



**The Application Of Littoral Vulnerability
Assessment Into The Integrated Coastal Zone
Management Process of Barbados, West Indies.**

**A thesis submitted to Cardiff University for the
Degree of Philosophiae Doctor**

by

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ABSTRACT

This research focuses on applying littoral vulnerability assessment (LVA) into the coastal management process of Barbados, W. I. using a multipurpose rapid assessment technique, making the most of limited data and process knowledge. The conceptual and theoretical components of coastal vulnerability assessment set the context on which the LVA process is built. Three environmental sensitivity indices (ESIs) have been developed to using to a selection of the variables to characterise the coastline.

Seventy four coastal locations are described according to the following ESIs: - Wave Exposure Index, Coastal Sensitivity Index, and Beach Aesthetic Index. These respectively represent the coastline being 92% being sheltered; 64% having a high to very high sensitivity to oil pollution; and 51% being of good to very good aesthetic quality. Factor and cluster analyses were used to develop Coastal Vulnerability and Degree of Risk Indices. Twenty three coastal segments were analysed of which 52% were considered to be high to very highly vulnerable to erosion and potential storm wave damage. The south coast's most vulnerable locations are Casuarina, Dover and St. Lawrence; while west coast locations are Fitts Village, Paynes Bay and Sandy Lane. The highest degrees of risk locations identified were Casuarina, St. Lawrence, Batts Rock, Dover and Carlisle Bay. The research has also interpreted case studies using GIS and available socio economic information to quantify property vulnerability based on potential economic loss value. These results show that 88% of the coast is fully urbanized, with 63% being used in tourism infrastructure and having the greatest land value. The thesis also includes the construction of LVA profile model, which is intended to: 1) contribute to the formulation of future coastal management policies in Barbados and 2) provide an easy to implement monitoring procedure for small islands embarking on coastal management initiatives.

The research demonstrates the use of scientifically valid yet inexpensive methods of quantitative shoreline monitoring and assessment, which could be of practical value in the coastal management of Small Island Developing States.

Do Noble Deeds

***“The heights of great men reached and kept,
were not attained by sudden flight;
but they, whilst their companions slept,
kept toiling upward through the night.”***

School Motto
St. Giles Boys Primary School
The Ivy,
St. Michael, Barbados

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With out struggle there is no progress !.... The struggle continues!

¹ "One word more is one word less to write, and one word closer to the end!"

Contents

Declaration	
Abstract	i
Acknowledgements	iii
Contents	iv
List of Figures	xii
List of Tables	xviii
Abbreviations	xx

Part I: The Conceptual Basis of Littoral Vulnerability Assessment

Chapter 1	Introduction.....	1
Chapter 2	Definitions and Background on Barbados W.I.....	15
Chapter 3	Literature Analysis of Coastal Classification and Coastal Vulnerability Indices	45

Part II: Research Investigation, Analysis and Interpretation

Chapter 4	Strategic Overview of Littoral Vulnerability Assessment Methodology ...	79
Chapter 5	Development of Environmental Sensitivity Indices of Littoral Vulnerability Assessment	119
Chapter 6	The Determination of the Coastal Vulnerability Index	206
Chapter 7	Quantification of Coastal Risk Using Geographic Information System Analysis	262
Chapter 8	Public Perception and Littoral Vulnerability Assessment.....	315

Part III: Integration of Littoral Vulnerability Assessment into the Integrated Coastal Zone Management Process

Chapter 9	Littoral Vulnerability Assessment Model and its Incorporation into the Integrated Coastal Zone Management Process.....	389
Chapter 10	Thesis Summary and Recommendations.....	455

Detailed Chapter Contents

Chapter 1 Introduction

1.1 INTRODUCTION.....	1
1.2 GENERIC COASTAL HAZARDS	1
1.3 RATIONALE FOR THE RESEARCH.....	5
1.3.1 SUSTAINABLE DEVELOPMENT AND SMALL ISLAND VULNERABILITY	5
1.3.2 RESEARCH AIMS AND OBJECTIVES.....	6
1.4 RESEARCH METHODOLOGY	8
1.4.1 LITERATURE REVIEW AND DESK TOP STUDY	10
1.4.2 FIELD DATA COLLECTION AND DETERMINATION OF LITTORAL VULNERABILITY INDICES	10
1.4.3 CASE STUDY INVESTIGATIONS.....	11
1.4.4 APPLICATION OF PUBLIC PERCEPTION QUESTIONNAIRES	11
1.5 THE RESOLUTION OF THE RESEARCH PROBLEM.....	12
1.6 THESIS STRUCTURE	12
1.7 JUSTIFICATION OF RESEARCH.....	13

Chapter 2 Definitions and Background on Barbados W.I.

2.1 INTRODUCTION.....	15
2.1.1 VULNERABILITY – SETTING THE CONTEXT.....	15
2.2 DEFINITION OF TERMINOLOGY.....	16
2.2.1 VULNERABILITY.....	16
2.2.2 COASTAL ZONE.....	19
2.2.3 INTEGRATED COASTAL ZONE MANAGEMENT	19
2.3 NATURAL COASTAL HAZARD EFFECTS.....	21
2.3.1 NATURAL COASTAL HAZARDS.....	21
2.4 SEA LEVEL RISE AND COASTAL VULNERABILITY: A CHALLENGE FOR SMALL ISLAND STATES	25
2.5 THE CARIBBEAN REGION AND ITS VULNERABILITY.....	28
2.6 COASTAL DESCRIPTION OF BARBADOS	30
2.6.1 LOCATION AND COASTAL FORM	30
2.6.2 COASTAL HABITATS AND ECOSYSTEMS OF BARBADOS.....	31
2.6.3 BARBADOS’ COASTAL DEVELOPMENT ASSETS.....	37
2.6.4 BARBADOS’ NATURAL HAZARD AND VULNERABILITY ISSUES.....	39

2.6.5 THE NEED FOR SYSTEMATIC RISK AND VULNERABILITY ASSESSMENT.....	42
2.7 SUMMARY	43

Chapter 3 Literature Analysis of Coastal Classification and Coastal Vulnerability Indices

