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Appendix 1.

TRAINING COURSE CONSTRUCTION

To work through all the exercises in this text would require about six weeks of field and drawing office/laboratory time, preceded by considerable preparatory effort from the tutors. When only shorter training periods are available, it will be necessary to select the most appropriate exercises for demonstrating the required concepts or skills. This selection can be made by the training course organiser, but the following comments are intended as guidelines.

1. One to two day courses:

The majority of exercises, apart from those in Chapter 3, can be completed in one or two days. If taken in isolation for this type of use, the tutor may need to provide additional introductory background materials.

2. One week courses:

Two approaches can be made to use of the Workbook over five to seven days.

(a) Using the first exercise in each chapter. This will expose students to the major concepts in coastal zone management. The lead exercises can be linked together by enlarging upon the introductory section of the chapter and the exercise background materials through a lecture or tutorial-type presentation.

(b) Using all exercises in any one chapter. Four or more exercises are presented in most chapters, and these deal with different aspects of major topics, e.g. Chapter 4 treats four aspects of Coastal Ecosystem Management, viz. status, habitat evaluation, resource yields and recovery of damaged resources. These four exercises can be extended by use of suggested alternative (i.e. additional) exercises. Chapter 5, with only two exercises presented, has alternative exercises which would take one or two additional days to complete.

3. Two weeks, or longer courses

Two week courses could be formulated by linking two or more chapters and carrying out the major exercises. Chapter 3, Natural Area Management, is designed for a minimum two weeks work, and is best taken as a whole as the exercises follow one another closely.

In all cases, the length of time to be devoted to any exercise depends on the sophistication of the students and the amount of prior preparation by the tutor. It should be emphasised, however, that the collection of data by field work, laboratory experimentation, library search and questionnaire is an important part of training experience; and that the essentially practical nature of the exercises should be retained as far as possible.

Figure Ap1.1 shows how selection of exercises can be made in order to construct an extended training course. From this diagram, it will be apparent that most exercises have "pre-requisites", i.e. for concepts and skills to be developed logically the exercises should be carried out in order. For example, a resource assessment cannot be made effectively before a resource inventory has been completed; and, similarly, advanced planning for a marine park must be preceded by agreement on the management objectives for the park. If single exercises are to be used, during short courses, the tutor must ensure that this pre-requisite information has been supplied and understood.

....

Level	Concept and/or skill	Chapter 1	Chapter 2	Chapter 3	Chapter 4	Chapter 5
1	Scoping	1				
2	Resource inventory	2	1	1 + 2		
3	Resource assessment, Data organisation & representation	3	2 - 4	3 + 4	1 + 2	
4	Analysis & Management decision-making		5	5	3	1
5	Advanced planning			6 - 8	4	2

(Exercises)

FIGURE Ap1.1 GUIDE TO EXERCISE SELECTION FOR TRAINING COURSES (arrows show some possible pathways)

Appendix 2.

GUIDELINES FOR CONDUCTING AERIAL SURVEYS OF COASTAL FEATURES

Aerial surveying is particularly valuable for observation of short-term coastal phenomena or occasional events. It has been used successfully to examine wave and current patterns in the nearshore environment, in the latter case going aloft to track the spread of dyes like fluorescein or rhodamine B which had been released some hours earlier. Aerial survey is an accepted method of inventorying many animal populations, such as resident and migratory shorebirds, manatees, dolphins, some of the larger pelagic fish and sharks, and also sea turtle nests. In a similar way, it can be used to count visitors on recreational beaches or concentrations of fishermen. Where recent aerial photographs are not available or maps have insufficient detail, the coastal manager can upgrade baseline data in a rapid and cost-effective way from the air.

Detailed guidelines for conducting aerial surveys of beaches were contained in the Manual of Sea Turtle Research and Conservation Techniques (Pritchard, Bacon, Berry et. al. 1983), prepared for the Western Atlantic Turtle Symposium. The guidelines which follow are a simplified version based on that manual, and are reproduced by kind permission of the publishers (Center for Environmental Education, Washington).

1. Decide on your **objectives**, i.e. what precisely do you want to observe, study or record.

2. Choose the type of **light aircraft** that you need .

    (a) The size is determined by the numbers of observers i.e. pilot plus one, two or three passengers.
    (b) A single engine, four seat, wing above cockpit aircraft is highly recommended.
    (c) If there is to be extensive flying over water twin-engine aircraft provide a greater degree of safety.
    (d) Helicopters permit hovering for longer-period observation, but are expensive.
    (e) It is recommended that the military or coast guard be approached for use of helicopters, as their pilots are frequently expert at observational flying and have good knowledge of island coastlines.

3. **Before the flight,**

(a) ensure that the pilot is familiar with your objectives. Plan your route in consultation with the pilot
(b) Ask the pilot to keep you informed continuously of your location relative to the charts, the plane's altitude, flight path and speed. Check the plane's fuel capacity in relation to the desired survey time.
(c) Check the local weather conditions
(d) Ensure that safety equipment has been provided and that you are familiar with safety procedures

4. **Survey personnel**

(a) A team of three observers is most versatile, as there can be one each on the left and right sides plus one recording information.
(b) Alternatively, there can be one observer, with the second person checking observations and keeping the records.
(c) If you are conducting a solo survey, it is advisable to have a tape recorder for keeping records, which can be transposed later on or to use a camera. Check this when on board to ensure it is recording clearly above the aircraft noise. A hand- held digital counter may be useful also for certain types of data collection.
(d) If aerial survey is to be conducted frequently, observers should check each other's reliability, especially with inexperienced observers, and factor this into the results,

5. **Time of survey**

The best time to survey the coastline from the air is early morning, from full sunrise to about 1000 hours. After this, reflection from the sea surface, beaches and vegetation obscures details. There may be a haze developed by late morning, continuing through the afternoon, especially during the wet season. For certain observation beach, the optimum time for observations should be ascertained in advance from ground survey.

6. **Speed, altitude and distance offshore**

These parameters are determined by the objectives of the survey. Most observers will want to fly as slowly as possible, and the safe speed/stalling speed must be ascertained from the pilot.

(a) For most observations of animal populations, ecosystems, coastal oceanographic and human activities, the plane should fly at about 80 knots, at an altitude of 1,000 ft, at a distance offshore that forms a 45 angle to the feature being observed, i.e. about 250-500 ft to the side of the feature.

(b) Visibility is normally best if the pilot flies with the sun behind the plane or with the plane between the sun and the feature being observed, i.e. the east coasts of islands give best results from morningtime surveys.

(c) When surveying greater distances, fly at a greater altitude.

7. **Data recording**

Observing from a fast moving aircraft and keeping notes simultaneously is difficult. It is advisable to have data recording forms prepared in advance, and these should be designed to suit the survey requirements. An example, used during sea turtle aerial beach survey to describe shoreline characteristics, is given as Table Ap2.1.

Table Ap2.1. Sample Aerial Survey Data Recording Form

Sea Turtle Aerial Beach Survey

Form 1: ZONE RECORDS Page___of_____

Country______________ State____________ Date(s)_____________

Chart(s) Used____

Observers(s)____

Recorder(s)____

Zone Name or Number	Zone Landmarks Start	End	Distance KM-NM	Lat	Long	Shoreline Characters

etc.....

Table Ap2.1 continued...

Form 1 Explanations

a. Country and State. Write these in. They will be computer-coded in subsequent analysis of the entire area.
b. Date(s). Of form preparation or when the flight(s) was made.
c. Chart(s) Used. Give source, number, scale.
d. Observer(s). List names of all involved in formulating this form.
e. Recorder(s). List names of people filling out form.
f. Headings(s). Give from start to end in approximate degrees or positions. In circling an island, headings will be inclusive.
g. Zone Name or Number. Before starting an aerial survey, the coastal zone should be divided into zones. Zones should be numbered serially and may be of different lengths. Zone borders should be based on permanent, easily recognised landmarks, which are shown on the charts.
h. Zone Landmarks. The name of a permanent physical feature (either natural or man-made) easily seen from the air is written in the "start column." When zones are continuous, the landmark at the "end" of one zone will be the "starting" landmark for the next zone. When areas are discontinuous, the new landmark is written in the next row and the zone name or number is repeated.
i. Distance KM-NM. This is the shoreline distance of the zone in kilometers or nautical miles. The time taken to travel this distance should be measured also.
j. Lat. Long. The latitude and longitude in degrees and minutes (to the nearest tenth minute) are calculated from a chart and recorded for the start of the zone.
k. Shoreline Characteristics. This is a synopsis of the characteristics of the shoreline that occur in each zone. Where more than one type of shoreline occurs along a zone, either record the dominant type or give the different types in estimated percentages.

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8. As many as possible of the aerial survey observations should be ground-truthed immediately after returning to base, as a check on observer reliability. Alternatively, a second team could be ground-truthing concurrently.

Appendix 3

SIMPLE WAVE THEORY

Introduction:

The effects of water waves are of the greatest importance to several coastal processes. However, when one examines waves in the ocean they often appear confused and constantly changing. This is particularly true while the waves are under influence of the wind, because of the presence of several wave fields. Actual water wave phenomena are complex. i.e. they are difficult to describe mathematically.

In order to deal with these phenomena a "simple wave", i.e. one which can be described in simple mathematical terms, is assumed. Several "simple" wave theories have been developed. The most elementary theory, referred to as linear wave theory, was developed by Airy. This wave theory assumes a sinusoidal wave form, and is applicable over a wide range of conditions. For shallow water conditions, sinusoidal wave theory predicts the waveform and associated conditions rather well, although there are difficulties in making the computations. At the limit of cnoidal theory, certain aspects of wave behaviour may be described satisfactorily by solitary wave theory. The solitary wave theory is particularly useful for describing conditions in the breaking zone, and is easy to use.

Some Definitions and Classifications

Definitions

Complex waves	- waves which cannot be described in simple mathematical terms.
Simple wave	- a wave which can be described in simple mathematical terms.
Periodic wave	- a wave whose motion and surface profile recur in equal periods of time.
Progressive wave	- a wave form which moves relative to the fluid.
Direction of propagation	- the direction in which the wave form moves.
Complete standing wave	- a wave form which merely moves up or down (clapotis) at a fixed position.

Classifications

Many types of action create disturbance, and hence wave action in the sea, viz.:

Attraction of sun and moon - Tides
Deep sea earthquakes - Tsunamis
Wind blowing over water - Wind Waves

Tides have periods of the order of 12 hours; tsunamis have periods of the order of 15 minutes; while wind waves generally have a period of less than 0.1 second to greater than 5 minutes. There are several restoring forces which attempt to bring the sea surface back to its equilibrium postion after it has been disturbed. The wind waves are classified by these restoring forces, which are :-

(a) Coriolis force - This acts on the longer wind waves.
(b) Surface tension - This acts on the very short wind waves.
(c) Gravity force - This acts on the high energy portion of the wind waves i.e. waves of period 1 to 30 seconds.

Gravity waves can be further separated into two states:

(a) Seas - when the waves are under the influence of wind in a generating area.
(b) Swell - when the waves move out of the generating area, and are no longer subject to significant wind action.

When dealing with coastal processes or determining wave forces on structures, we are usually interested in gravity waves i.e. waves of period 1 to 30 seconds. In particular, waves of period 5 to 15 seconds occur with great regularity. These are either :-

(a) Simple, periodic, progressive gravity waves.
(b) Simple, periodic, standing gravity waves.

