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PROFESSIONAL DEVELOPMENT PROGRAMME: COASTAL INFRASTRUCTURE DESIGN, CONSTRUCTION AND MAINTENANCE

A COURSE IN

COASTAL ZONE/ISLAND SYSTEMS MANAGEMENT

CHAPTER 9

INTEGRATED WATERSHED MANAGEMENT

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Antigua, West Indies, June 18-22, 2001

1.0 INTRODUCTION

In an effort to appreciate the need for and importance of (integrated) Watershed Management it is necessary to understand what is a watershed, the interactions in a watershed, the effects of watershed degradation and a basic approach to implementing watershed management.

Perspectives of a Watershed

A watershed can be described as the area of land that delivers runoff water, sediment and dissolved substances to a river.

A watershed is a hydrological unit that catches, stores and releases water through networks of streams into the main rivers, which finally end in their estuaries by the sea.

A watershed is also an integration of ecosystems of flora and fauna, land and water and their mutually interacting elements.

Watershed Management Plan

A sound watershed management plan will provide the frame for harmonizing economic development and environmental protection. It will also integrate socio-economic and cultural realities, institutional structures and the biological aspects into upland protection and conservation in order to attain sustainable development.

A watershed management plan provides actions to

- protect a watershed or prevent damage to it
- mitigate the effects of land use to an acceptable level
- restore degraded environments
- optimize the availability of water resources

Integrated watershed plans have to be based on a complete inventory of the country's physical and human resources. A multidisciplinary approach has to be followed and the objectives of the plan should not be limited to prevention of watershed degradation. Increased production from the land on a sustained basis and a general improvement of the standard of living for the people living in the catchments must be an integral part.

1.1 Definitions of Watershed Management

Watershed management is the comprehensive development of a watershed (basin) so as to make productive use of all its natural resources and protect them. This includes land improvements, rehabilitation and other technical works as well as the human considerations.

Watershed management is defined as the analysis, protection, repair, utilization and maintenance of drainage basins for optimum control and conservation of water in relation to other resources.

1.2 Water as the Integrator

There is no aspect of environmental concern that does not relate in some way to water. Land, air and water are all interrelated as are water and all life forms.

Water is the inextricable link in the environment it is essential to all life and it is one common element in nearly every development.

In land development there is usually an increased demand for water. Similarly higher economic development invariably brings about higher water use. Consequently the proper management of water resources is an essential component of development. One viewpoint is that water is the best index of 'watershed management', that is, a basin properly managed for water is also likely to be properly managed in other ways. Water is an excellent monitoring mechanism as it reflects the state of the watershed.

2.0 THE HYDROLOGIC CYCLE

It is quite clear that a knowledge of hydrologic principles is a requisite for dealing with the diversity of issues in a watershed since hydrology encompasses the occurrence, distribution, movement and properties of the waters of the earth. As already stated, water and environmental issues are inextricably linked and it is important to clearly understand how water is affected by and how water affects the ecosystem.

The hydrologic cycle describes the various paths water may take during its continuous circulation from ocean to atmosphere to earth and back to ocean. Water is only temporarily stored in streams, in lakes, in the soil and as groundwater.

The watershed equation is :-

$$P = I + F + E + T + Q \pm S$$

P is precipitation, I is interception, F is infiltration, E is evaporation, T is plant transportation and Q is runoff and S is storage.

Atmospheric moisture is one of the smallest storage volumes of the earth’s water, yet it is the most vital source of freshwater for humankind. The distribution and amount of precipitation (P) depends on air mass circulation patterns, distance and direction from large water bodies and local topography.

Precipitation may be intercepted or captured by leaves, twigs, stems and soil surface organic matter and returned to the atmosphere as water vapour. This process known as interception (I) does not help to recharge soil moisture or generate streamflow in fact it lessens the impact of the raindrop on the soil surface and the danger of soil erosion.

When water reaches the ground surface, a portion of it is absorbed by the soil. Infiltration (F) is the process of water seeping into the soil and is controlled by surface soil conditions, such as soil texture, vegetation type and land use.

The table following shows the high rates of infiltration of various forest floors compared to the infiltration rates of pastures.

Table—Infiltration Rates of Forest and Pasture

Habitat	**Capacity**
Undisturbed forest floor	60
Forest floor without litter and humus layers	49
Forest Floor burned annually	40
Pasture, unimproved	24
Old pasture	43

Source: In handbook of Applied Hydrology, V.T. Chow, ed., Mc Graw – Hill, New York, 1964.

However the movement of water through soil, referred to as percolation, is largely independent of factors controlling infiltration. Once precipitation intensity exceeds the infiltration rate, the excess precipitation becomes surface runoff.