3.1 INTRODUCTION.....	46
3.2 GENERAL DEVELOPMENT OF COASTAL VULNERABILITY ASSESSMENT CLASSIFICATION SCHEME.....	47
3.2.1 APPROACHES TO COASTAL VULNERABILITY ASSESSMENT.....	48
3.2.2 RAPID ASSESSMENT PROCEDURES IN COASTAL MANAGEMENT.....	51
3.3 PURPOSE OF COASTAL VULNERABILITY ANALYSIS	52
3.3.1 PURPOSE OF CVI DEVELOPMENT AND APPLICATION	52
3.3.2 APPLICATION PURPOSE OF CVI.....	55
3.4 SCALE OF APPLICATION	57
3.4.1 APPLICATION TO BARBADOS.....	61
3.5 REVIEW OF VARIABLES USED TO DOCUMENT COASTAL CLASSIFICATION AND COASTAL VULNERABILITY INDICES.	62
3.5.1 VARIABLE SELECTION	62
3.5.2 NUMBER AND RANGE OF VARIABLES	63
3.5.3 SPECIFIC CATEGORIES	64
3.5.4 APPLICATION TO BARBADOS.....	66
3.6 DATA COLLECTION PROCEDURES USED	69
3.6.1 APPLICATION TO BARBADOS.....	69
3.7 SCORING AND RANKING PROCESSES.....	71
3.7.1 QUALITATIVE MEASUREMENTS	71
3.7.2 QUANTITATIVE AND SEMI-QUANTITATIVE MEASUREMENTS.	72
3.8 DATA ANALYSIS	73
3.8.1 CONCERNS ARISING FROM THE REVIEWED DATA ANALYSIS TECHNIQUES.....	74
3.8.2 APPLICATION TO BARBADOS.....	75
3.9 PRESENTATION FORMAT	75
3.9.1 APPLICATION TO BARBADOS.....	76
3.10 SUGGESTIONS FOR FURTHER STUDY	76
3.10.1 APPLICATION TO BARBADOS.....	77
3.11 CONCLUSION	78

Chapter 4 Strategic Overview of Littoral Vulnerability Assessment Methodology

4.1 INTRODUCTION.....	79
4.2 LITTORAL VULNERABILITY ASSESSMENT METHODOLOGY.....	80
4.2.1 LVA METHODOLOGY DESCRIPTION	80
4.2.2 APPLIED METHODOLOGY AND ANALYSIS.....	88
4.3 METHODOLOGY USED IN THE SELECTION OF VARIABLES	89
4.4 COASTAL ZONING METHODOLOGY	90
4.4.1 COASTAL BOUNDARIES DEFINITION.....	91
4.4.2 COASTAL HAZARD ZONE.....	93
4.4.3 SHORELINE DESCRIPTIONS.....	93
4.5 CASE STUDY AREA DESCRIPTIONS.....	98
4.5.1 WEST COAST LOCATIONS	100
4.5.2 SOUTH COAST.....	106
4.6 DESIGN OF FIELD SAMPLING PROGRAM	110
4.6.1 SELECTION AND LOCATION OF SITES.....	110
4.6.2 DATA COLLECTION PROCEDURES	111
4.6.3 DATA RECORDING PROCEDURES.....	113
4.7 SUMMARY	116

Chapter 5 Development of Environmental Sensitivity Indices for Littoral Vulnerability Assessment

5.1 INTRODUCTION.....	118
5.2 DETERMINATION OF THE WAVE EXPOSURE INDEX	119
5.2.1 VARIABLE DESCRIPTORS	119
5.2.2 PROCEDURE	119
5.2.3 WEI RESULTS - INTERPRETATION OF THE BARBADOS FINDINGS.....	121
5.2.4 DISCUSSION	128
5.2.5 EVALUATION OF THE TECHNIQUE USED	129
5.2.6 RECOMMENDATIONS	133
5.3 DETERMINATION OF THE COASTAL SENSITIVITY INDEX	134
5.3.1 VARIABLE DESCRIPTORS	135
5.3.2 PROCEDURE	137
5.3.3 CSI RESULTS - INTERPRETATION OF THE BARBADOS FINDINGS	138

5.3.4 DISCUSSION	145
5.3.5 EVALUATION OF THE TECHNIQUE.....	151
5.3.6 RECOMMENDATIONS	155
5.4. DETERMINATION OF THE BEACH AESTHETIC INDEX.....	156
5.4.1 CHECKLIST ADAPTATIONS TO SUIT THE BARBADOS COAST	157
5.4.2 PROCEDURE	166
5.4.3 BAI RESULTS - INTERPRETATION OF THE BARBADOS FINDINGS.....	167
5.4.4 DISCUSSION	184
5.4.5 EVALUATION OF THE TECHNIQUE.....	185
5.4.6 RECOMMENDATIONS	192
5.5 SUMMARY	193

Chapter 6 The Determination of the Coastal Vulnerability Index

6.1 INTRODUCTION.....	206
6.2 DETERMINATION OF THE COASTAL VULNERABILITY INDEX.....	206
6.2.1 VARIABLES	206
6.2.2 LITTORAL VARIABLE DESCRIPTIONS.....	210
6.3 COASTAL VULNERABILITY INDEX METHODOLOGY	213
6.3.1 PROCEDURE FOR SHORELINE CLASSIFICATION ANALYSIS	213
6.3.2 DEGREE OF URBANISATION PROCEDURE	215
6.3.3 EVALUATION OF COASTAL VULNERABILITY	215
6.3.4 DEGREE OF RISK	215
6.4 COASTAL VULNERABILITY INDEX RESULTS	216
6.4.1 INTERPRETATION OF RESULTS FOR DETERMINING THE COASTAL VULNERABILITY INDEX.....	216
6.4.2 CLUSTER ANALYSIS	226
6.4.3 COASTAL SEGMENT ZONATION DETERMINED BY CLUSTER ANALYSIS	232
6.4.4 COASTAL VULNERABILITY DETERMINATION USING FACTOR ANALYSIS.....	237
6.4.5 DEGREE OF RISK	252
6.5 DISCUSSION	255
6.6 EVALUATION OF THE TECHNIQUE USED	257
6.6.1 VARIABLES USED IN THE BARBADOS EXPERIENCE AND THEIR APPLICATION IN A WIDER CONTEXT	257
6.6.2 AVAILABLE DATA	257
6.6.3 ECONOMIC COST	257
6.6.4 LOGISTICS AND ADMINISTRATION.....	260
6.7 RECOMMENDATIONS.....	260