Linear Wave Theory

Descriptions and Definitions - Figure Ap3.1 shows

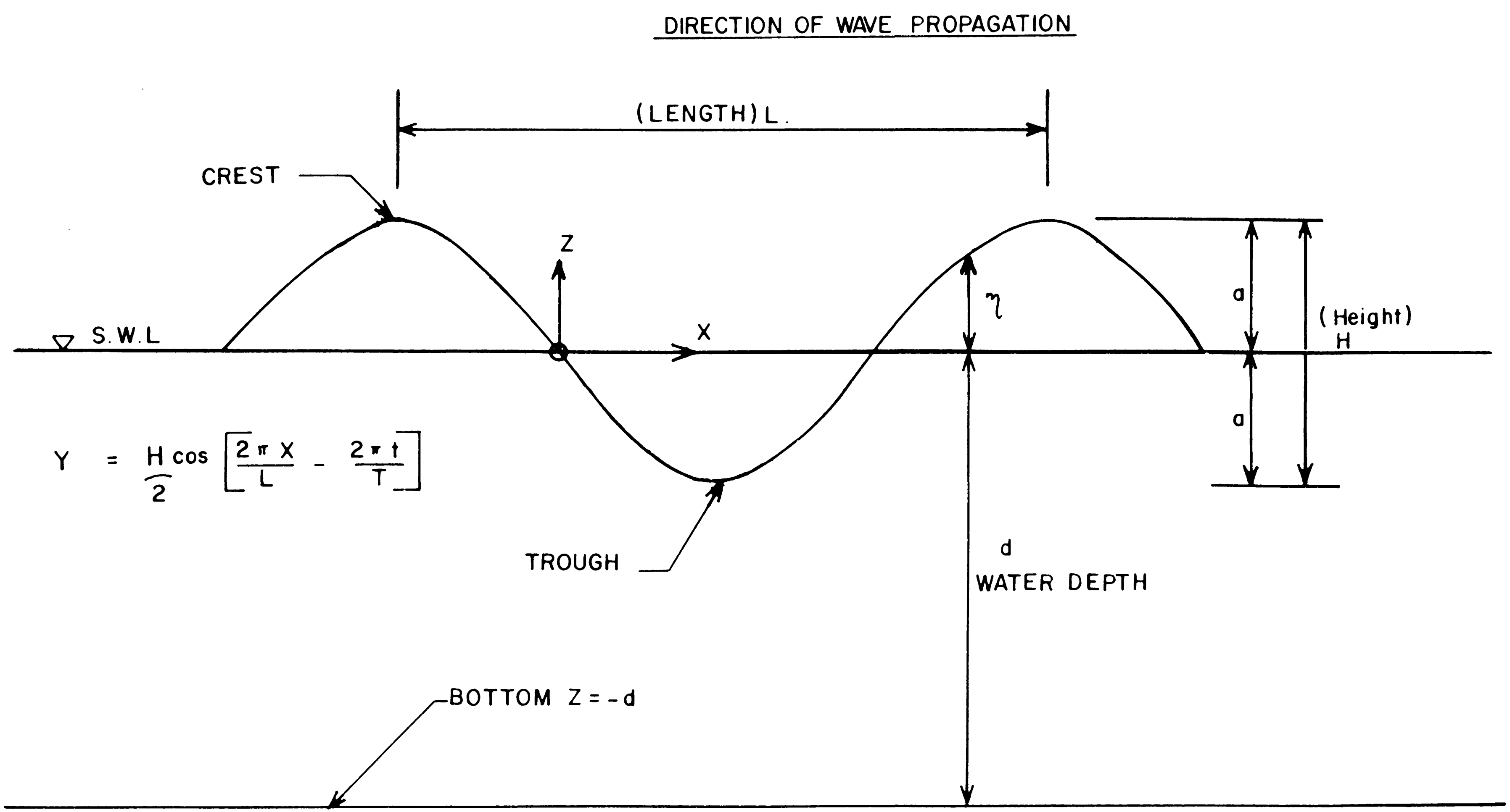

FIGURE Ap 3.1 DEFINITION OF TERMS LINEAR WAVE THEORY the simple progressive wave propagating in the x - direction. The equation of the wave profile is :-

$$y = \frac{H}{2} \cos\left[\frac{2\pi x}{L} - \frac{2\pi t}{T}\right] \quad (3.1)$$

where y = displacement of water surface relative to still water level (S.W.L.)
H = wave height (vertical distance from crest to trough)
L = wave length (horizontal distance between corresponding points on two successive waves)
T = wave period (time for two successive crests to pass a given point)
d = depth (distance from bed to still water level)

Wave Celerity, Length and Period

The speed at which a wave form propagates is termed the wave celerity, C.

$$C = \frac{L}{T} \quad (3.2)$$

The general equation for the celerity of gravity waves is:-

$$C = \left[\frac{gL}{2\pi} \tanh\left(\frac{2\pi d}{L}\right)\right]^{1/2} \quad (3.3)$$

where $g = 9.80665 \text{ m s}^{-2}$

when $d/L \geq 0.5$ $\tanh\left(\frac{2\pi d}{L}\right) \longrightarrow 1.0$

and $C_o = \left(\frac{gL_o}{2\pi}\right)^{1/2}$ DEEP WATER WAVES (3.4)

The subscript is used to represent deep water conditions.

When $d/L \leq 0.04$ $\tanh\left(\frac{2\pi d}{L}\right) \longrightarrow \frac{2\pi d}{L}$

and $C = (gd)^{1/2}$ SHALLOW WATER WAVES (3.5)

Equation 3.3 is used for TRANSITIONAL WAVES, i.e.

$0.04 < d/L < 0.5$

From Equation 3.3. we obtain:-

$$L = \frac{gT^2}{2\pi} \tanh\left(\frac{2\pi d}{L}\right) \qquad (3.6)$$

And from Equations 3.2 and 3.4 we get:-

$$L_o = \frac{gT^2}{2\pi} \qquad (3.7)$$

Now, T remains constant throughout the travel of a wave form; moreover T is easily measured. Hence L_o, the wave length in deep water, can be determined easily. The following relationship is used to determine the wave length at any depth, once the wave period is known:

$$d/L_o = d/L \tanh\left(\frac{2\pi d}{L}\right) \qquad (3.8)$$

The term d/L has been tabulated as a function of d/L_o by Weigel (1948), and is presented as Appendix C in Volume 111 of the Shore Protection Manual (CERC, 1984).

Breaking Wave - The maximum height of a wave travelling in deep water is limited by a maximum wave steepness for which the wave form can remain stable. Waves reaching the limiting steepness will begin to break.

In deep water the limiting steepness is given by:-

$$\frac{H_o}{L_o} \simeq 0.142 \qquad (3.9)$$

When the wave moves into shoaling water, the limiting steepness which it can attain decreases. The limiting steepness then becomes a function of the relative depth, d/L, and the beach slope perpendicular to the direction of wave advance. Several investigators have presented empirical equations and curves relating breaker height to wave steepness and beach slope. However, as a first approximation, the following equations are recommended:-

$$H_b/H'_o = \frac{1}{3.3(H'_o/L_o)^{1/3}} \qquad (3.10)$$

and $$d_b/H_b = 1.28 \qquad (3.11)$$

where d_b = depth of water at point of breaking

H_b = breaker height above S.W.L.

H'_o=unrefracted deep water wave height

There are three types of breakers: Spilling, plunging and surging. Spilling breakers break gradually, and are characterized frequently by "white water" at the crest. Plunging breakers are characterised by a curling over of the top of the crest and a plunging down of this mass of water. Surging breakers peak up as if to break in the manner of a plunging breaker; but then the base of the wave surges up the beach face with the disappearance of the collapsing wave crest.

Wave Refraction

Theoretical Considerations - Equation 3.3 shows that wave celerity depends on the depth of water in which the wave propagates. If the wave celerity decreases with depth, wave length must decrease proportionally. Variation in wave celerity occurs along the crest of a wave moving at an angle to underwater contours, because part of the wave in deeper water is moving faster than the part in shallower water.

In addition to refraction caused by variations in bathymetry, waves may be refracted by current or any other phenomenon which causes one part of a wave to travel faster than another. However, quantitative evaluation of the effects of refraction by currents is difficult.

The decrease in wave celerity with decreasing water depth is analogous to the decrease in the speed of light with an increase in the refractive index of the transmitting medium. This analogy has allowed the use of Snell's Law for the preparation of refraction diagrams. Several graphical and numerical procedures are available, but fundamentally all methods of refraction analysis are based on Snell's Law with some simplifying assumptions.

The assumptions usually made are:

(1) Wave energy between wave rays or orthogonals remains constant. (Orthogonals are lines drawn perpendicular to the wave crests, and extend in the direction of wave advance.)
(2) Direction of wave advance is perpendicular to the wave crest, that is, in the direction of the orthogonals.
(3) Speed of a wave of given period at a particular location depends only on the depth at that location.
(4) Changes in bottom topography are gradual.
(5) Waves are long-crested, constant period, small-

amplitude and monochromatic.

(6) Effects of currents, winds, and reflections from beaches and underwater topographic variations are considered negligible.

The change of direction of an orthogonal as it passes over relatively simple hydrography may be approximated by Snell's Law:

$$\text{i.e } \sin\alpha_2 = \frac{C_2}{C_1}\sin\alpha_1 \qquad (3.12)$$

where α_1 = the angle a wave crest makes with the bottom contour over which the wave is passing

α_2 = a similar angle measured as the wave crest passes over the next bottom contour

C_1 = wave celerity at the first bottom contour

C_2 = wave celerity at the second bottom contour

From equation 3.12, a template may be constructed which will show the angular change in that occurs as an orthogonal passes over a particular contour interval, and permits the construction of a changed-direction orthogonal. Such a template is shown in Figure Ap3.2.

<u>Procedure for construction of a refraction diagram by the orthogonal method</u> - Charts showing the bottom topography of the study area are obtained. Underwater contours are drawn on a tracing paper overlay, on which the shoreline has been placed. In tracing the contours small irregularities are smoothed out.

The range of wave periods, wave heights and wave direction is obtained from previous studies or by hindcasting. C_2/C_1 values for each interval are calculated - see Table Ap3.1. A different table and refraction diagram is required for each separate wave period and/or direction.