Water losses by evaporation (E) and Transpiration (T) are often combined in the single term evapotranspiration (ET).

Watershed shortage (S) is the temporary detention of water in a drainage basin. Water may be stored in surface depressions and as soil moisture or groundwater.

Streamflow or runoff (Q) is the portion of water that is left over after evapotranspirational needs are met, given no change in storage.

(Subsurface stormflow is that water that has infiltrated and moves laterally through the soil profile because water in the soil is beyond field moisture capacity).

Baseflow is the portion of precipitation that percolates through the soil and is released slowly, thereby sustaining streamflow during periods without precipitation. Baseflow often cannot be separated from the subsurface stormflow.
The short life of ephemeral streams are attributable to insufficient moisture retention by the basin soils or to precipitation that is insufficient to generate streamflow year round.

Streamflow is a temporal and spatial integration of the hydrologic cycle processes and represents the volume of water passing a given point in the watershed over a specific time. It is usually represented as Q, with units of cubic meters per second.

A graphical representation of changes in stream discharge with time is called a hydrograph. The length of time for a given hydrograph may vary from hours to months. The hydrograph is commonly used to determine total water yield, that is, the volume of stream discharge distributed over the watershed area.

Special mention must be made of the hydrograph as Hydrograph Analysis is the most widely used method of analyzing surface runoff. A knowledge of the magnitude and time distribution of streamflow is essential to many aspects of water management and environmental planning.

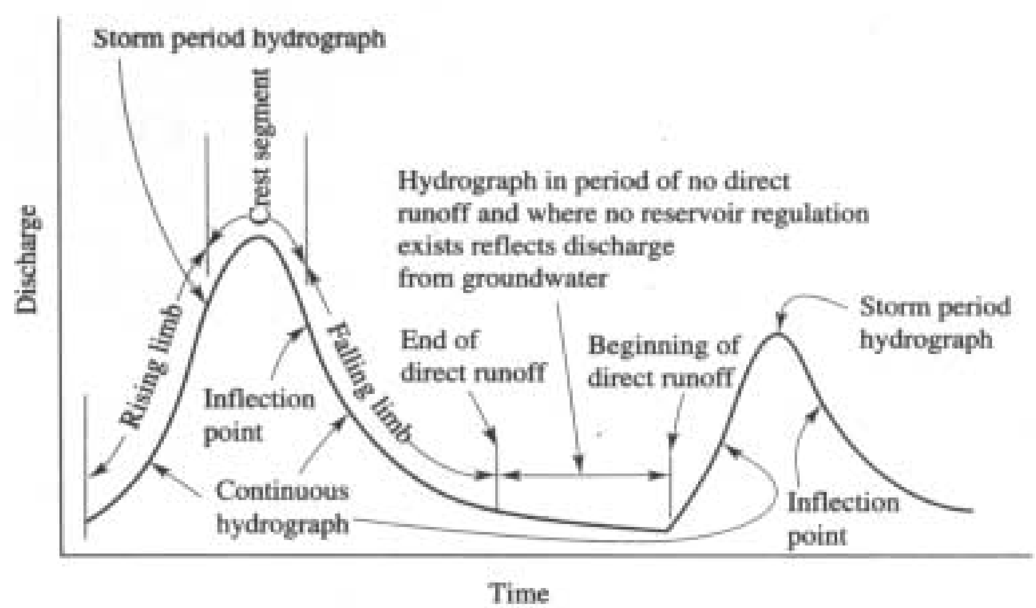
A streamflow hydrograph provides

- the rate of flow at all points in time during and after a storm or precipitation event
- peak flow rates so that hydraulic structures can be designed to accommodate flow safely
- the total volume of water passing a point of interest during the time interval by integration of the area beneath the hydrograph between any two points in time (the hydrograph plots volumetric flow rates against time).