6.7.1 MODIFICATION OF THE TECHNIQUE.....	260
6.8 SUMMARY	261

Chapter 7 Quantification of Coastal Risk Using Geographic Information System Analysis

7.1 INTRODUCTION.....	262
7.2 REVIEW OF GEOGRAPHIC INFORMATION SYSTEM USE IN COASTAL MANAGEMENT.....	262
7.3 QUANTIFICATION OF SHORELINE RISK METHODOLOGY	265
7.3.1 INTRODUCTION.....	265
7.3.2 RESULTS OF GIS RISK QUANTIFICATION.....	271
7.3.3 DISCUSSION	278
7.4 METHODOLOGY FOR ECONOMIC VULNERABILITY DETERMINATION.....	283
7.4.1 INTRODUCTION.....	283
7.4.2 RESULTS OF ECONOMIC VULNERABILITY DETERMINATION.....	285
7.4.3 DISCUSSION	304
7.4.4 RECOMMENDATIONS	310
7.5 SUMMARY	314

Chapter 8 Public Perception and Littoral Vulnerability Assessment

8.1 INTRODUCTION.....	315
8.2 REVIEW OF PUBLIC PERCEPTION AND LITTORAL VULNERABILTY	316
8.2.1 INTEGRATION OF PUBLIC PERCEPTION.....	318
8.2.2 LINKAGE BETWEEN PUBLIC PERCEPTION AND LVA.....	319
8.3 PUBLIC PERCEPTION QUESTIONNAIRE AIMS	320
8.3.1 BEACH USER QUESTIONNAIRE AIMS.....	321
8.3.2 PROPERTY OWNER QUESTIONNAIRE AIMS	322
8.4 QUESTIONNAIRE METHODOLOGY	323
8.4.1 QUESTION DESIGN AND STYLE	323
8.4.2 COASTAL PROPERTY OWNER SURVEY.....	329
8.4.3 RESPONSE RATES	337
8.5 QUESTIONNAIRE RESULTS.	341
8.5.1 PUBLIC BEACH USER QUESTIONNAIRE.....	341

8.5.2 PROPERTY OWNER QUESTIONNAIRE RESULTS.....	355
8.6 DISCUSSION	373
8.6.1 BEACH USER PERCEPTION SURVEY.....	373
8.6.2 PROPERTY OWNER PERCEPTION SURVEY	376
8.7 EVALUATION OF THE TECHNIQUE USED	379
8.7.1 QUESTIONNAIRE STYLES AND ADMINISTRATION USED IN THE BARBADOS EXPERIENCE AND THEIR APPLICATION IN A WIDER CONTEXT	380
8.7.2 ECONOMIC COST.....	380
8.7.3 MODIFICATIONS TO QUESTIONNAIRES.....	383
8.8 SUMMARY.....	384
8.8.1 BEACH USER SURVEY	384
8.8.2 PROPERTY OWNER’S SURVEY	386

Chapter 9 Littoral Vulnerability Assessment Model and its Incorporation into the Coastal Zone Management Process

9.1 INTRODUCTION.....	388
9.2 EVALUATION OF THE LVA PROCESS.....	388
9.2.1 Discussion on the LVAP Model Developed.....	388
9.2.2 Model Structure Issues	393
9.2.3 Model Data Considerations.....	394
9.2.4 Selection Assessment of Methodologies and Variables.....	402
9.2.5 Costing Summary of Methodologies Used.....	408
9.3 INTEGRATED CZM IN BARBADOS	417
9.3.1 Phases of the ICZM Process	420
9.3.2 Functional ICZM in Barbados	426
9.4 INCORPORATION OF LITTORAL VULNERABILITY ASSESSMENT INTO THE INTEGRATED COASTAL ZONE MANAGEMENT PROCESS	442
9.4.1 Where Vulnerability Assessment fits in the ICZM Process.....	442
9.4.2 Incorporation of the Research Model into the ICZM Process of Barbados	446
9.5 CONCLUSION.....	451

Chapter 10 Thesis Summary and Recommendations

10.1 INTRODUCTION.....	453
10.2 SUMMARY AND RECOMMENDATIONS.....	454

10.2.1 DEVELOPMENT OF INDICES454
10.2.2 RISK QUANTIFICATION AND POTENTIAL ECONOMIC LOSS OF COASTAL PROPERTY
.....457
10.2.3 PUBLIC PERCEPTION CONSIDERATIONS458
10.2.4 MODEL DEVELOPMENT.....460
10.3 RECOMMENDATIONS.....462
10.3.1 A VIEW OF THE WAY AHEAD.....464

References

List of Figures

Chapter 1

Figure 1.1	Coastal Environment Descriptors	3
Figure 1.2a	Natural Hazards and Disaster Sources of Vulnerability	4
Figure 1.2b	Social Pressure Sources for Social Vulnerability	4
Figure 1.3	The Research Process	9

Chapter 2

Figure 2.1	The Coastal Zone	20
Figure 2.2	Coastal Geohazards Descriptors	23
Figure 2.3	Map of Wider Caribbean Region	28
Figure 2.4	Map of Barbados Coastal Physiographic Form	31
Figure 2.5	Offshore Bathymetry of Barbados	34
Figure 2.6	Types of Wave Generation Mechanisms in the Caribbean Sea	35
Figure 2.7	Plot of Hourly Wave Height as a Function of Wave Direction	36
Figure 2.8	Wave Height Rose offshore Barbados	36
Figure 2.9	Map of Barbados Coastal Industry Locations	38
Figure 2.10	Major Meteorological Hazard Types Affecting Barbados	39
Figure 2.11	Hazard Ecology of Barbados	45

