	3	0.7856	33
Applicable Situations	2.5000	2.3200	2.20000	3	0.5319	33
Model Cost	2.2500	1.9583	6.60317	4	1.1584	32
Availability of Quali-fied Manpower	2.5000	1.8400	1.84250	3	0.6057	33
Ease of Appli-cation	2.1250	1.8800	0.70125	4	0.8729	33
Simplicity of Model	2.1250	1.8400	0.84425	3	0.8389	33
Realistic Model Outputs	1.8750	1.7200	1.82738	3	0.6090	33
Model Accuracy	1.1250	1.6400	1.38836	4	0.8462	33

Table 5.4b: Differences in Responses Between Respondents with simulation Experience in LDCs and Respondents Without

Criteria	Experience (mean) n=10	Without (mean) n=13	chi-square	DF	Significance	No. of cases
Data Availability	2.8000	2.4091*	2.41778	4	0.2985	32
Parameters Modeled	2.3000	2.4783	3.25851	3	0.3563	33
Applicable Situations	1.9000	2.5652	5.09348	3	0.1651	33
Model Costs	2.1000	2.0000*	2.38823	3	0.6648	32
Availability of Qualified Manpower	1.8000	2.0870	1.64522	3	0.6492	33
Ease of Application	1.8000	2.0000	0.82500	3	0.8435	33
Simplicity of Model	1.8000	1.9565	0.96130	3	0.8106	33
Realistic Model Outputs	1.7000	1.7826	3.68380		0.2977	33
Model Accuracy	1.8000	1.3913	8.20080	3	0.8435	33

* = n-1

Table 5.5b: Differences in Responses Between Respondents Currently working in the Water Resource Profession and Those in Other Professions.

Criteria	Water (mean) n=22	Other (mean) n=11	Chi-square	DF	Significance	No. of cases
Data Availability	2.5455	2.5000*	4.20202	2	0.1223	32
Parameters Modeled	2.4091	2.4545	0.75000	3	0.8614	33
Applicable Situations	2.4091	2.2727	3.72727	3	0.2925	33
Model Costs	2.0952*	1.9041	3.29169	4	0.5102	32
Availability of Qualified Manpower	1.9091	2.1818	2.25000	3	0.5222	33
Ease of Application	1.8636	2.09009	1.10795	3	0.7752	33
Simplicity of Model	1.9091	1.9091	0.95000	3	0.6670	33
Realistic Model Ourputs	1.7727	1.7272	2.13750	3	0.5444	33
Model Accuracy	1.5909	1.3636	3.82013	4	0.4309	33

* 1 = n-1

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