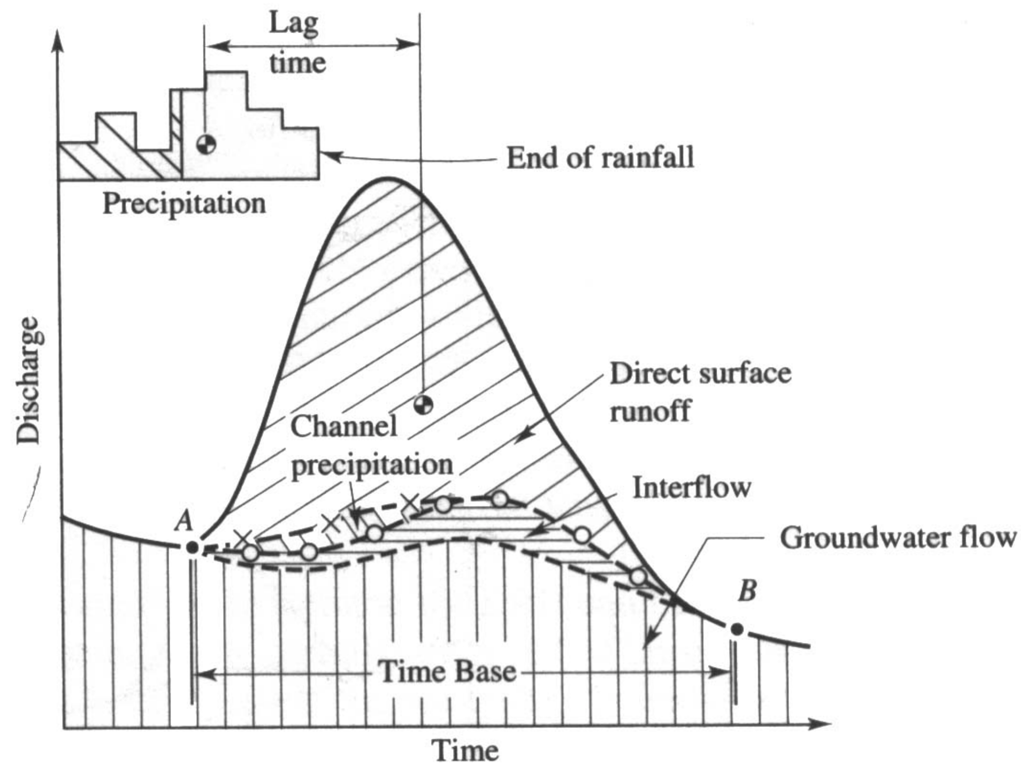
- for the analysis of sizes of reservoirs, storage tanks, detention ponds and other facilities that deal with volumes of runoff

A hydrograph has four component elements
(i) direct surface runoff (ii) interflow (iii) groundwater or baseflow
(iv) channel precipitation

The rising portion of a hydrograph is known as the concentration curve; in the vicinity of the peak is called the crest segment and the falling portion is the recession. The shape of a hydrograph depends on precipitation pattern characteristics and basin properties.



Hydrograph definition.



Components of the hydrograph.

3.0 MANAGEMENT APPROACHES

Watershed management often depends on the management of other resources, as any landuse within a watershed may affect the water resources. Good land management therefore implies good watershed management. Land uses and their effects on water resources may change water yield and/or water quality.

As human population and associated consumer needs increase the demands for water resources increase. With limited water resources and the pursuit of sources of new water, land management techniques designed to increase water yield are becoming more important.

3.1 Water quality

Water from undisturbed forested watershed is often considered by the public to have excellent quality whereas water form watersheds with various land uses are often perceived as having less desirable quality. Water quality like stream flow represents a temporal and spatial integration of hydrological processes.

Nonpoint water pollution can only be controlled by managing the type of activity that takes place on a watershed. Many nonpoint sources of pollution are present naturally in varying qualities. Therefore policy and legislation should aim to ensure that streams maintain or progress toward the state in which they existed when the ecosystems were in their pristine state.

The most effective unit available for prevention and control of nonpoint source pollution constitutes what in known as a Best Management Practice. (BMP)

Practices are examined with appropriate public participation for practicality and effectiveness in preventing or reducing the amount of pollution generated from nonpoint sources to a level compatible with water quality goals.

Careful consideration must be given to actions taking place over a period of time, which may be individually minor but collectively significant.

It must also be noted that cumulation impacts to a stream transcend ownership boundaries – this is of particular concern where no single agency or owner has total regulatory authority.

3.2 Watershed Degradation

Integrated Watershed management has been identified as the approach to be followed to address watershed degradation. Land use planning and soil and water conservation techniques are important elements in the broader logical framework.

Land use and Conservation Measures

The recommended land use as in the UNDP/FAO 'Guidelines for Preparation of Integrated Watershed Management Plans', which is still valid, states that for slopes less than 5^{O} (without conservation measures) is intensive agriculture, on slopes between 5^{O} and 10^{O} annual crops can be grown and some conservation practices may be needed. Slopes of 10^{O} to 20^{O} are also suitable for annual crops provided that intensive soil conservation measures are taken. Slopes between 20^{O} and 30^{O} should be reserved for agroforestry, while slopes steeper than 30^{O} should remain under forest.