Chapter 3

Figure 3.1	Applied Use of CVIs found in Literature	56
Figure 3.2	Applied Scales of Multidisciplinary Approaches to CVA in Literature	60
Figure 3.3	Analysis Methods used to Determine Coastal Classification and CVIs	74
Figure 3.4	Proposed Future Data Requirements for Incorporation into CVA	77

Chapter 4

Figure 4.1	Proposed Methodology for Determining a Littoral Vulnerability Assessment Profile	82
Figure 4.2	Variable and Criteria Selection Process	90
Figure 4.3	Map of Coastal Boundaries Used in Thesis	92
Figure 4.4	Maps of West Coast Case Study Locations	99
Figure 4.5	Map of South Coast Case Study Locations	99
Figure 4.6	Map of Weston, St. James to Porters, St James	101

Figure 4.7	Map of Holetown St. James to Sandy Lane bay St. James	103
Figure 4.8	Map of Freshwater Bay St. Michael to Brandons St. Michael	105
Figure 4.9	Map of Hastings Rocks St. Michael to Rockley Christ Church	107
Figure 4.10	Map of Casuarina Beach Christ church to Oistins Christ Church	109

Chapter 5

Figure 5.1a	West Coast Beaches: Overall Aesthetic Percentage Scores	168
Figure 5.1b	South Coast Beaches: Overall Aesthetic Percentage Scores	168
Figure 5.2a	Percentage Scores for Physical Factors on West Coast Beaches	173
Figure 5.2b	Percentage Scores for Biological Factors on West Coast Beaches	175
Figure 5.2c	Percentage Scores for Human Use Factors on West Coast Beaches	177
Figure 5.3a	Percentage Scores for Physical Factors on South Coast Beaches	179
Figure 5.3b	Percentage Scores for Biological Factors on South Coast Beaches	180
Figure 5.3c	Percentage Scores for Human Use Factors on South Coast Beaches	183
Figure 5.4a	Map of South Coast – South Point to Oistins	196
Figure 5.4b	Map of South Coast – Welches to Worthing	197
Figure 5.4c	Map of South Coast – Cacrabank to Needham’s Point	198
Figure 5.4d	Map of South Coast – Needham’s Point to Bridgetown	199
Figure 5.5a	Map of West Coast – Bridgetown to Fitts Village	200
Figure 5.5b	Map of West Coast – Fitts Village to Almond Beach Club	201
Figure 5.5c	Map of West Coast – Regent to Mount Standfast	202
Figure 5.5d	Map of West Coast – Mount Standfast to Gibbs	203
Figure 5.5e	Map of West Coast – Gibbs to Almond Beach Village	204
Figure 5.5f	Map of West Coast – Port St. Charles to Fryers Well Bay	205

Chapter 6

Figure 6.1	Decision flow Chart for Use in CVI Development	209
Figure 6.2a	Positive Correlation between Beach Slope and Beach Elevation	220
Figure 6.2b	Positive Correlation between Beach Slope and Beach Sediment Size	220
Figure 6.2c	Positive Correlation between Beach Volume and Beach Width	221
Figure 6.2d	Positive Correlation between Beach Width and Beach Elevation	222
Figure 6.3a	Negative Correlation between Beach Sediment Size and Wave Height	224
Figure 6.3b	Negative Correlation between Beach Sediment Size and Wave Period	225
Figure 6.3c	Negative Correlation between Coastal Orientation and Sea Floor Sediment Size	226

Figure 6.4	Dendrogram of All Clustered Variables (Average Linkage Method)	228
Figure 6.5	Dendrogram of 13 Clustered Variables (Average Linkage Method)	230
Figure 6.6	Dendrogram of 14 Clustered Variables (Average Linkage Method)	232
Figure 6.7	Dendrogram of Coastal Segment Clusters (Average Linkage Method)	234
Figure 6.8a	Map of South Coast – South Point to Oistins	241
Figure 6.8b	Map of South Coast – Welches to Worthing	242
Figure 6.8c	Map of South Coast – Cacrabank to Needham’s Point	243
Figure 6.8d	Map of South Coast – Needham’s Point to Bridgetown	244
Figure 6.9a	Map of West Coast – Bridgetown to Fitts Village	246
Figure 6.9b	Map of West Coast – Fitts Village to Almond Beach Club	247
Figure 6.9c	Map of West Coast – Regent to Mount Standfast	248
Figure 6.9d	Map of West Coast – Mount Standfast to Gibbs	249
Figure 6.9e	Map of West Coast – Gibbs to Almond Beach Village	250
Figure 6.9f	Map of West Coast – Port St. Charles to Fryers Well Bay	251
Figure 6.10	Degree of Risk of Coastal Segment	253
 Chapter 7		
Figure 7.1a	Percentage Areal Urbanisation Types along Study Areas	273
Figure 7.1b	Percentage Total Areal Beach Coverage for Study Areas	273
Figure 7.1c	Percentage Areal Commercial Coverage for Study Areas	273
Figure 7.1d	Percentage Areal Residential Coverage for Study Areas	274
Figure 7.1e	Percentage Total Residential and Tourism Coverage for Study Areas	274
Figure 7.2	Proportion of Linear Features along Study Areas	276
Figure 7.3	Total Length of Structures found along Study Area	276
Figure 7.4	Percentage Total Structure Length of Study Areas	277
Figure 7.5	Cumulative Road Network Length for Study Areas	277
Figure 7.6	Proportional Land use Classification for the Case Study Areas	286
Figure 7.7	Potential Vulnerability Loss Value per Land Use Category for Combined Study Areas	286
Figure 7.8	Proportional Land Use Classification for the West Coast Study Area	288
Figure 7.9	Potential Vulnerability Loss Value per Land Use Category for Combined Study Areas	289
Figure 7.10	Potential Land Area Vulnerable to Loss in the West Coast Study Areas	289
Figure 7.11	Proportional Land Use Classification for the South Coast Study Areas	290
Figure 7.12	Potential Vulnerability Loss Value per Land Use Category for Combined	