To construct orthogonals from deep to shallow water, the deep water direction of wave approach is first determined. A deep water wave front (crest) is drawn as a straight line perpendicular to this wave direction, and suitably spaced orthogonals are drawn perpendicular to this wave front and parallel to the chosen direction of wave approach. These lines are extended to the first depth contour shallower than $L_o/2$ where $L_o = gT^2/2$

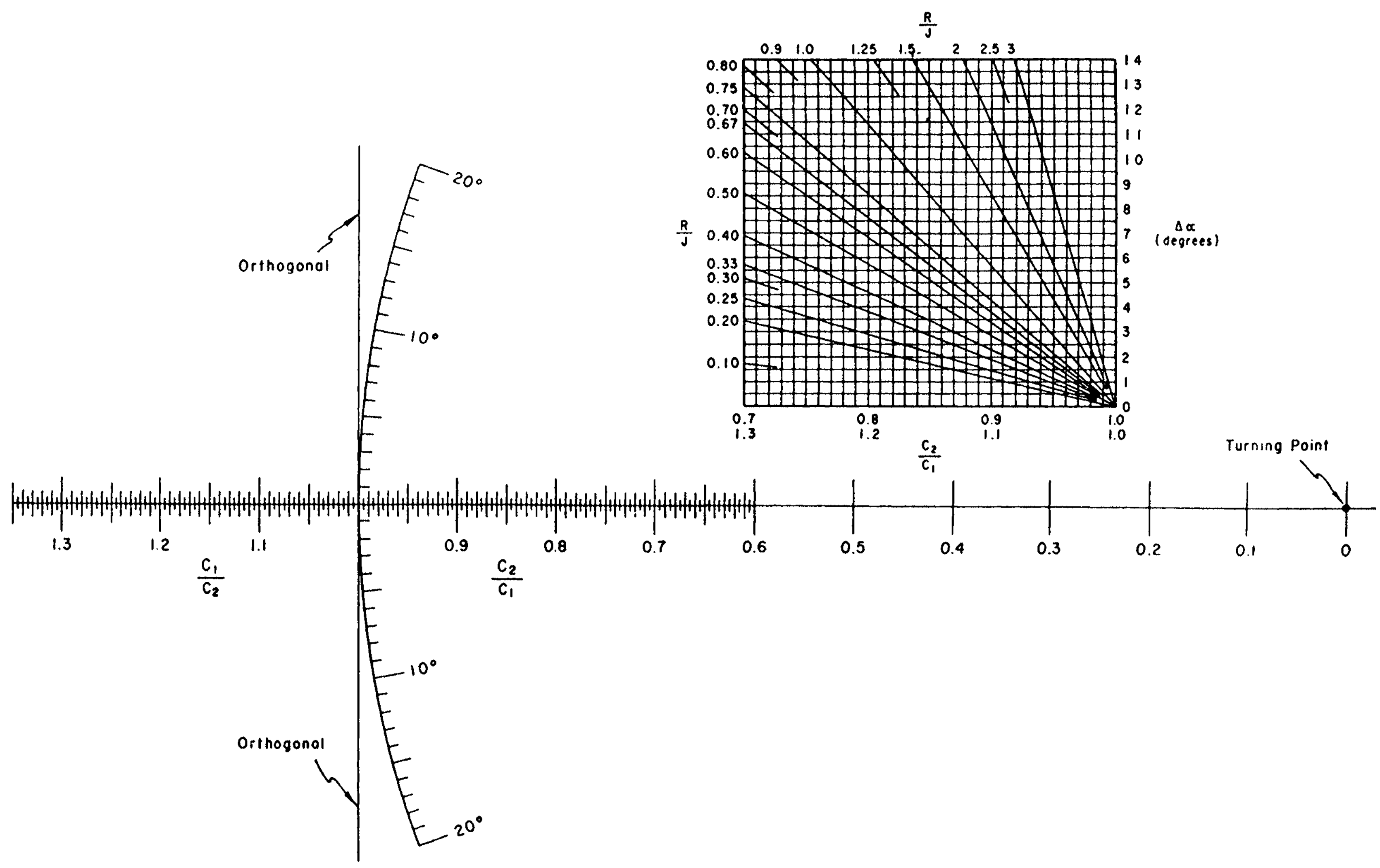

FIGURE Ap 3.2 Refraction Template

Table Ap3.1 Sample Data Table for Wave Refraction Studies.

DATE:________________ COUNTRY________________

LOCATION________________

Wave Period (T) = 10 sec.

Wave Length (L_o) = $gT^2/2\pi$ = 156.1m

d (m)	d/L_o	$\tanh 2\pi d/L$	C_1/C_2	C_2/C_1
60	0.384	0.9852	0.984	1.017
50	0.320	0.9690	0.967	1.034
40	0.256	0.9374	0.938	1.066
30	0.192	0.8791	0.883	1.132
20	0.128	0.7763	0.762	1.313
10	0.064	0.5914		

NOTES : (1) Refraction calculations should begin at d=L/2
(2) Col. 3 obtained from Table D-1 in Appendix 1.

Prepared by________________

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Starting with any one orthogonal, and using the template in Figure Ap3.2, the following steps are performed in extending the orthogonal to shore:

(a) Sketch a contour midway between the first two contours to be crossed, extend the orthogonal to the midcontour, and construct a tangent to the midcontour at this point.
(b) Lay the line on the template labelled <u>orthogonal</u> along the incoming orthogonal with the point marked 1.0 at

the intersection of the orthogonal and midcontour. (See also text Figures 2.10 and 2.11)

(c) Rotate the template about the turning point until the C_2/C_1 value corresponding to the contour interval being crossed intersects the tangent to the midcontour. The orthogonal line on the chart now lies in the direction of the turned orthogonal on the template.

(d) Place a set square along the base of the template and construct a perpendicular to it so that the intersection is midway between the two contours when the distances are measured along the incoming orthogonal and the perpendicular. Note that this point is not necessarily on the midcontour line. This line is the turned orthogonal.

(e) Repeat the above steps for successive contour intervals.

Interpretation of Results - Refraction diagrams can provide a measure of changes in waves approaching a shore. However, the accuracy of refraction diagrams is limited by the validity of the theory of construction, the accuracy of depth contours, and the care taken in the preparation of the diagrams. The direction of the nearshore waves can be determined from the refraction diagram, while the wave height can be estimated from the following formula:

$$H = KH_o = \sqrt{(b_o/b)}\,.H_o \qquad (3.13)$$

Where H = refracted wave height
b = distance between orthogonals

Wave Diffraction

Introduction - This is the phenomenon by which energy is transmitted laterally along a wave crest. It is most noticeable on the leeward sides of islands, and where an otherwise regular train of waves is interrupted by a barrier such as a breakwater. Calculation of diffraction effects is important for several reasons. Wave height distribution in a harbour or sheltered bay is determined to some degree by the diffraction effects of the natural or man-made structures which provide protection.

The process is similar for other types of waves, such as light or sound waves. The problem has been studied by several researchers, who used the following assumptions:

(a) Water is an ideal fluid.
(b) Waves are of small-amplitude and can be described by linear theory.
(c) Depth shoreward of the breakwater is constant.

Diffraction Calculations - Wiegel(1962) used a theoretical approach to study wave diffraction around a single breakwater. From his presentation, diffraction diagrams have been prepared which, for a uniform depth adjacent to an impervious structure, show lines of equal wave height reduction. These diagrams are shown in Figures 2-28 to 2-58 of Volume 1 of the Shore Protection Manual.

The graph coordinates are in units of wavelength (L). The diffraction coefficient (K′) is defined as:

$$H = K'H_i \tag{3.14}$$

where H = Wave height in the area protected by the breakwater

and H_i = Incident wave height in the area unaffected by the breakwater

When applying the diffraction diagrams to actual problems, the wave-length must first be determined using Equation 3.7 and the table in Appendix 1. It is then useful to construct a scaled diffraction overlay template on tracing paper to correspond to the hydrographic chart being used. One radius wavelength on the template must be identical to one radius wavelength on the hydrographic chart. The lines of equal K′ can be sketched in.

Charts have also been prepared for waves passing a gap comprising two breakwaters. They are available in the Shore Protection Manual.

Wave Reflection - Water waves may be either partially or totally reflected from natural or man-made barriers. The phenomenon is very important in the design of harbours, as the reflection may be very uncomfortable for the vessels using the facility.

A reflection coefficient is usually denoted:

$$r = H_r/H_i \tag{3.15}$$

where H_r = reflected wave height

and H_i = incident wave height

Table Ap3.2. lists reflection coefficients frequently used.

Table Ap3.2 REFLECTION COEFFICIENTS

Covering	Reflection Coefficient (r)
Smooth, impermeable wall	1.0
Concrete blocks	0.9
Turf	0.85 - 0.90
1 layer of rubble	0.8
2 or more layer of rubble	0.50 - 0.55
Tetrapods	0.5
Natural beaches	0.001 - 0.40

Using Linear wave theory (Equation 3.1),

$$y_i = \frac{H_i}{2} \cos\left[\frac{2\pi x}{L} - \frac{2\pi t}{T}\right] \qquad (3.16)$$

Where r = 1.0, i.e. full reflection:

$$y_r = \frac{H_i}{2} \cos\left[\frac{2\pi x}{L} + \frac{2\pi t}{T}\right] \qquad (3.17)$$

The water surface of the combined wave is:

$$y = y_i + y_r$$

$$\text{Therefore, } y = H_i \cos\frac{2\pi x}{L} \cdot \cos\frac{2\pi t}{T} \qquad (3.18)$$

Equation 3.18 represents the water surface for a STANDING WAVE or CLAPOTIS, which is periodic in time and in x, and has a maximum height of 2H.

Wind Waves - The earlier discussion was concerned with idealized, monochromatic waves. The pattern of waves on any body of water exposed to wind action is unlike this ideal picture. Waves of different heights and periods are usually present, as are various directions of wave propagation. At present, there are several methods of presenting measured wave data in terms of wave spectra. However, before the development of those methods, waves were measured by visual methods, and the concept of Significant Wave Height was developed. Most of the formulae for shore processes use the significant wave height, H . It has been found that waves measured in nature are statistically distributed, and that the Rayleigh probability distribution fits the data. It has also been found that $H_s = H_{1/3}$

where $H_{1/3}$ = average height of one-third highest waves

and $H_{1/3} = 1.6\ H$

where H_{av} = average height of all waves.

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Further Reading:

U.S. Army Coastal Engineering Research Center 1984. Shore Protection Manual. Department of the Army, Corps of Engineers.

* * *

Appendix 4.

BASIC FLUID MECHANICS

Introduction - Fluids differ substantially from solids in their behaviour. In simple terms, unlike a solid, a fluid is a substance which cannot resist a shear force without moving. Fluids are usually classified as liquids or gases. A liquid has intermolecular forces which hold it together so that it possesses volume but no definite shape. A gas, on the other hand, consists of molecules in motion which collide with each other tending to disperse it so that a gas has no set volume or shape.

Hence, a liquid poured into a container will fill the container up to the volume of the liquid regardless of container's shape; on the other hand, a gas will fill any container into which it is placed.

Some Definitions - the following terms and definitions will be used throughout:-

Pressure - The pressure in a fluid at rest is defined as the normal compressive force per unit area acting on a surface immersed in the fluid. The pressure at a point in a fluid at rest is the same in all directions. Such an isotropic pressure is called hydrostatic pressure. In addition, there exist not only normal pressure, but shear forces or stresses when the fluid is in motion.

Viscosity, Friction, and Ideal Flow - All fluids have viscosity which causes friction. The importance of this friction in physical situations depends on the type of fluid and the physical configuration or turbulence. If the friction is negligible the flow is classified as ideal.

Figure Ap4.1 shows different relationships between shear stress and shear strain rate in fluids. A wide range of fluids show a simple relationship between shear stress and shear strain rate - these are classified as Newtonian fluids. The relation between shear stress and strain may be written

$$\tau = \mu \frac{du}{dy} \qquad (4.1)$$

where is called the coefficient of dynamic viscosity. The coefficient of kinematic viscosity ν is denoted by:-

$$\nu = \mu / \rho \qquad (4.2)$$

where ρ is the mass density.