Conservation practices that can be applied are :-

Engineering practices –	hillside ditching, construction of individual basins, bench terracing, construction of checkdams;
Agronomic practices –	mulching, minimum tillage, minimum weeding, contour ploughing, contour cropping and the use of vegetative buffers

Agro forestry recommended for slopes between 20^{O} and 30^{O} is the combined cultivation of trees for fruits, fuel, food or timber and annual crops. Through tree selection suitable spacings and simple soil conservation techniques, soil erosion can be minimised and production levels can be maintained on marginal lands with relatively low inputs. Reforestation used for addressing the problems of erosion and flooding has as its primary objective protection of the watershed.

Land capability, based on slope, soil depth and other soil characteristics, forms the basis for the assessment of the recommended land use and required soil conservation practices.

Soil conservation measures include bonding, strip cropping construction of contour drains, construction of graded drains, contour planting and the construction of vegetative barriers.
The conservation technique that should be applied at a specific location depends very much on the local circumstances.

SUMMARY OF THE MAJOR HYDROLOGIC EFFECTS OF LAND-USE CHANGE

Land-use change	Component affected	Principal hydrologic process involved	Geographic scale and likely magnitude of effect
Afforestation (deforestation has converse effect except where disturbance caused by forest clearance may be of overriding importance)	Annual flow	Increased interception in wet periods Increased transpiration in dry periods through increased water availability to deep root systems	Basin scale; magnitude proportional to forest cover, world average is 34 mm year ' reduction for 10% increase in forest cover
	Seasonal flow	Increased interception and increased dry period transpiration will increase soil moisture deficits and reduce dry season flow	Basin scale; can be of sufficient magnitude to stop dry season flows
		Drainage activities associated with planting may increase dry season flows through initial dewatering and also through long-term effects of the drainage system	Basin scale; drainage activities will increase dry season flows
		Cloud water (mist or fog) deposition will augment dry season flows	High-altitude basins only; increased cloud water deposition may have a significant effect on dry season flows
	Floods	Interception reduces floods by removing a proportion of the storm rainfall and by allowing buildup of soil moisture storage	Basin scale; effect is generally small but greatest for small storm events
		Management activities: cultivation, drainage, road construction, all increase floods	Basin scale; increased floods for all sizes of storm events
	Water quality	Leaching of nutrients is less from forests through reduced surface runoff and reduced fertilizer applications	Basin scale; variable but leaching can be an order of magnitude less than from agricultural land
		Deposition of most atmospheric pollutants is higher to forests because of reduced aerodynamic resistance	Basin scale; leads to acidification of catchments and runoff
	Erosion	High infiltration rates in natural, mixed forests reduce surface runoff and erosion	Basin scale; reduces erosion
		Slope stability is enhanced by reduced soil pore water pressure and binding of forest roots Windthrow of trees and weight of tree crop reduce slope stability	Basin scale; reduces erosion Basin scale; increases erosion

		Soil erosion, through splash detachment, is increased from forests without an understory of shrubs or grass	Basin scale; increases erosion
		Management activities: cultivation, drainage, road construction, felling, all increase erosion	Basin scale; management activities are often more important than the direct effect of the forest
	Climate	Increased evaporation and reduced sensible heat fluxes from forests affect climate	Micro, meso, and global scale; forests generally cool and humidify the atmosphere; a 2ºC increase in regional temperature is predicted for Amazonia if deforestation continues
Agricultural intensification	Water quantity	Alternation of transpiration rates affects runoff Timing of storm runoff altered through land drainage	Basin scale; effect is marginal Basin scale; significant effect
	Water quality: fertilizers	Application of inorganic fertilizers	Basin scale; increased nutrient concentrations in surface and groundwaters
	Pesticides	Application of nonselective and persistent pesticides poses health risks to humans and animal life	Basin, regional, and global scale; effects can be long lasting
	Farm wastes	Inadequate disposal of farm organic and inorganic water pollutes surface and groundwater bodies	Basin scale; effect on groundwater and surface waters
	Erosion	Cultivation without proper soil conservation measures and uncontrolled grazing on steep slopes increases erosion	Basin scale; effects are very site-dependent
Draining wetlands	Seasonal flow	Upland peat bogs, groundwater fens, and African dambos have little effect in maintaining dry season flows	Basin scale; drainage or removal of wetland will not reduce, and may increase dry season flows

Source : After Moudment, D.R., Handbook of Hydrology, Mc Graw – Hill, Inc., 1993.

4.0 HOW TO INTEGRATE

There are essentially three (3) factors in initiating integrated development efforts:

a) The existing level of development, from a technical viewpoint;
b) The local social structure and human behavioural patterns;
c) The prevailing economic conditions.