	Study Areas	290
Figure 7.13	Potential Land Area Vulnerable to Loss in the South Coast Study Areas	291
Figure 7.14	Proportional Land Use Classification for Weston to Mount Standfast Coastline	292
Figure 7.15	Potential Vulnerability Loss Value per Land Use Category for Weston to Mount Standfast	292
Figure 7.16	Percentage Land Area Vulnerable to Loss in Weston to Mount Standfast Study Area	293
Figure 7.17	Percentage Contribution to Land Values for Weston to Mount Standfast Study Area	294
Figure 7.18	Proportional Land use Classification for the Holetown to Sandy Lane Study Area	295
Figure 7.19	Potential Vulnerability Loss Value per Land Use Category for Holetown to Sandy Lane Study Area	295
Figure 7.20	Percentage Land Area Vulnerable to Loss in Holetown to Sandy Lane Study Area	296
Figure 7.21	Percentage Contribution to Land Values for Holetown to Sandy Lane Study Area	296
Figure 7.22	Proportional Land Use Classification for Holetown to Sandy Lane Study Area	297
Figure 7.23a	Potential Vulnerability Loss Value per Land Use Category for Paradise to Brighton Study Area (> GB £ 10 Million)	298
Figure 7.23b	Potential Vulnerability Loss Value per Land Use Category for Paradise to Brighton Study Area (< GB £ 1 Million)	298
Figure 7.24	Percentage Land Area Vulnerable to Loss in Paradise to Brighton Study Areas	299
Figure 7.25	Percentage Contribution to Land Values for Paradise to Brighton Study Area	299
Figure 7.26	Proportional Land Use Classification for Hastings to Rockley Study Areas	300
Figure 7.27	Potential Vulnerability Loss Value per Land Use Category for Hastings to Rockley Study Area	301
Figure 7.28	Percentage Land Area Vulnerable to Loss in Hastings to Rockley Study Area	301
Figure 7.29	Percentage Contribution to Land Values for Hastings to Rockley Study Area	302

Figure 7.30	Proportional Land Use Classification for Dover to Welches Study Area	303
Figure 7.31	Potential Vulnerability Loss Value per Land Use Category for Dover to Welches Study Area	303
Figure 7.32	Percentage Land Area Vulnerable to Loss in Dover to Welches Study Area	304
Figure 7.33	Percentage Contribution to Land Values for Dover to Welches Study Area	304

Chapter 8

Figure 8.1	Postal Survey Response Rate of Case Study Areas	338
Figure 8.2	Interviewee Group Type	341
Figure 8.3	Interviewee Employment Level	342
Figure 8.4	Age of Beach User	342
Figure 8.5	Beach User Length of Stay at Beach	343
Figure 8.6	Beach User Preferred Reason for choosing Beach	344
Figure 8.7	Beach User Preferred Recreational Activity	344
Figure 8.8a	Beach Slope Preference	345
Figure 8.8b	Nearshore Bottom Condition Preference	346
Figure 8.8c	Nearshore Seabed Slope Preference	346
Figure 8.9	Perception of Recreational Use of Beach at Time of Survey	347
Figure 8.10	Perception of Beach Development Level	348
Figure 8.11	Perception of Murky Water as Poor Water Quality Indicator	349
Figure 8.12	Beach User Priority Ranking of Problems Affecting the Beach	351
Figure 8.13a	Beach Cleanliness Issues Considered in Beach Selection	354
Figure 8.13b	Beach Facility Issues Considered in Beach Selection	354
Figure 8.13c	Beach Safety Issues Considered in Beach Selection	354
Figure 8.14	Public Perception of Beach Quality	355
Figure 8.15	Proportion of Property types found in Combined Study Areas	356
Figure 8.16	Property Owner Association to Property	356
Figure 8.17	Length of Property Owner Association to Property	356
Figure 8.18	Property Owner Perception of Coastal Issues Awareness	357
Figure 8.19	Percentage Ranked Order of Information Sources (Coastal Issues)	357
Figure 8.20	Property Owner Perception of Responsibility for Correcting Beach Erosion	359
Figure 8.21	Property Damage Suffered as a Result of Storm Wave Action	360
Figure 8.22	Frequency of Property Damage	360
Figure 8.23	Property Owner Perception of Coastal Hazard Awareness	362
Figure 8.24	Percentage Ranked Order of Information Sources (Coastal Hazards)	363

Figure 8.25	Property Owner Selection of Best Option in Event of Property Damage due to Storm Event	365
Figure 8.26	Property Owners that have Seen the ICZMP	365
Figure 8.27	Property Owner Perception of Usefulness of ICZMP	368
Figure 8.28	Ranked Priority of Coastal Hazards of Concern to Property Owners	369
Figure 8.29	Categories of Identified Threats Based on Questionnaire Responses	370
Figure 8.30	Most Frequently Chosen Coastal Hazards Based on First and Second Ranked Priority Options	370
Figure 8.31	Most Frequently Chosen Coastal Hazards Based on First and Second Ranked Priority Options (and the Third Ranked Priority Equivalent)	371
Figure 8.32	Total Responses for the Most Frequently Selected Coastal Hazards in First 3 Rankings	372
Figure 8.33	Property Owner Perception of Property Risk from Coastal Hazards	372
Figure 8.34	Property Owner Identified Priority Problems	372
Figure 8.35	Property Owner Assessment of Risk to their Property	372
Chapter 9		
Figure 9.1	Research Model Developed for Determining the LVAP for Coastlines	390
Figure 9.2	Sources of Uncertainty	398
Figure 9.3	Basic Components of the Barbados Coastal Zone Management Process	419
Figure 9.4	Project Life Cycle followed in the Development of the Barbados Coastal Zone Management Programme	422
Figure 9.5	Present Coastal Management System In Barbados	428
Figure 9.6a	Main Legal and Institutional Framework and Management Instruments Applied to the Integrated Management of the Barbados Coastline	436
Figure 9.6b	Structural and Administrative Framework for Primary ICZM Requirements in Barbados	437
Figure 9.7	Vulnerability Assessment Linkage Between Research, Monitoring and the Policy Decision-Making Process	442
Figure 9.8	Framework for Integrated Coastal Zone Management and the Incorporation of Impact and Vulnerability Assessment	445
Figure 9.9a	Expanded Coastal Zone Management Programme with LVAP Inclusion	448
Figure 9.9b	Expanded Coastal Zone Management Programme with LVAP Model Inclusion	450