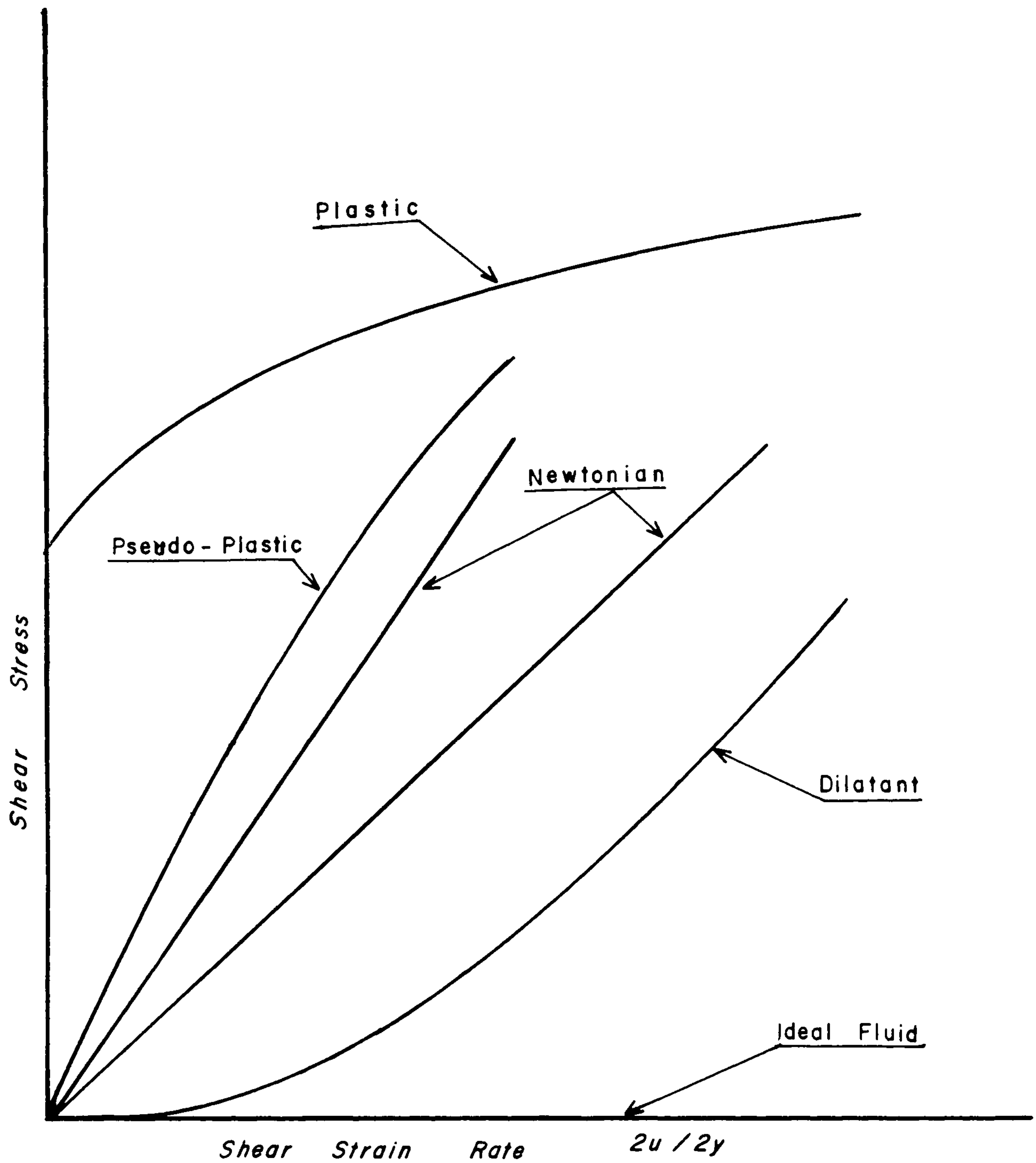


FIGURE Ap4.1 TYPES OF VISCOUS AND PLASTIC FLUIDS

Water, air and gasses are essentially Newtonian: while grease and muds show non-Newtonian behaviour.

If a fluid has no viscosity and does not flow in a turbulent manner, the flow is said to be ideal. An ideal flow then has no internal friction and hence no internal dissipation or losses. Actually, of course no fluid is ever really ideal, but some fluids, at least in certain regions of flow, approach ideal conditions very closely and are considered such for analysis.

Laminar and Turbulent Flow - the term laminar flow is used to describe a flow in which the fluid flows in laminae or layers, as opposed to turbulent flow in which the velocity components have random fluctuations imposed on their mean values (Figure Ap4.2). A stream of dye inserted in a laminar flow will streak out in a thin line and always be composed of the same fluid particles. However, in turbulent flow the dye line will quickly become tangled up and mixed in with the fluid as it flows along.

Reynolds Number, R_x - for any fluid the velocity and channel configuration determines whether flow is laminar or turbulent. As the velocity increases the flow changes from laminar to turbulent, passing through a transition regime. Both laminar and turbulent regimes occur in nature, but turbulent flow seems to be the more natural state of affairs. A dimensionless number, the Reynolds Number, R_x ,is used to characterize the flow regime.

$$R_x = \frac{u.x}{\nu} \qquad (4.3)$$

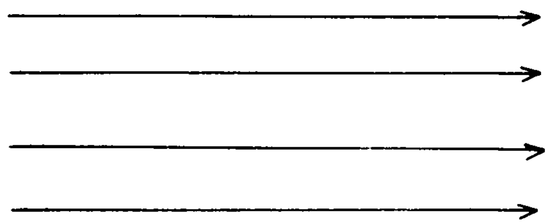
where u = velocity of flow

ν = kinematic viscosity of fluid

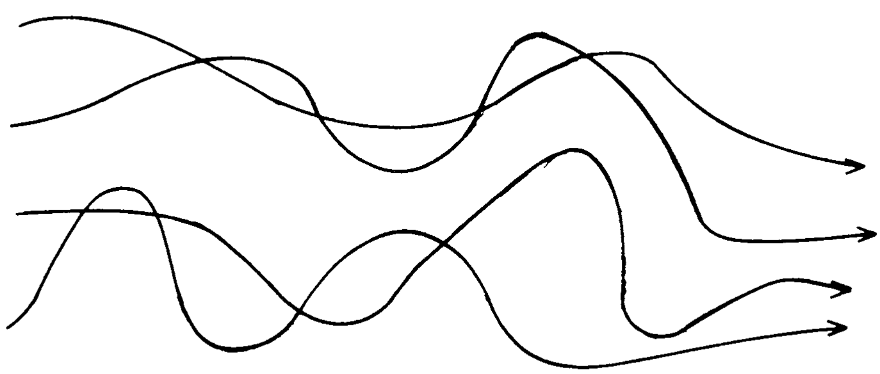
and x = characteristic dimension (length, diameter, depth)

Streamlines and Patterns of Flow - It is often desirable to have a complete diagram of the direction of motion at a number of points in a fluid stream. This can be done by drawing streamlines on a plan of the flow. These lines are drawn so that they are tangential to the direction of flow at every point. Streamlines are therefore often curved, and an infinite number of them can be drawn in any particular part of a flow. Frequently, it is desired to consider a finite portion of a flow - in such cases a streamtube is often postulated. This is a prism of fluid bounded by streamlines. Therefore, by definition, no flow can occur across the walls of a streamtube.

When fluid flows over a solid surface or shape, it is sometimes found that a streamline which is touching the surface at one place is not touching somewhere else. The



Laminar Flow



Turbulent Flow

The lines are pathlines which indicate the flow paths of particles.

FIGURE Ap 4.2 LAMINAR AND TURBULENT FLOW.

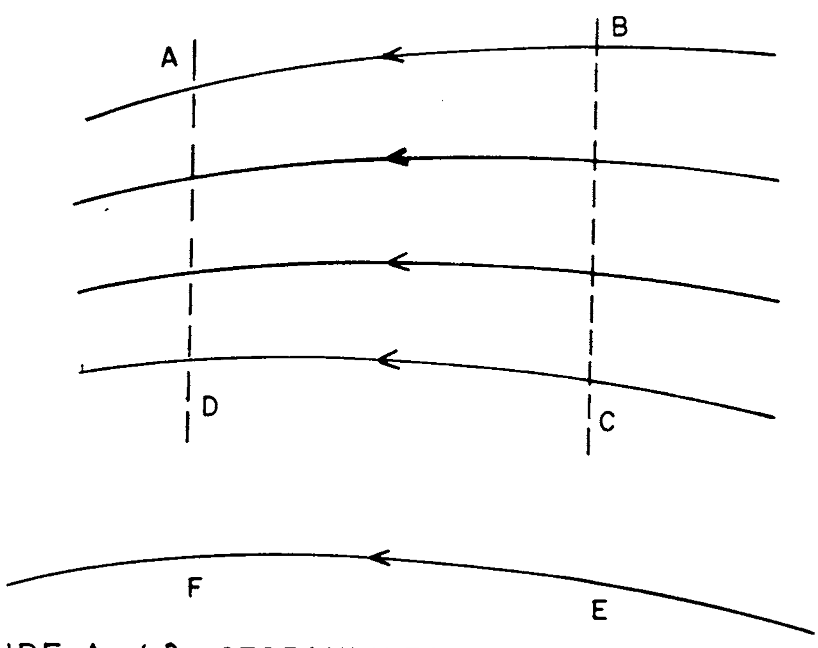


FIGURE Ap 4.3 STREAMLINES

flow is now said to breakaway or separate from the surface. At low velocities of flow (laminar flow) a mass of fluid called the wake remains between the separated streamline and the surface: this mass does not take part in the main flow and may rotate slowly forming an eddy. At higher velocities of flow (turbulent flow), there are rotary irregular motions, with non-permanent eddies being shed from the surface.

Some shapes, notably aircraft wings and well-designed ships hulls, have no breakaway on them at all in their normal operating condition, so that their shape is that of a streamline. Their shapes are therefore called streamlined.

Theoretical plotting of Streamlines - There are several experimental methods for obtaining the patterns of flow around objects. However, it is frequently desirable or necessary to predict a flow pattern at the planning stage. By using the essential property of streamlines, that they do not cross, it is possible to produce methods of plotting flow patterns.

Consider any two streamlines, AB and CD, not necessarily parallel, of a fluid in motion (Figure Ap4.3). The fluid is of constant depth and there are other streamlines between AB and CD. Since there is no flow across streamlines, the same quantity of fluid per unit time passes AD as passes BC.

That is $$\int_A^D u\,dn = \int_B^C u\,dn = \text{constant} = \psi \qquad (4.4.)$$

where u is the velocity at any point on the lines AD or BC and dn is a small length at right angles to the streamline at that point. The quantity is expressed as a volume per unit time, or, in other words, streamline CD is always a 'discharge' of ψ distant from AB even if the length it is distant from AB changes. Consequently CD can be labelled by its discharge from AB, and it can be called streamline

$$\left(\psi = \int_A^D u\,dn\right) \text{ relative to AB.}$$

Another streamline such as EF, further from AB than CD, will clearly have a larger value of ψ than CD. ψ is called the stream function and is only a method of labelling streamlines, to give them a quantitative meaning, depending on their position within the stream.

A different method of marking a flow is by the plotting of "potential" lines on it. Along any streamline values of a quantity ϕ = uds, called the potential, can be marked off, where s is the distance measured along the streamline. The potential, though having this precise meaning is a fictitious quantity and it cannot be measured directly with instruments. Referring to Figure Ap4.3, if A is taken as the zero point for potential on AB, then

$$\phi \text{ at } B = \int_A^B u\,ds \tag{4.5}$$

Points on other streamlines can also be marked off with their values of ϕ, and those with the same value on different streamlines linked to give contours of the same ϕ, called equipotential lines. By their definitions:-

equipotential lines are always at right angles to streamlines.

The two properties are used to draw streamline maps by a method of successive approximations. Although the method of successive approximations produces the correct streamline pattern for any boundary, a correct way is to combine two or more simple patterns until one of the streamlines coincides with the boundaries concerned. The method of conformal transformation has also been used to obtain flow patterns for a large number of cases.

For incompressible flow situations in which the boundary layer remains thin, ideal-fluid results may be applied to flow of a real fluid to a satisfactory degree of approximation. Converging or accelerating flow situations generally have thin boundary layers, but decelerating flow may have separation of the boundary layer and development of a large wake that is difficult to predict analytically.

Boundary Layer Concepts - The methods described above are applicable to cases of ideal fluid flow (these are approximated by cases of low velocity.). In 1904 Prandtl developed the concept of the boundary layer, which provides an important link between ideal-fluid flow and real-fluid flow. The boundary layer concept states:-

For fluids having relatively small viscosity, the effect of internal friction in a fluid is appreciable only in a narrow region surrounding the fluid boundaries.