The integration strategy for a watershed can be carried out by various procedures. However a first step is usually a resource survey or inventory. This attempts to answer the question of the supply and demand for resources both natural and human resources. Depending upon the area involved, a survey may include socio-economic characteristics, soil characteristics, land capacity/suitability classifications, forest and other vegetation inventories, erosion appraisals, flood information, hydrological assessment including climate characteristics, water use and other parameters as needed. No inventory system is likely to fit all needs. The amount of detail included will vary according to objectives and available information.

Of note is that the purpose of any data collection scheme must be very clear from the start. A minimum number of parameters or, even better, indices to describe the existing conditions should be selected. Before data collection, the sampling design and analytical techniques to be used should be established.

The following outline illustrates the different kinds of information that may be included in a Watershed Inventory.

Watershed Inventory
Name of watershed:
Location:
Tributary to:
Area:

I. Human elements
- A. Land ownership, use and development
  - 1. Ownership – maps
  - 2. Ownership – statistical and descriptive
    - a. Public
      - (1) Area by agency
      - (2) Use; demands, including special use

b, Private
(1) Areas by class of owner
a. corporate & large pvt
b. medium
c. small
(2) Use and demands
3. Cultural features – maps and descriptive: roads, railroads, communication and transportation
Dams, reservoirs, canals
Cities and towns

B. Population – statistical, descriptive
1. Numbers
In watershed
Out of watershed but using goods or services
2. Sources of livelihood and use of watershed resources
a. Wood
Number, kind of activity, value, problems
b. Forage
Number, kind of activity, value, problems
c. Wildlife
Number, kind of activity, value, problems
d. Recreation
Number, kind of activity, value, problems
e. Minerals
Number, kind of activity, value, problems
f. Water
Law: kind, ownership of rights
Uses: Domestic and municipal – who, how much, where, value
Agriculture – who, how much, where, value
Industry – who, how much, where, value
Recreation & Wildlife – who, how much, where, value
Problems: Quantity – who, how much, where, value
Regimen – who, how much, where, value
Quality – who, how much, where, value
3. Social conditions
a. History and traditions
b. Organizations – social, political, fraternal, etc.
c. Technical and educational status
d. Leaders: their characteristics and outlook
e. Planned developments

II. Watershed
A. The physical setting – maps, statistics and description
1. Topography and drainage system

2. Land forms and geology
3. Soils
   a. Hydrologic depth (storage characteristics)
   b. permeability and internal drainage
   c. surface characteristics (infiltration and erodibility)
   d. mass stability
   e. Soil mechanics and other engineering characteristics

B. Climate – local – may require interpolation on basis of general relationships (maps, statistics and descriptive)
1. Precipitation
   a. rainfall
      (1) amount, seasonal distribution, intensity-duration-frequency, drought
   b. snowfall
      (1) amount, areal distribution and accumulation, temporal accumulation and melt patterns
   c. other factors
      (1) cloud-drip, prevailing storm path and wind direction, rain-shadows, etc.
2. Energy sources and partitioning
   a. Irradiation distribution – areal and temporal
   b. Advected heat (air mass movement pattern) latent and sensible, temporal characteristics .
   c. Temperature – temporal and areal distribution, including means, extremes, length of "growing season," etc.
   d. Potential water losses
      (1) evaporation data (empirical)
      (2) water balance models (theoretical)

C. Runoff
1. Quantity – total, seasonal; measured or estimated
2. Regimen
   a. High How – peaks, volumes, frequencies, time of concentration, by location and cause
   b. Low How – amount, duration, frequency, by location
3. Quality
   a. turbidity and sediment
   b. contaminants other than sediment
   c. temperature
   d. other physical, chemical, and biotic characteristics that may be important (dissolved O„nutrients, algae, Bsh, pH, etc.)

D. Channel characteristics (including flood plain)
1. density
2. shape of drainage net
3. gradient
4. orders

5. capacities – channel and flood plain
6. nature of bed – shape, materials
7. condition (erosion classes)
8. areas of effluence and influence, springs

E. Vegetation

1. Forest or woodland (include unstocked, but capable of supporting forest or woodland)
   a. Overstory
      (1) type
      (2) stocking (density)
      (3) age or size class
      (4) site quality
      (5) hazards (insects, disease, fire)
      (6) successional status
      (7) special features (wildlife, recreation)

   b. Understory and litter
      (1) type of understory
      (2) density
      (3) age or size class
      (4) browse or grazing value
      (5) ground cover
         (a) type (litter, grass, rock, bare soil, etc.)
         (b) depth (litter)

2. Rangeland
   a. types
   b. density (by species or range types)
   c. productivity (by species or range types)
   d. browse or grazing values
   e. condition
   f. ground cover (as above)
   g. season of use
   h. special features

F. Wildlife (by species)

1. kinds and amounts, location
2. habitat conditions
   a. Food
      (1) kind
      (2) amount
      (3) availability in time and space
   b. Cover
      (1) kind
      (2) amount
      (3) dispersion
   c. Waters

d. Other

G. Other factors – amenities, unique values: historical sites, rare plants, geological formations, etc.

4.1 Preparation of the Integrated Watershed Development Plan.

An integrated watershed plan, including technical as well as the human aspects is drawn up on the basis of the inventory.