List of Tables

Chapter 2

Table 2.1	Definitions used in Research	17
Table 2.2	Summary of Natural actors Affecting Shoreline Change	24
Table 2.3	Effects of Coastal Flooding due to Accelerated Sea Level Rise	26
Table 2.4	Vulnerability Characteristics of Small Island Developing States	27
Table 2.5	Vulnerability to Natural Hazards of Caribbean Countries	29
Table 2.6	Main Coastal Ecosystems of Barbados	32

Chapter 3

Table 3.1	Comparative Stages between Common Methodology and Technical Guidelines	49
Table 3.2	Application Scales derived from the Literature	58
Table 3.3	Examples of Funding Sources for CVI Development	61
Table 3.4	Summary of Some Indicator Selection Criteria	65
Table 3.5	Variable Groupings identified from Literature Review	67
Table 3.6	Summary of Data Collection Procedures for Variable Types	70

Chapter 4

Table 4.1	Methodology and Results Chapter Titles	79
Table 4.2	Variables used in LVAP Category Descriptions	83
Table 4.3	Coastal Descriptions for Selected Case Study Areas	95
Table 4.4	Case Study Locations	97
Table 4.5a	Terrestrial Field Data Sheet for Collecting Site Variable Data	114
Table 4.5b	Marine Field Data Sheet for collecting Site Variable Data	115

Chapter 5

Table 5.1a	Value Ranges Developed for Exposure Scale Determination for South Coast Segments	121
Table 5.1b	Value Ranges used in Exposure Scale and WEI Determination	121
Table 5.2	Summary of Exposure Scale for South Coast	122
Table 5.3	Summary of Exposure Scale for West Coast	123
Table 5.4a	Beach Safety Rating Table	125

Table 5.4b	Summary Beach Rating Scale for South Coast Locations	126
Table 5.4c	Summary Beach Rating Scale for West Coast Locations	127
Table 5.5	Main Equipment Items used in the Determination of WEI	129
Table 5.6	Cost Associated with the Determination of WEI	132
Table 5.7a	Sensitivity Criteria for Coastal Habitats on West and South Coasts	139
Table 5.7b	Weighting Factors of Sensitivity and Total Relative Response for Protection Priority	140
Table 5.8a	Sensitivity Classification Developed for Coastal Habitats	141
Table 5.8b	Determination of Environmental Protection Priority and CSI	141
Table 5.9	Coastal Sensitivity Index Comparison for Coastal Habitats	147
Table 5.10	Main Equipment Items used in the Determination of WEI	152
Table 5.11	Cost Associated with the CSI Determination	154
Table 5.12a	Modified Variables in BAI Checklist	158
Table 5.12b	Beach Rating Checklist	161
Table 5.13a	Summary Results for West Coast Beach Aesthetic Quality	169
Table 5.13b	West Coast Beach Aesthetic Quality Rating	169
Table 5.13c	West Coast BAI and Rankings	170
Table 5.14a	Summary Results for South Coast Beach Aesthetic Quality	171
Table 5.14b	South Coast Beach Aesthetic Quality Rating	171
Table 5.14c	South Coast BAI and Rankings	171
Table 5.15a	West Coast Beaches with Very Good Physical Factors	173
Table 5.15b	West Coast Beaches with Very Good Biological Factors	174
Table 5.15c	West Coast Beaches with Very Good Human Use Factors	176
Table 5.16a	South Coast Beaches with Very Good Physical Factors	179
Table 5.16b	South Coast Beaches with Very Good Biological Factors	180
Table 5.16c	South Coast Beaches with Very Good Human Use Factors	182
Table 5.17	Equipment Items used to increase the Accuracy of the Variables Measured	188
Table 5.18a	Main Equipment Items used in Determining BAI	190
Table 5.18b	Cost Associated with the BAI Determination	191
Table 5.19	Key for Representation of Indices on Study Area Maps	195
 Chapter 6		
Table 6.1	Positively Correlated Variables	219
Table 6.2	Negatively Correlated Variables	223
Table 6.3	Normalised Varimax Factor Components	239

Table 9.5	Stages for Integrated Coastal Zone Management	421
Table 9.6	Current Government Agencies involved in ICZM in Barbados	438

List of Abbreviations

ASLR	Accelerated Sea Level Rise
BAI	Beach Aesthetic Index
CC	Coastal Classification
CERO	Central Emergency Relief Organization
CPACC	Caribbean Planning for Adaptation to Climate Change
CSI	Coastal Sensitivity Index
CZMU	Coastal Zone Management Unit
CZ	Coastal Zone
CM	Coastal Management
CVI	Coastal Vulnerability Index
CVA	Coastal Vulnerability Assessment
DEFRA	Department of Environment Food and Rural Affairs
EVI	Environmental Vulnerability Index
ESI	Environmental Sensitivity Index
IUCN	International Union for the Conservation of Nature and Natural Resources
ICZMP	Integrated Coastal Zone Management Plan
IDNDR	International Decade for Natural Disaster Reduction
IPCC	Intergovernmental Panel on Climate Change
IRF	Island Resource Foundation
LVA	Littoral Vulnerability Assessment
LVAP	Littoral Vulnerability Assessment Profile
NCC	National Conservation Commission
OAS	Organisation of American States
PDP	Physical Development Plan
SIDS	Small Island Developing State
TCPO	Town and Country Planning Office
UNCED	United Nations Conference on Environment and Development
UNEP	United Nations Environment Programme
WEI	Wave Exposure Index