From this hypothesis, the flow outside of the narrow region near the solid boundaries may be considered as ideal flow and treated theoretically.

A boundary layer on a plane surface parallel to the direction of flow is the simplest case to study. Since the fluid at the boundaries has a zero velocity relative to the boundaries, there is a steep velocity gradient from the boundary in to the flow. This layer moves along the body, the continual action of shear stress tends to slow down additional fluid particles, causing the thickness of the boundary layer to increase with distance from the upstream point. (See Figure Ap.4.4).

For smooth upstream boundaries, the boundary layer starts out as a laminar boundary layer in which the fluid moves in smooth layers. As the thickness of the boundary increases, it becomes unstable and finally transforms into a turbulent boundary layer in which the fluid particles move in haphazard paths, although their velocity has been reduced by the action of viscosity at the boundary.

The thickness of the laminar boundary layer, δ , at a distance x from the leading edge is given by:-

$$\frac{\delta}{x} = \frac{4.65}{\sqrt{R_x}} \qquad (4.6)$$

in which $R_x = \frac{u.x}{\nu}$ (4.7)

and u = velocity beyond the boundary layer.

When the Reynolds number for the plate, R_ℓ , reaches a value between 500,000 and 2,000,000, the boundary layer becomes turbulent, and :-

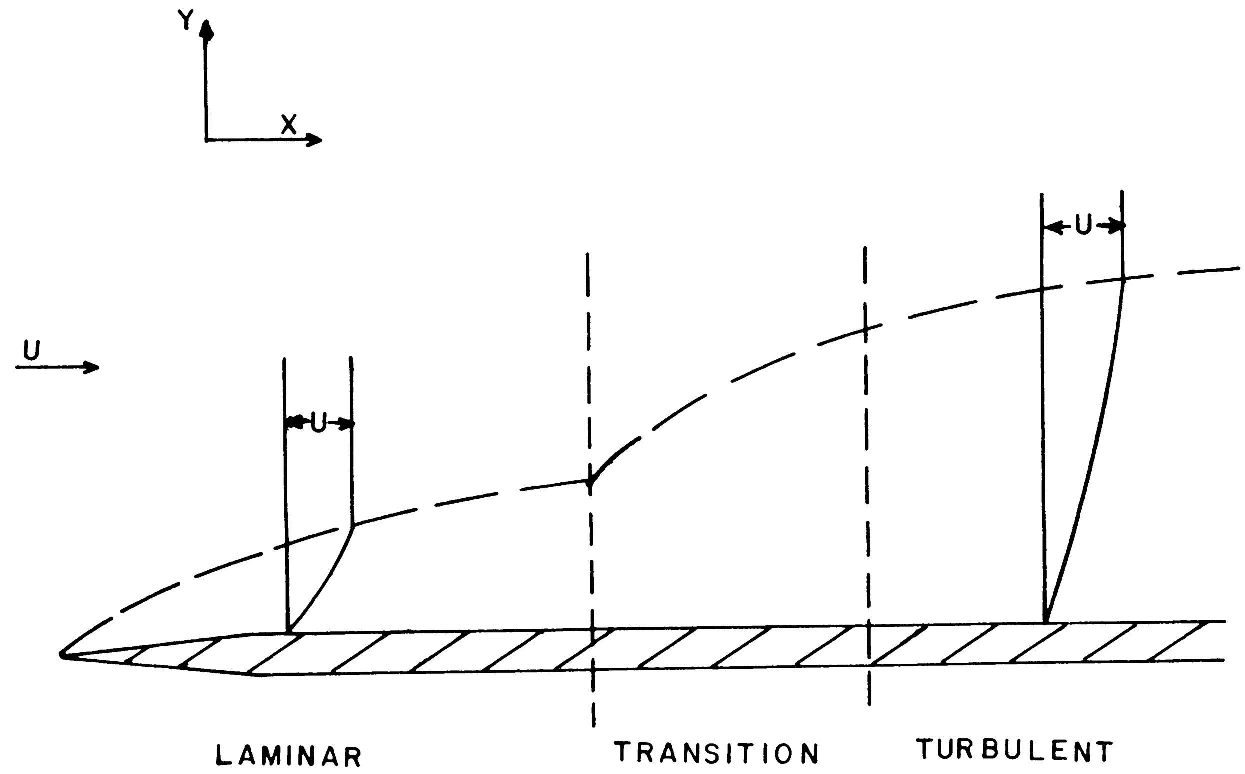
$$R_\ell = \frac{u.\ell}{\nu} \qquad (4.8)$$

Where ℓ = the distance from the leading edge.

The thickness of the turbulent boundary layer, δ , at a distance x from the leading edge is given by:-

$$\delta = 0.37 \; x / R_x^{1/5} \qquad (4.9)$$

Along a flat plate the boundary layer continues to grow in the downstream direction, regardless of the length of the plate, when the pressure gradient remains zero. With the pressure reducing in the downstream direction, as in a conical reducing section, the boundary layer tends to be reduced in thickness.



Dotted Line shows outer Limit of Boundary Layer
Scale in Y direction greatly exaggerated.

FIGURE Ap4.4 BOUNDARY LAYER GROWTH ON A FLAT SURFACE.

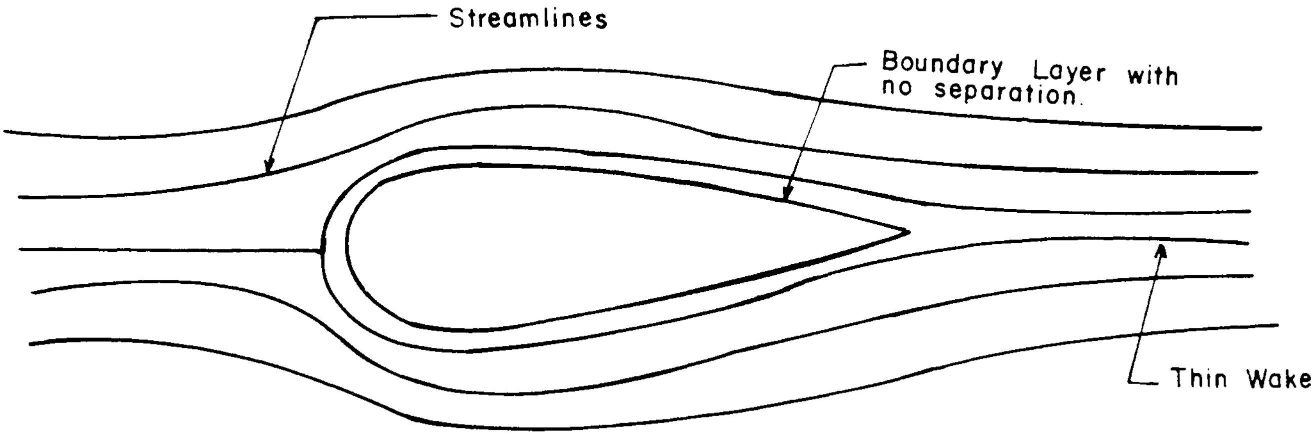
For adverse pressure gradients, i.e. with pressure increasing in the downstream direction, the boundary layer thickens rapidly. The adverse gradient plus the boundary shear decrease the momentum in the boundary layer, and if they both act over a sufficient distance, they cause the boundary layer to come to rest. This phenomenon is called separation. The boundary streamline must leave the boundary at the separation point, and downstream from this point the adverse pressure causes backflow near the wall. The region downstream from the streamline that separates from the boundary is known as the wake.

Streamlined bodies are designed so that separation occurs as far downstream along the body as possible, and as a result the wake is small. For a bluff body, on the other hand the flow is separated over much of the surface, and the wake is large. Examples of streamlined and bluff bodies are shown in Figure Ap4.5.

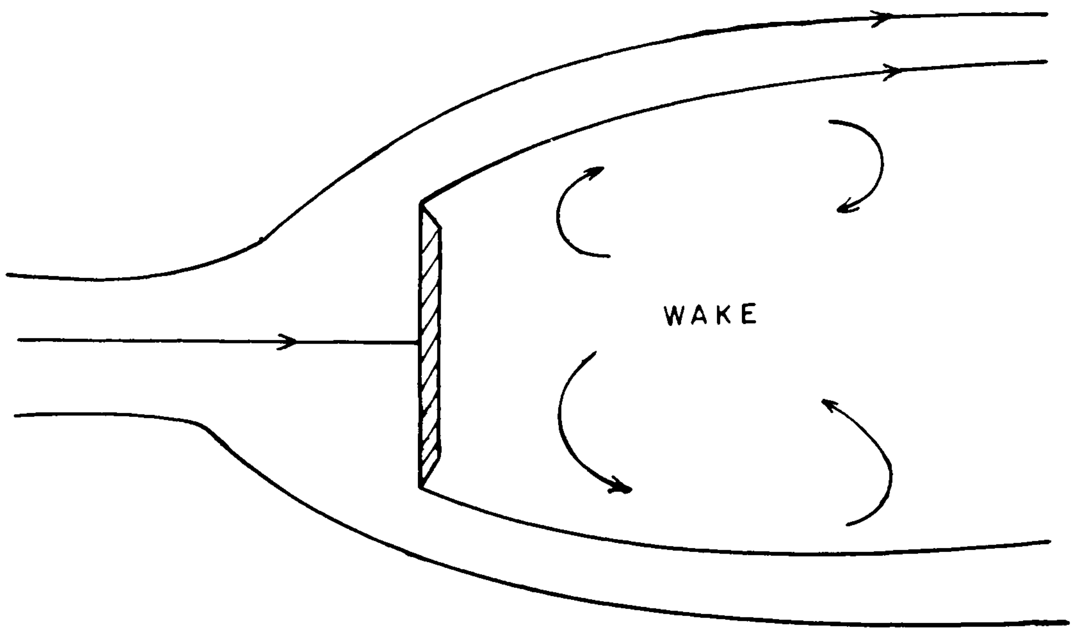
The flow pattern in the wake depends on the Reynolds number of the flow. We may consider as an example the flow past a circular cylinder of diameter d, with its axis perpendicular to the flow. For very low values of $Re = ud/v$ ($Re < 0.5$) the streamlines come together as shown in Figure Ap4.6(a). If Re is increased to range 2-30, the boundary layer separates symmetrically from the two sides at the positions S,S (Figure Ap4.6(b)) and two eddies are formed which rotate in opposite directions. At these Reynolds numbers they remain unchanged in position. Behind the eddies, however, the main streamlines come together, and the length of the wake is limited. With the increase of Re the eddies elongate as shown in 4.6(c) but the arrangement is unstable and at Re approximately equal 40-70 (for a circular cylinder) a periodic oscillation of the wake is observed. Then at a limiting value of Re (about 90 for a circular cylinder), the eddies break off from each side of the cylinder alternately and are washed downstream. In a certain range of Re above the limiting value, the eddies are continuously shed alternately from the two sides of the cylinder and, as a result, they form two rows of vortices in its wake, the centre of a vortex in one row being opposite the point midway between the centres of consecutive vortices in the other row. This arrangement of vortices is known as a vortex street or vortex trail. The energy of the vortices is ultimately consumed by viscosity and beyond a certain distance from the cylinder the regular pattern disappears.

Similar behaviour is observed when fluid flows past different bluff shapes.