The analysis for each parameter normally should describe:

- The present status or conditions (e.g. good, poor, etc.)
- The present trend
- The potential (development opportunity for the resource, likely future trends, potential problems, etc.)

The purpose of the watershed analysis should be to develop and interpret memory data in a form that will permit selection of appropriate alternative methods of managing the watersheds.
Integrated planning should be a multi-disciplinary effort.

Some of the base maps, which should be used to prepare a watershed plan, are as follows:

- A topographic map prepared from aerial photographs (a suitable scale is usually 1:10,000)
- A slope map with, say, 0-5, 5-15, 15-35, 35-85 and greater than 85 percent slope intervals
- A soil and land capability map which may include soil types, depths or other details with slope scale and degree of soil management intensity
- An erosion and site degradation map showing the degree, size and stage of degradation as well as the courses, if possible
- A vegetative cover map, including the type of (nature) vegetation and permanent, perennial and annual crops.
- A land use and ownership map. A land use planning map should show the potential land uses as well as the existing land uses.

A watershed development plan is drawn up from this information and it should give priority to sustainable use and development of the natural resources and simultaneously facilitate socio economic development. Overall the objective must be a better standard of living for the present and future generations.

4.2 Coordination

To be able to maintain and manage watersheds at a sustainable level, coordination is absolutely necessary. Therefore creating a strong unit, which has overall responsibility for watershed management and which actively, coordinates the research, monitoring and implementation activities of the various agencies involved in watershed management are strongly supported.

However for a comprehensive watershed development plan to be undertaken on a regional basis, especially in remote areas, decentralizing is important. A central body will not efficiently govern a development project, which requires knowledge of local conditions, demands immediate decisions and depends on contact with the local people.

Coordination is essential at national, regional and local levels. National level coordination should deal mainly with the development policy, legislation, institutional improvements, market promotion, subsidies, credit and other incentives after careful analysis of regional requirements.

Regional level coordination should concentrate on planning and on developing work programmes taking care to assign authority to the departments and agencies concerned. Local level coordination should concentrate on the efficient use of the expertise and available equipment.

4.3 Watershed Management Mechanism

Watershed Management must

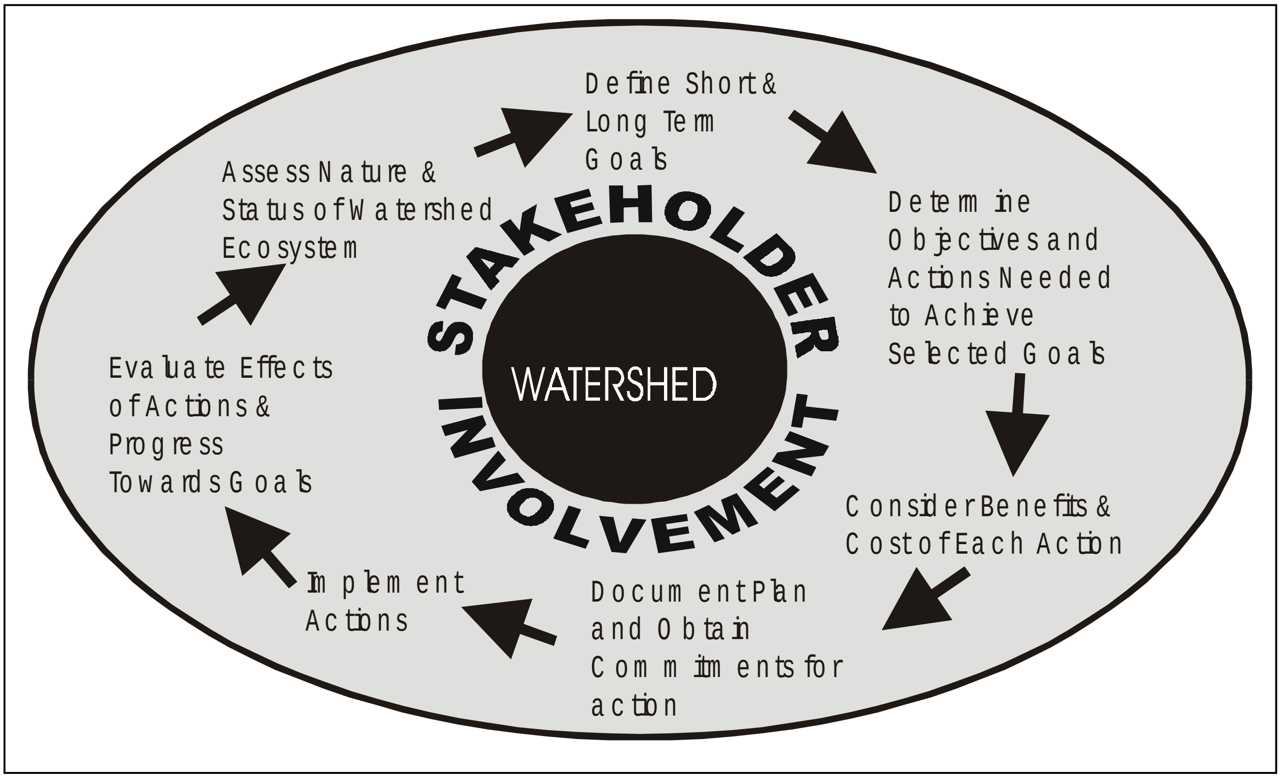
- be undertaken within the framework of integrated development planning and national goals and priorities
- operate within a holistic framework (research, policy, mitigative interventions)
- be intersectoral
- include stakeholder participation in the planning and decision making process
- Be supported by public awareness programs and public education, institutional strengthening and capacity building and application of appropriate technology
- Include data collection, monitoring, feedback and refinement of the management plan