Chapter 1

Introduction

Chapter 1

Introduction

1.1 INTRODUCTION	1
1.2 GENERIC COASTAL HAZARDS.....	1
1.3 RATIONALE FOR THE RESEARCH	5
1.3.1 SUSTAINABLE DEVELOPMENT AND SMALL ISLAND VULNERABILITY	5
1.3.2 RESEARCH AIMS AND OBJECTIVES	6
1.3.2.1 Aim.....	6
1.3.2.2 Objectives	6
1.4 RESEARCH METHODOLOGY	8
1.4.1 LITERATURE REVIEW AND DESK TOP STUDY	10
1.4.2 FIELD DATA COLLECTION AND DETERMINATION OF LITTORAL VULNERABILITY INDICES.....	10
1.4.2.1 Determination of an Environmental Sensitivity Index System for Beaches.....	10
1.4.2.2 Multivariate Analysis for the Development of a Coastal Vulnerability Index...	11
1.4.3 CASE STUDY INVESTIGATIONS	11
1.4.4 APPLICATION OF PUBLIC PERCEPTION QUESTIONNAIRES.....	11
1.5 THE RESOLUTION OF THE RESEARCH PROBLEM	12
1.6 THESIS STRUCTURE.....	12
1.7 JUSTIFICATION OF RESEARCH	13

1.1 INTRODUCTION

This thesis investigates the development and incorporation of a low cost littoral vulnerability assessment (LVA) procedure into the existing coastal management (CM) process of Barbados, West Indies, and its potential application to other Small Island Developing States (SIDS). It highlights the main difficulties and opportunities associated with the use of LVA and its role in the process of integrated coastal zone management (ICZM). In order to analyse and evaluate the research, quantitative, and qualitative research methodologies have been used. This introductory chapter establishes the purpose, aims and objectives of the research as well as the thesis' conceptual basis.

1.2 GENERIC COASTAL HAZARDS

Vulnerability can be broadly described as the degree to which a natural system is susceptible to or unable to cope with the effects of external stimuli. The relationship between a hazard and vulnerability generates a condition of risk, and when this situation is inadequately managed, natural disasters occur (Fig 1.2a and Table 2.1). Coastal shorelines are subject to a wide range of geological forces and climatic conditions (Fig. 1.1) that continually shape the coast, and, depending on location, can put life and property at risk (Griggs 1994, The Heinz III Centre 2000a, WCU 2001). On small islands, coastal hazards include flooding, shoreline erosion, as well as wind and wave damage during hurricanes and tropical storms (Solomon and Forbes 1999). Climatic conditions and sea level rise together exacerbate chronic coastline erosion problems, resulting in dramatic losses of beaches and in some instances property.

Human intervention (whether deliberate or inadvertent) to coastal processes can exacerbate the existing hazard potential of an area or introduce detrimental affects to the hazard exposure (Walker 1984)¹. Apart from the natural characteristics of a particular

¹ Reference should be made to Potts and Pettit (1997) who have reviewed many of the coastal geohazards and their impacts, including human accentuated and human induced hazards.

location, its social and economic condition can create additional vulnerability (Fig. 1.2b). In the developing world, natural disasters threaten sustainable development, destroying years of development effort and investments, placing new demands on society for reconstruction and rehabilitation. They can also shift development policies and priorities, often with long-term consequences.

The coastal zone (CZ) is prone to major alterations and modifications arising from planned or unplanned coastal development. It is recognised that with expanding coastal development globally², human life and property in coastal areas are at risk from the effects of coastal hazards. Consequently, there is a pressing need to establish a means of effectively and routinely evaluating: 1) potential risks from coastal processes to development; 2) disaster preparedness; and 3) disaster response. Of primary importance in a small island context is the reduction of deaths during tropical storms, and property damage. These considerations, together with ecosystem sensitivity issues, require environmentally sustainable management approaches to achieve an acceptable balance between the development process needs and the values associated with conservation and environmental protection.

² More than 50% of the world's population lives on coastal plains and another quarter within 60 km of the coast. Two thirds of the world's largest cities with populations greater than 2.5 million are located in coastal and tidal estuarine areas and populations of coastal areas are growing faster than island populations. (Cicin-Sain and Knecht 1998).

Fig. 1.1 Coastal Environment Descriptors (Source: Potts and Pettit 1997)