Turbulence occurs not only when fluid flows past a solid boundary, but also when two fluids flow past each other with different velocities. Turbulent mixing then takes place between the streams so as to equalize their velocities. This free turbulence - that is turbulence not bounded by solid

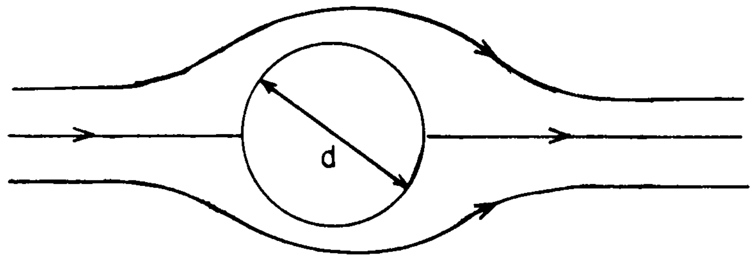


(a) Streamlined body

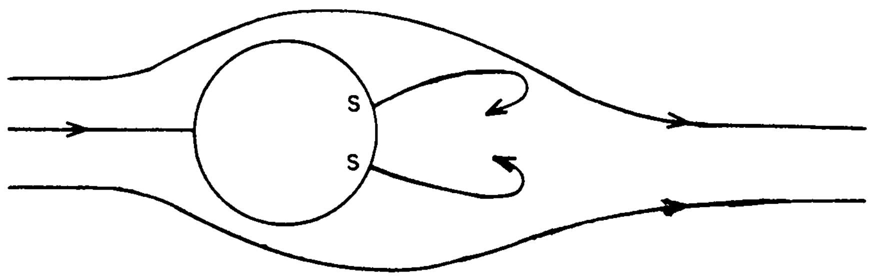


(b) Bluff body

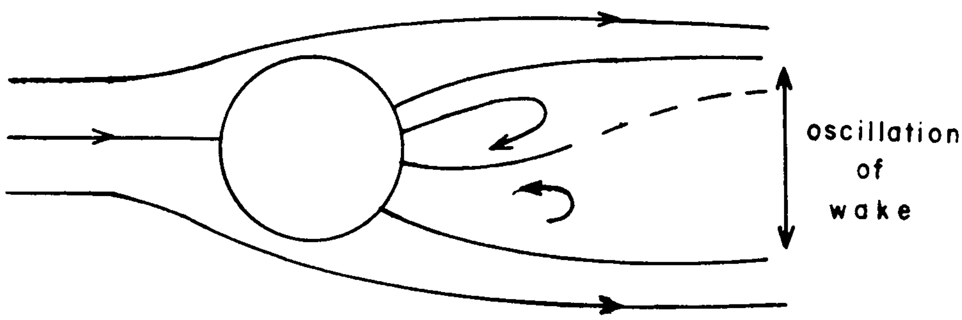
FIGURE Ap 4.5 FLOW AROUND STREAMLINED AND BLUFF OBJECTS.



(a) Re < 0·5



(b) Re = 2 to 10



(c) Re 40 to 70

FIGURE Ap 4.6 DEVELOPMENT OF WAKE BEHIND A CYLINDER walls - occurs, for example, when an oceanic current flows into a large expanse of nearly stationary fluid enclosed in a gulf or bay.

Drawing streamlines by successive approximations - the property of streamlines and potential lines being at right angles to each other is made use of in this method of drawing streamlines. If streamlines and potential lines are drawn at equal intervals, then the shapes between them are squares.

The boundaries of the flow are drawn to scale, and a guessed set of streamlines put in, using the boundaries as streamlines. At one part of this guessed pattern, preferably where the velocity is uniform, commence drawing smooth curved lines at right angles to the guessed streamlines, spacing these lines so that at one area they produce squares. It will soon be found that if squares are drawn in the space between two streamlines then the continuation of the lines at right angles will not result in squares between other pairs of streamlines. This is due to errors in the original guessed streamlines.

Revisions can therefore be made to the streamlines at the places where the squares are most in error, but this process will be found to make the original equipotential lines incorrect, so that revisions are necessary to them. In this way, successive adjustments to the guessed streamlines and equipotentials are made until a correct pattern is obtained. In places where there are rapid changes of streamline spacing, additional streamlines and equipotential lines can be drawn between the original set of both.

The patterns obtained by this method give a good representation of flow of oceanic currents past islands only in the area before the formation of a wake. The type of wake can be estimated from the information given in paragraph 4.5 above.

Further Reading:

Massey, B. S. 1970. Mechanics of Fluids. Van Norstrand Reinhold, New York; 508 pages.

Streeter, V. L. 1966. Fluid Mechanics. McGraw Hill, New York; 705 pages.

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Appendix 5.

AN EXAMPLE OF PROTECTED AREA CATEGORIES FOR SMALL ISLANDS

A Case Study from the British Virgin Islands.

Because of the proliferation of names for protected areas worldwide, the International Union for the Conservation of Nature and Natural Resources (IUCN) has adopted a standardised series of categories (IUCN, 1978). These have been designated with continental countries in mind, in which national parks are often many times larger than the entire British Virgin Islands. However, many of these categories can be altered slightly for application to the BVI. The following categories (with their IUCN number) are especially applicable to the BVI.

- National categories

  II National Park
  III Natural Monument
  IV Nature Conservation Reserve
  V Protected Landscape
  VIII Multiple Use Management Area

- International categories

  IX Biosphere Reserve
  X World Heritage Site

Using the IUCN recommendations as a guideline, and taking into account the particular local circumstances, the following categories are recommended for the Parks and Protected Areas System for the British Virgin Islands:

Category 1:

These are established to protect relatively large natural and scenic areas of national significance for recreational, educational, and scientific use. They contain large areas and entire ecosystems that are less altered by human exploitation and occupation. Category 1 areas are managed to prevent adverse human impacts on the area and to enforce effectively respect for the ecological, geomorphological, or aesthetic features which have led to their establishment. The park is managed and developed so as to permit human use for research, education, recreation, and tourism on a controlled basis while maintaining the area in a natural or near-natural state. Portions of the area should be devoted to preserving in an unaltered state representative samples of physiographic regions, biotic communities and genetic resources, and species in danger of extinction. This category has been adapted from the IUCN "National Park" category.

Category II:

These are created to protect and preserve nationally significant natural and historic features because of their special interest or unique characteristics and, to the extent consistent with this, provide opportunities for public appreciation, tourism, education, and research. This category normally contains one or more discrete features such as a geological formation, a unique natural site, or an historic property. Natural features to be protected ideally show little or no evidence of man's impact. These areas may be of any size and generally do not contain a diversity of features or representative ecosystems to justify their inclusion in Category 1, but they have particular importance for public education and appreciation. Although they have recreational and touristic value, these areas should be managed in such a way that they remain relatively free from human disturbance, and retain their inherent features unimpaired for the long term. This category has been adapted from the IUCN's "Natural Monument" category.

Category III:

These are established to assure the natural conditions necessary to protect nationally significant species or biotic communities. The size of the area will depend on the habitat requirements or specific characteristics of the species or community to be protected. Relatively small areas, such as nesting sites, mangrove stands, or other communities of special interest may be included in this category. Human intervention or habitat manipulation may be required to provide optimum conditions for the species or community, according to individual circumstances. Limited portions of the area may be developed for public education. Non-exploitative recreational activities may be permitted in some areas. This category combines elements of IUCN's "Scientific Reserve" and "Nature Conservation Reserve" categories, but permits more flexibility concerning human activity.

Category IV:

This category has been established for small parks and gardens in developed countries. Category IV includes National Parks Trust areas that have been altered significantly from their natural state and that are managed for local recreation and education. There is no corresponding IUCN category.

Category V:

These are established to maintain areas which retain nationally important natural and scenic values for public enjoyment and economic development through recreation and tourism. The normal lifestyle and economic activity of the area is maintained, but the preservation and development of natural and scenic resources, traditional landscapes and resource uses, and historic and archaeological features are promoted for cultural, educational, and scientific purposes, as well as tourism development. Given the importance of these areas to local communities, management policy is developed by a committee made up of local residents, resource users, relevant government departments, and the National Parks Trust. The area should be large enough to maintain its special natural, cultural, and scenic qualities. Category V areas will be established often in association with more stringently protected areas with which they will comprise single legal entities. The category includes some of the objectives of IUCN's "Protected Landscape" and "Multiple Use Management Area" categories, but essentially is a new category adapted to the special management needs of small islands like the BVI.

Two **International Categories** of protected area may be used also, or be superimposed on National Categories. These are:

Biosphere Reserve:

This category is established to create a worldwide network of areas representative of the World's natural diversity. It includes representative samples of a major biome in both its natural state and as altered by human use. The area is managed to conserve ecosystems and ecological diversity, and to link conservation and development. Research, education, and training opportunities are provided to develop and promote conservation and ecologically sound development. The area should be sufficiently large to accommodate its several uses without conflict and have adequate long-term legal protection. Each area must be approved by the Man and the Biosphere International Coordinating Council before it can receive designation as a Biosphere Reserve. In the BVI, management policy for each reserve would be established by a local committee consisting of representatives of the local community, resource users, relevant government departments, and the National Parks Trust. A core natural area would be established on Crown Lands, but areas under various forms of use on private lands may be included also. This international category may overlap with some of the national categories.

World Heritage Site:

This category is established through the International Convention concerning the Protection of the World's Cultural and Natural Heritage, and designates areas of "outstanding universal value". The primary objective is to protect the features for which the area was considered of World Heritage quality. Research and education may be secondary objectives. Areas to be considered under the Convention are restricted to those which are truly of international significance. Natural sites must meet one or more of the following criteria:

- be outstanding examples representing the major stages of the Earth's evolutionary history
- be outstanding examples representing significant ongoing geological processes, biological evolution and man's interaction with his natural environment
- contain unique, rare or superlative natural phenomena, formations or features or areas of exceptional natural beauty
- be habitats where populations of rare or endangered species of plants and animals still survive

Also World Heritage Sites must fulfill conditions relative to the integrity of the site. Management stresses the maintenance of the heritage values, continuation of legal protection, and promotion as to its significance to the country, its people, and the World. All sites must have strict legal protection and be owned by government or a non-profit trust. While recreation and on-site interpretation will generally be developed, some sites may be of such significance and fragility that public use will either be strictly controlled or prohibited. These exceptional areas must be recommended by the nation responsible for the site for declaration by the International World Heritage Committee. This international category may overlap with national categories.

Source: British Virgin Islands National Parks Trust and Eastern Caribbean Natural Area Management Programme, 1986. A Parks and Protected Areas System for the British Virgin Islands. Unpublished Report, 90 pages.

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Appendix 6

INTRODUCTION TO THE METHODOLOGY FOR BIOLOGICAL RESOURCE YIELD PREDICTION

Estimation of the potential yield from any type of coastal plant or animal resource must be based on an understanding of the population structure, and how this changes naturally and as a result of exploitation. The same factors govern natural changes in plant and animal populations as those which affect human population size, i.e. the rate of change in the population number N can be expressed as:

$$\Delta N = B - D + I - E$$

Where B = number of births per year
D = number of deaths per year
I = number of immigrants
E = number of emigrants

This equation can be adapted for commercially important populations, such as fisheries, using the equation of Russell:

$$P_2 = P_1 + (R' + G') - (M + F)$$

where P_1 = the stock in the first year (or start of sampling period)

P_2 = the stock in the second year (or end of sampling period)

R' = annual increment through recruitment

G' = annual increment through growth

M = annual sum of deaths due to natural causes

F = annual sum of deaths due to exploitation (e.g. fishing)

Each of these parameters can be measured (with varying degrees of difficulty) for any population of resource organisms. Some basic biological information is required, such as breeding seasons and numbers of juveniles normally recruited, and other aspects will need to be measured over a valid time period. Once a basic understanding of the dynamics of the population has been obtained, models can be prepared for optimising the harvest. Several production models are used by fisheries scientists and can be studied in the texts suggested for Further Reading in Exercise 4.3. The general principles behind three of these are discussed below.

a. Surplus Yield Production Model:

A population of resource organisms is maintained by the balance between recruitment to the population and loss from it. Part of the loss through natural causes can be transferred to man through harvesting. However, the population will increase in size (weight) by entry of young to the stock and growth of all individuals, until limited by the carrying capacity of the environment. If the amount of recruitment can be estimated, it is possible, theoretically, to remove an equivalent amount while the population size remains stable; and the population will have the capacity to increase again until its carrying capacity is reached:

$$dN / dt = a' N (1 - N / K^*)$$

Where N = number in the population
a' = instantaneous rate of increase
K^* = carrying capacity of the environment.