5.0 CONCLUSION

Practically, watershed management is an iterative process of integrated decision-making regarding uses and modifications of lands and waters within a watershed. This process allows for stakeholders to balance diverse goals and uses for environmental resources, and to consider how their cumulative actions may affect long-term sustainability of these resources. The Guiding Principles of the process are Partnerships, Geographic Focus, and Sound Management including strong science and reliable data utilizing programme approach rather than a project approach

Human modifications of lands and waters directly alter delivery of water, sediments, and nutrients, and thus fundamentally alter aquatic systems. People have varying goals and values relative to uses of local land and water resources. Watershed management provides a framework for integrated decision-making, where we strive to: (1) assess the nature and status of the watershed ecosystem; (2) define short-term and long-term goals for the system; (3) determine objectives and actions needed to achieve selected goals; (4) assess both benefits and costs of each action; (5) implement desired actions; (6) evaluate the effects of actions and progress toward goals; and (7) re-evaluate goals and objectives as part of an iterative process.

Watershed management is multidisciplinary and requires among others the use of the social, ecological, and economic sciences. Common goals for land and water resources must be developed among people of diverse social backgrounds and values. An understanding of the structure and historical and current function of the watershed system is required, to effectively consider the ecological effects of various alternative actions. The decision process also must weigh the economic benefits and costs of alternative actions, ensuring long-term sustainability of the ecosystem and a better standard of living for the people..



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APPENDIX I

Overview On The Status Of Watersheds Or Watershed Management In Caribbean Islands

Overall Caribbean Watersheds' Status

(taken from A Synthesis Of Country Reports On Water Resources Management In The Caribbean – IICA, 1999)

- Water demand matches or exceeds maximum annual receivable fresh water resources.
- Rainfall dependent to feed surface intakes and replenish ground water resources.
- Water resources management complicated by local geological conditions
- Quality and quantity of water resources declining partially because of intensive agriculture (especially in the windward islands and Jamaica), accelerated land development, road building and deforestation.
- Urbanization is posing a serious problem in countries with the heaviest reliance on groundwater reserves causing a reduction in opportunities for groundwater rechange and lowering of the groundwater table.

  Heavy demand is promptly the over abstraction of groundwater and causing the water tables to decline thereby increasing opportunities for saline intrusion.
- Upperslope catchment and forest reserves particularly in the higher elevation islands are not adequately protected against deforestation and other often illegal land uses.
- Governments have found it difficult to exercise authority in most protected areas to prevent non – compatible development activities.

Water quality issues – the pollution of water resources is a major environmental problem in most islands.

Major causes of water quality degradation are

- high population densities especially in cities
- changes in land use
- inappropriate disposal of waste – human, animal and household
- climatic changes.

The availability of safe water is regarded as a visible indicator of the environment

Eastern Caribbean states (OECS) and Sub-region.