The model is concerned with utilising the fraction of the stock (a'), and the equation has been modified to the standard descriptive model of Schaefer, as follows:

$$dP / dt = a' P (Pm - P) - FP$$

Where P = stock (weight)
Pm = maximum stock (weight) at carrying capacity of the environment
a' = instantaneous rate of natural increase
F = fishing mortality (i.e. F at which maximum sustainable yield is maintained)

The Surplus Yield Model is useful only where accurate estimates of the stock density are available. Although the amount of the production "surplus" which is available for harvest can be estimated, the timing of its availability is less easily forecast, because the increment results mainly from recruitment rather than growth. The recruitment of juveniles to any population can fluctuate widely depending on previous conditions during reproduction and existing conditions for juvenile survival; thus, it may not be regular or instantaneous.

b. Yield Curves

A more accurate estimate of stock size at any one time would be obtained by following the growth/weight increase of different year classes. Any population of organisms will contain groups of individuals that recruited into the population following successive breeding periods. The available yield will be determined, thus, by the different rates of weight increase by year classes at different stages of their life cycle. Wide fluctuations in the timing and size of recruitment will lead to variation in the available stocks. Although referred to commonly as "year classes", recruitment in tropical marine populations seldom occurs only once per year, so the term "cohort analysis" is to be preferred.

Yield curves can be prepared, as in Figure Ap.6.1, which separate the stock and its recruitment from catch and fishing effort/intensity. This models the relationship between catch and effort. For example, for Species 1, the yield per recruit rises rapidly to the asymptote (A) giving maximum harvest; an increase in fishing effort (B) may give slight increase in catch as population size fluctuates around this level. With Species 2, there will be a peak in yield at F = 0.5 (A), but, because of a rapid decline in average weight as the population ages, there will be a decline in yield with any increase in effort (B).

Yield Curves are particularly useful for single species resource stocks. However, many currently harvested tropical resources contain mixed stocks, sometimes including large numbers of species, as in fish-pot fisheries common in coral reef areas. The Schaefer-type model can be adapted by calculating catchability coefficients for all components of the stock, and assuming these are constant because of the relatively uniform seasonal conditions experienced by tropical species. This would include use of a cohort analysis to follow individual species throughout their growth cycles.

c. Morphoedaphic Index of Yield

The yield analyses described assume that morphometric factors are the only ones affecting population size. However, production (yield) by tropical marine populations is influenced be edaphic and climatic conditions, and also by other factors of the biological environment in which the resource stock lives. For populations of fish, sea turtles, conch or lobsters important environmental influences include (a) physical characteristics - area of suitable habitat, depth, current and tidal movements, and extent of shoreline development; (b) physicochemical characteristics - mean temperature, dissolved oxygen levels, presence of pollutants; and (c) biological characteristics - number of trophic levels in their food chains, levels of predation,

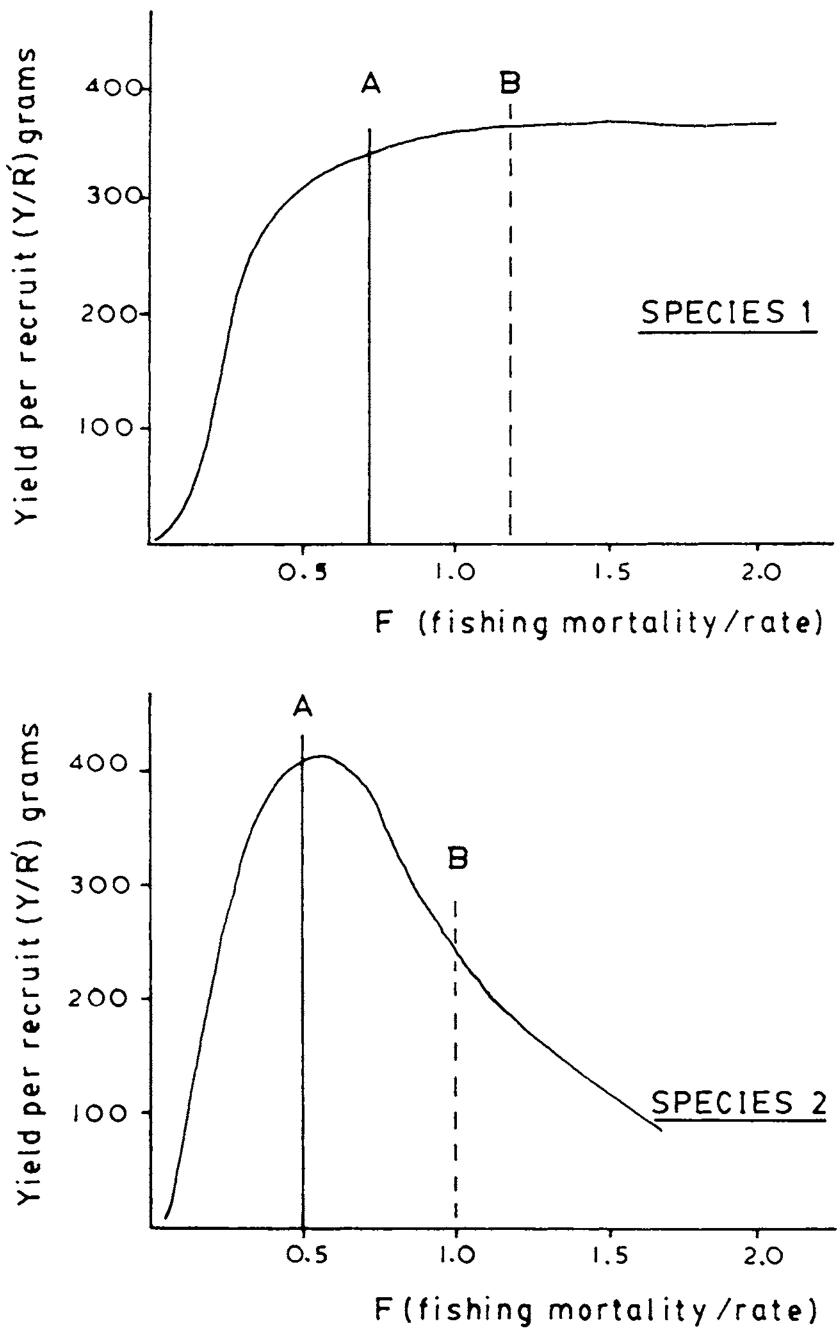

FIGURE Ap6.1 SAMPLE YIELD CURVES

parasites and disease.

These factors influence the general levels of attainable production, and can be assessed by use of a Morphoedaphic Index. For example, one could use a regression of resource production on morphometric and edaphic factors, such as the production of a conch population as a function of mean water depth and area of available food materials. In its simplest form, suitable available habitat is a key factor in production of a resource organism; for example, if 150 km^2 of mangrove root habitat occur around the coast with an estimated potential oyster productivity of 2.5 mt km^{-2} yr^{-1}, it can be expected that the sustainable yield for the whole island will be below 375 mt yr^{-1}. If poor water circulation gives lower growth rates in one area, pollution restricts use of oysters from another area, and predation by pufferfish leads to 15 % mortality throughout the island during the dry season months, the oyster fishery must plan for much lower annual yields.

Resulting Management Methods:

From the above, it is apparent that a relationship exists between the attainable harvest and the ability of the resource population to sustain that harvest. Yield assessment leads logically towards yield restriction at levels or in ways that will sustain the desired yields. Restrictions can be applied by resource managers in several ways:

a. Capture of certain species - to preserve lower trophic level food organisms used by commercially important species.
b. Capture of certain age classes - to reduce harvest of juveniles or immatures that have not yet reproduced. This can be accomplished by gear restrictions, such as banning of small mesh fishing nets, or size restrictions, such as minimum catch sizes for sea turtles or lobsters.
c. Harvest rotation - by prohibiting capture of the resource in different areas of the coast on a rotational basis. This is a standard technique with forestry resources, for example, where timber is cut from an area which is then left for long periods, such as 30-50 years, while stands of new trees mature. The annual timber quota is taken in rotation from further forest plots, with the industry's planners ensuring that sufficient timber is available, or is being replanted, to maintain output during the intervening years while the harvested plots are re-growing. The rotation period must be related to the time required for growth to maturity of the target organism, or to re-establishment of the community composition that gives the best economic returns when harvested. Closing an area for fixed periods is beneficial if it permits recovery from

damage caused by harvesting procedures, such as trawl disturbance to seagrass beds or root loss through cutting of mangrove oysters. It may also permit re-establishment of valuable climax species which, under conditions of continuous exploitation, have little chance to grow.

The size of plot and amount of resources in a plot currently being exploited in a rotation cycle must be large enough to support the total number of fishermen, or other resource users, that will be concentrated there due to exclusion from closed areas. Resource management schemes which include rotational harvesting depend upon an accurate understanding of the population dynamics of the resource organism in the target area; but they must be devised in consultation with the resource users, as they have important social and economic implications.

One of the major factors contributing to resource over-exploitation in tropical island coastal environments is the open nature of the use of resource below the high tide line. Generally speaking, marine resources are available on a free-for-all basis, in the absence of controls similar to private land ownership or forest reserve type restrictions for terrestrial resources. Although detailed treatment of the legal aspects of coastal resource utilization is beyond the scope of this text, it can be appreciated that rational management can only be applied if restrictions are introduced in order to ensure sustainable yields. One important task for coastal managers is to assist resource users in making agreements on which resources will be exploited, in which areas, at which times and at what rates; and how resource replenishment will be accomplished.

d. Maintenance of traditional harvest methods - by restriction of advanced technologies or gear, and supporting local village or community efforts.
e. Restricting entry - reducing the numbers of persons utilizing the resource by licensing. Numbers can be restricted also by use of incentives which encourage persons into alternative activities.

Support can be applied to resource populations in several ways:

a. Establishment of sanctuaries - to permit growth and reproduction of parts of the population of organisms without interference, with the intention of their spreading out to restock the utilization areas. For example, the juveniles of many commercially important tropical fish species use mangrove areas as "nursery habitat". By designating mangrove areas as "Fish Sanctuaries", critical life history stages can be protected and fish populations sustained.

Where continuous breeding takes place, as it does in many tropical species, permanent sanctuaries may be required. On the other hand, seabird and sea turtle populations could be sustained by giving sanctuary status to nesting areas only during the breeding season; although it would be advisible for some parts of the adult populations to be protected at all times as resource reservoirs.

Exploitation of the stocks of all tropical island coastal resource organisms should be supported by a strictly enforced sanctuaries programme. As indicated in Chapter 3, one of the major functions of a Protected Areas System is to help sustain an island's resource capital.

b. Removal of physical or ecological limits to population increase - in order that an increased number of juveniles will recruit into the population; as with provision of cultch surfaces for spat and removal of predators in oyster culture schemes.

c. Juvenile rearing and release - maintaining eggs and early juveniles under laboratory conditions can significantly decrease mortality. Release of late juveniles into the natural environment should lead to increased recruitment in wild stocks. This is the principle behind headstarting of sea turtle hatchlings. This process, which is still at the experimental stage, attempts to reduce the very heavy natural mortality of freshly emerged hatchlings by rearing them until they are larger, stronger and better able to feed for themselves.