The main characteristics of the watersheds in the sub-region, especially in the Windward islands, is the fragility of soils and the role forest play in the natural management of the watershed. Because the islands are small, human activities extend up steep slopes and there are many cases of resource use conflicts.

Watersheds are used for agriculture, water supply, timber and forest products (food crops, wild life, fruits) and housing settlements. Watershed problems in the Eastern Caribbean States can be categorized as

- physiological (steep slopes, heavy rains, excessive run off, soil types).
- resource use conflicts.
- end problems (erosion, sedimentation, flood, water pollution)
- socio-economic

Like most of the Caribbean islands, there are no watershed management policies. In addition lands are mainly privately owned and distribution is in small parcels among several owners. Management is therefore difficult since governments have little control over the types of developments activities and land use practices. This together with the absence of a comprehensive land use Policy gives rise to problems of resource use conflicts, especially in watersheds with a supply of drinking water.

Human activities and poor management practices in watersheds have impacted the environment negatively. In addition land clearing for agriculture has resulted in soil erosion, loss of habitat for wildlife and reduction in biodiversity. While pesticides and agro chemicals have entered the water cycle because of the lack of buffer zones along waterways resulting in intensive erosion.

Trinidad & Tobago.

One of the major problems in managing the water resources in Trinidad and Tobago is the continuing watershed degradation. Soil erosion and watershed degradation are increasing at an alarming rate, particularly at the foot hills of the Northern Range. The main reasons for the degradation are the indiscriminant cleaning of forests for housing and urban development, shifting cultivation and squatting, the loss of forest and protective vegetation cover by forest and bush fires, quarrying operations, and road construction and cultivation on steep slopes, without the application of appropriate soil conservation measures. Although some reforestation takes place, the balance is negative.

Knowledge of erosion rates under different land use and soil and slope conditions is indispensable to design an appropriate watershed management programme for degraded areas. For areas, which are not yet degraded, environmental conditions must be known to design a management plan and specific measures which will prevent degradation in the future.

Insufficient information is available on catchment sediment yields, and quantitative assessment of the effects of soil erosion and catchment degradation is lacking because of scarce data on soil productivity, changes in sedimentation rates of rivers and reservoirs and on changes in the hydrological response of the catchments to rainfall.

The impacts on the water resources sector are related to sediment yields in rivers and canals and changes inn the distribution of the total catchment runoff over peak flows and baseflows. High sediment yields increase the cost of the treatment of water for domestic and industrial use. Also, sedimentation decreases the discharge capacity and increased the risk of flooding. Flood risk has also increased as a result of increased flood peaks, while low flows have decreased, leading to more serious water shortages in dry season.

Jamaica.

Watershed Conditions and Effects	*Causes*
Landslides and slope failures	Steep slopes, thin or erosive soils crumpled by heavy and high intensity rains.
Inappropriate use of slope	Agricultural activities – farming. unsuitable agricultural practices.
Soil loss through soil erosion, siltation of drains and rivers and destructive flooding downstream.	Unsuitable agricultural practices. Farmers do not consider protection and conservation of natural resources because of a lack of agricultural education, incentives and insecurity of land tenure
Increased demand and pressures on the land and water resources.	Growth in industrial and agricultural activity increased population and urbanization
Increased water pollution.	Crop expansion, increased use of agro and industrial chemicals, improper disposal of sewage effluents.
Removal of trees	For resettlement Programmes and For squatter settlements.
Deforestation (Illegal removal of forest cover)	For lumber, charcoal production etc. and in forest fires due to extended dry periods (drought).

Increased surface runoff	Excavation of slopes, diminished vegetation cover, compacted soils.
Floods in the wet season	Heavy rains resulting in loss of property, crops and to a lesser extent lifes.

The above has resulted in

- polluted rivers, beaches and harbours
- degraded coral reefs ultimately affecting the tourism industry adversely
- heavy siltation of rivers, reservoirs, irrigation canals, water intakes as well as harbours

APPENDIX II

Challenges of Small Island Developing Countries

Small island developing states share many of the same problems experienced elsewhere but have additional ones caused by

- Limited water availability.
- Limited land and increasing populations, which put extreme pressure on water producing areas/ protection zones.
- Vulnerability to natural hazards (hurricanes, storms, earthquakes)
- Vulnerability to climate variability and change (e.g. Sea level rise)
- Vulnerability to over extraction of ground water.
- Vulnerability of groundwater to biological and chemical contamination from human settlement.
- Developing status of most small island nations.
- Dependence of small islands for economic development on tourism in many of the countries.

Islands are one of the most hydrologically dynamic and vulnerable physical environments in the humid tropics. Changes in land use or waste disposal can often times manifest as impacts in water quality within less than a day.