Biological resource yield prediction should be based on analysis of past and present catch statistics, on the description of suitable habitat conditions, and on the likely effects of intensive management on the size of the resource stocks.

* * *

Appendix 7.

SUMMARY OF SEAGRASS REPLANTING METHODOLOGY

1. Survey the area, identify and map regions covered with seagrass (Figure Ap.7.1) (label as areas A), and areas requiring replanting (label as areas B). Areas thought to require replanting must be chosen with care. It is not sufficient to assume that a bare patch within or close to a seagrass bed should be revegetated, as the sediment type or prevailing current strength might make this patch unsuitable. It is essential to refer to published descriptions or seek expert local opinion of the previous extent of seagrass cover. Alternatively, air photos at an appropriate scale can be studied, in order to ascertain the previous extent and distribution of seagrass cover in an area.

   Seagrass beds are rarely uniform over large areas, but field survey should quickly distinguish the healthy patches. Generally, these will be dense, with long leaf blades, relatively sparse epiphytic growth, and a diverse associated benthic invertebrate and fish fauna. Patches deviating widely from this general form may benefit from replanting. However, it must be remembered that latitudinal variation, sediment composition, water depth and clarity all influence seagrass bed development.

2. Identify and note on the map any areas (B) with strong currents, or strong sediment scour; designate as (BB).

3. Collect seagrass transplants from donor beds (A). These should be "Sprigs", which are apical meristems with about 150 mm of rhizome and several leaf blade shoots; "Plugs" which are 150 mm lengths of rhizome, roots and soil; and seeds, collected from beds where fruiting is taking place, according to season. Sprigs and plugs should be collected in a ratio of 3:2, and they should be stored in net bags underwater or in trays dampened with seawater.

4. In the laboratory, or in the boat if replanting is to be done immediately, prepare the sprigs for transplanting (see Figure Ap. 7.1). Two to three sprigs should be attached to a section of 10 mm diameter construction rod 10 cm long, using twine or plastic bag-ties. Plugs will be planted as they are. Three seeds should be placed in holes in a concrete disk, 5 cms in diameter (Figure Ap.7.1) and the holes plugged with a mixture of clay and a phosphate-based fertilizer.

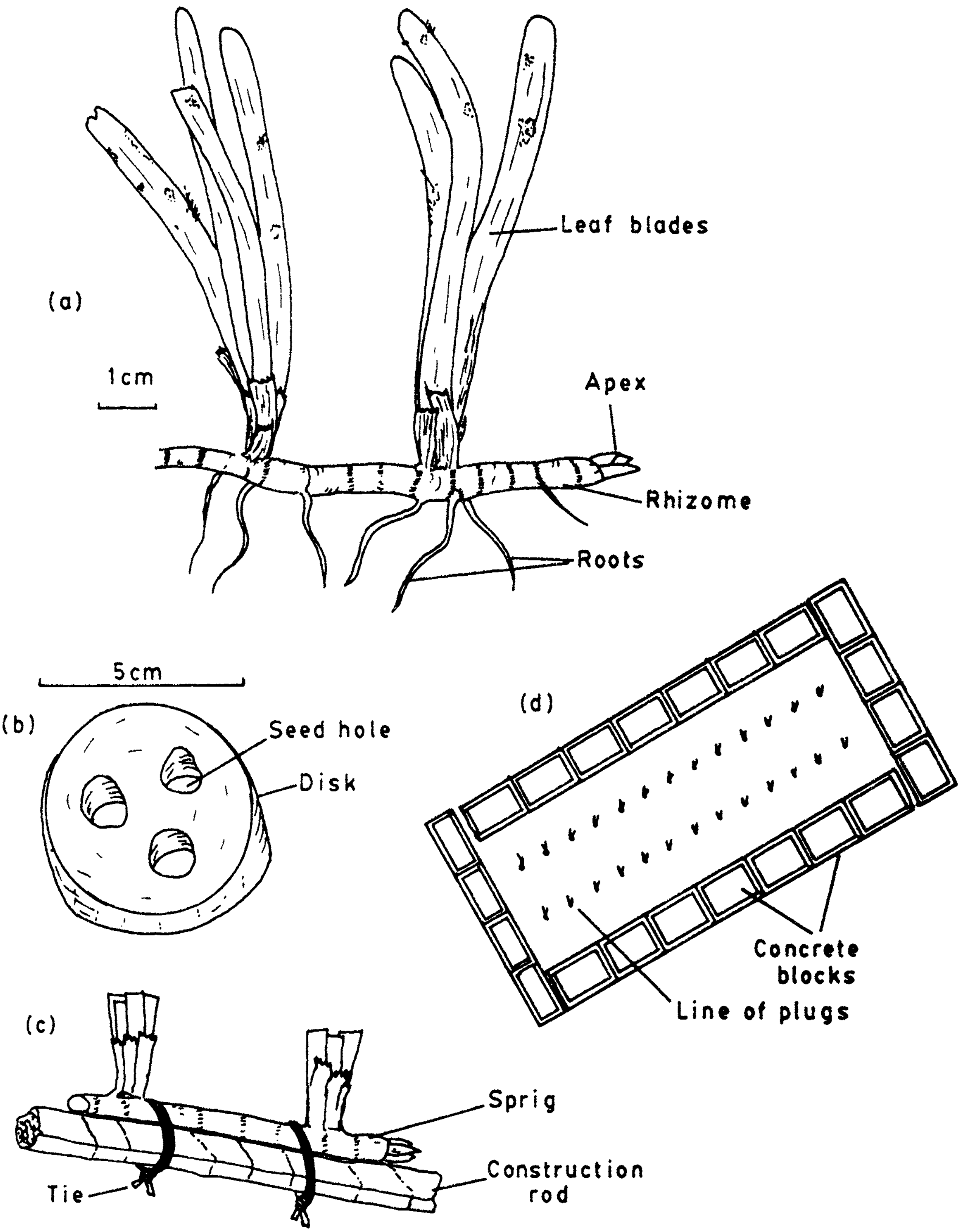

FIGURE Ap7.1 (a) SEAGRASS PLANT, (b) CEMENT SEED RING, (c) SPRIG PREPARED FOR PLANTING, AND (d) WALL OF BLOCKS ACTING AS A BAFFLE.

5. For large replanting areas, distribute the transplants along transects 3 m apart, running perpendicular to the main current direction. Sprigs and plugs or seed rings should be planted alongside a measuring tape at 0.5 m intervals, and also 0.5 and 1.0 m apart on either side of the tape.

6. For small replanting areas, distribute the transplants from centres so they are 0.5 m apart.

7. Sprigs and plugs should be pushed into the sediment, after making a hole by hand or with a suitable instrument, and tamped into place. Seed rings should be placed firmly on the sediment surface.

8. For best results, a sequence of 3 sprigs - 2 plugs - 1 seed ring - 3 sprigs should be used along the transects.

9. For areas designated (BB), a wall of blocks should be built to act as a baffle protecting the transplants from current scour. This should be constructed along the upstream side of the planting area, as shown in Figure Ap.7.1. For large areas or serious current scour, lines of blocks should be placed 1 m apart. Where strong wave action occurs in shallow water, blocks may need to be anchored securely with sections of construction rod.

10. Transplants and seed can be collected from shallow areas by wading or snorkelling. Planting in deeper areas is best done by using SCUBA. Planting teams should consist of (minimum) a pair of divers, supported by a boatman and two assistants (loaders, transplant suppliers).

11. The planting team should be able to complete a 10 x 20 m plot in 1 to 2 hours, and to work 4 similar plots per day; provided that there is a steady supply of previously prepared sprigs, plugs and seed rings.

12. Replanted seagrass beds should be monitored for at least 18 months. There should be an inspection after the first and second months, and subsequently at two-month intervals, to assess replanting success. Subsequent replanting may be needed where patches of transplants have not taken or have been uprooted.

(**Sources:** Kelly et al, 1971; Thorhaug et al, 1985; van Breedveld, 1975, and personal communication P. Gayle).

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Appendix 8.

USEFUL ADDRESSES, including those of agencies mentioned in the text

American Public Health Association (APHA)
1015 18th St. N.W., Washington, D.C., 20036, U.S.A

Association of Island Marine Laboratories of the Caribbean (AIMLC)
c/o Department of Marina Sciences, University of Puerto Rico, Mayaguez, Puerto Rico.

Canadian International Development Agency (CIDA)
Place du Centre, 200 Promenade du Portage, Hull, Canada K1A OG4.

Caribbean Conservation Association (CCA)
Savannah Lodge, The Garrison, St. Michael, Barbados.

Caribbean Environmental Health Institute (CEHI)
P.O. Box 1111, Morne Fortune, Castries, St. Lucia.

Center for Environmental Education (CEE)
624 9th St. N.W., Washington, D.C. 20001, U.S.A.

Center for Resource Management and Environmental Studies (CERMES)
University of the West Indies, Cave Hill, Barbados.

Coastal Area Management and Planning Network (CAMP)
c/o John Clark, National Park Service, International Affairs, P.O. Box 37127, Washington, D.C. 20013-7127, USA.

Commonwealth Science Council (CSC)
Commonwealth Secretariat, Marlborough House, Pall Mall, London SW1Y 5HX, England.

Eastern Caribbean Natural Area Management Program (ECNAMP)
6A Caravelle Arcade, Christiansted, St. Croix, U.S. Virgin Islands 00820.

Food and Agriculture Organisation of the United Nations (FAO)
Via delle Terme di Caracalla, 00100 - Roma, Italy.

Forest Division, Government of Trinidad and Tobago.
Long Circular Rd., Port of Spain, Trinidad.

Island Resources Foundation (IRF)
Red Hook, Box 33, St. Thomas, U.S. Virgin Islands 00902.

Institute of Marine Affairs (IMA)
P.O. Box 3160, Carenage Post Office, Trinidad.

International Union for the Conservation of Nature and Natural Resources (IUCN)
Avenue du Mont Blanc, CH-1196 Gland, Switzerland.

IUCN Conservation Monitoring Centre
219C Huntingdon Rd., Cambridge, CB3 ODL, England.

Law of the Sea Institute (LSI)
University of Hawaii, 2515 Dole St., Room 208, Honolulu, HI 96822, USA.

Marine Information Centre (UNESCO)
Division of Marine Sciences, UNESCO, 7 Place de Fontenoy, 75700 Paris, France.

Marine Science Unit (MSU)
University of the West Indies, Mona, Jamaica.

National Marine Fisheries Service (NMFS)
Galveston Laboratory, 4700 Avenue U, Galveston, Texas 77550, U.S.A.

Ocean Economics and Technology Branch (OETB)
United Nations, 1 UN Plaza, New York 10017, USA.

United Nations Development Programme (UNDP)
One, United Nations Plaza, New York, N.Y. 10017, U.S.A.

United Nations Educational, Scientific and Cultural Organisation (UNESCO)
For UNESCO's major Interregional Project on Research and Training leading to Integrated Management of Coastal Systems in S.E. Asia (COMAR) - information from the Division of Marine Sciences, Paris, or the UNESCO Regional office for Science and Technology for Southeast Asia, JL Thamrin 14, Jakarta, Indonesia. Components for Africa and for Latin America and the Caribbean are COMARF and COSALC.

United Nations Environment Programme (UNEP)
P.O. Box 30552, Gigiri, Kenya.

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