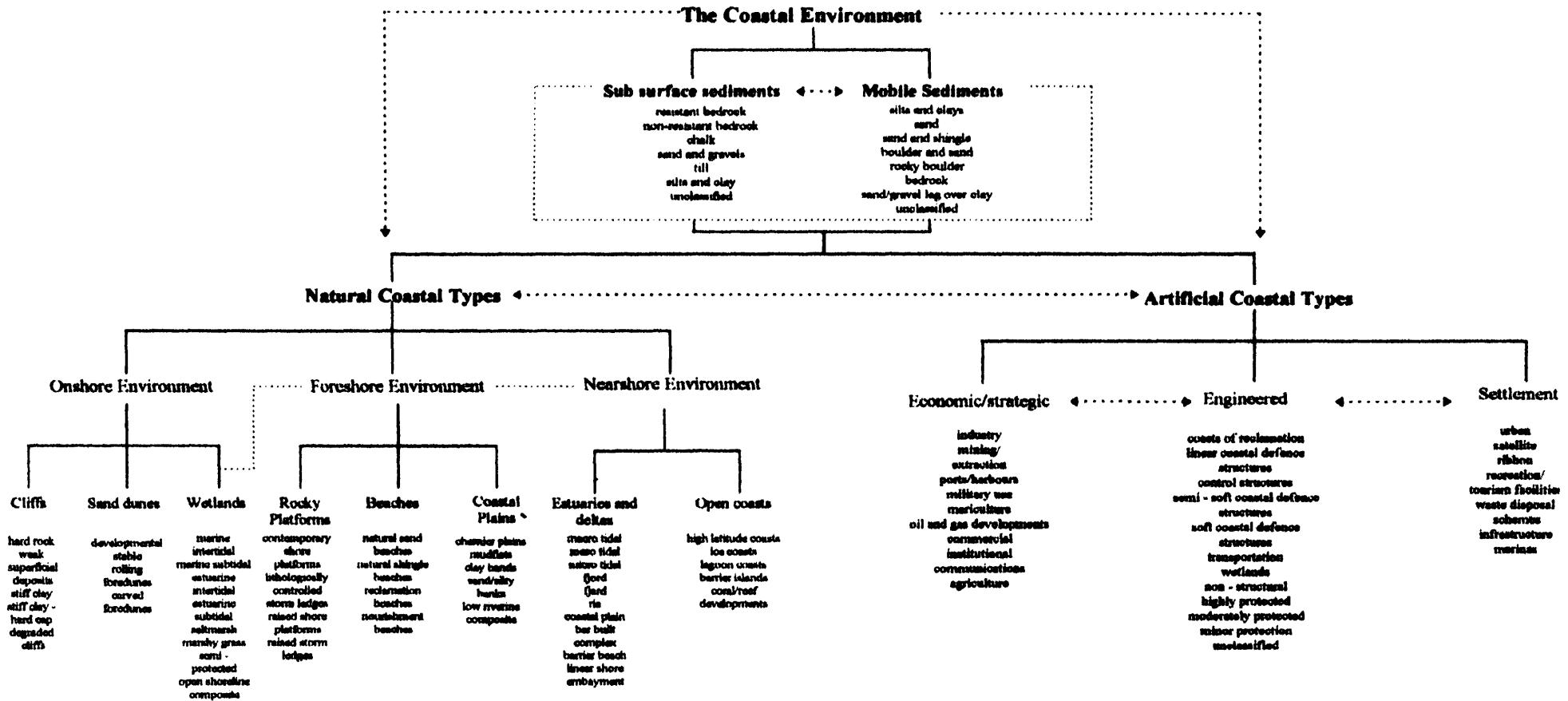


Fig. 1.2a Natural Hazard and Disaster Sources for Natural Vulnerability
(Source: Original)

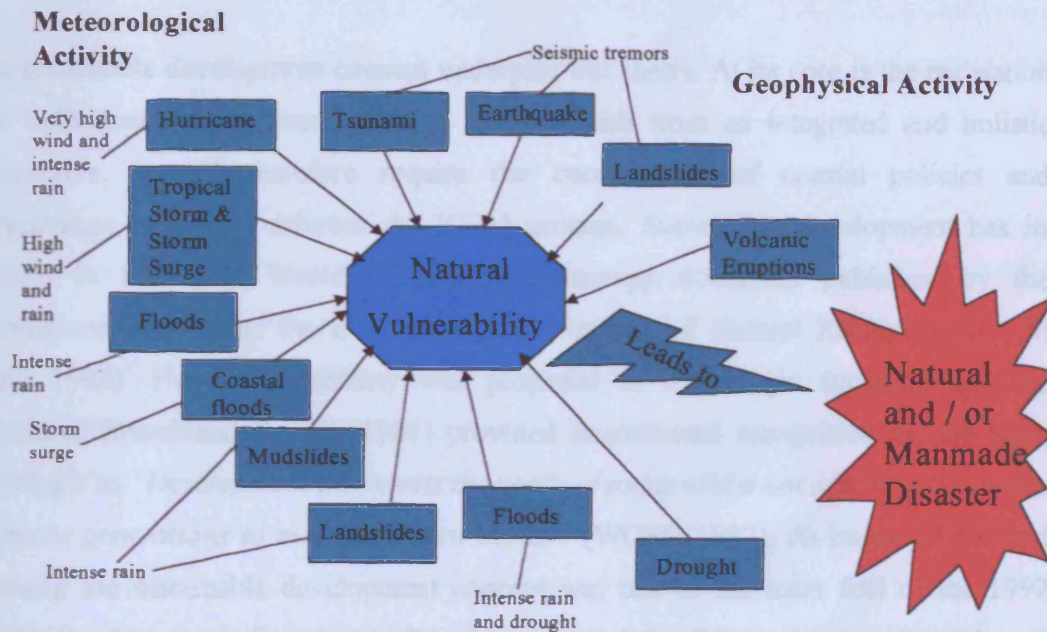
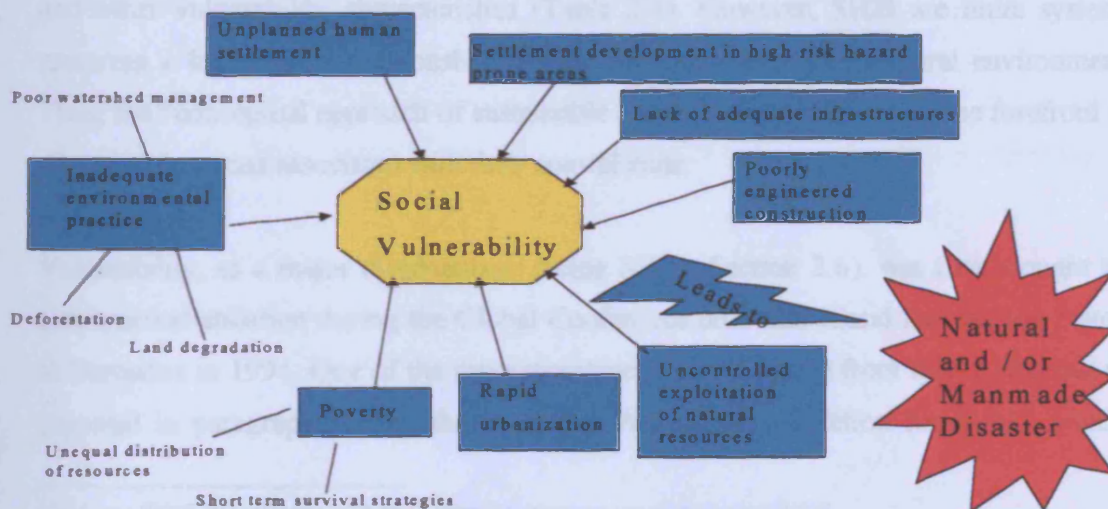


Fig. 1.2b Social Pressure Sources for Social Vulnerability (Source: Original)



1.3 RATIONALE FOR THE RESEARCH

1.3.1 Sustainable Development and Small Island Vulnerability

The sustainable development concept underpins this thesis. At its core is the realisation that individual coastal issues need to be dealt with from an integrated and holistic perspective. It will therefore require the coordination of coastal policies and programmes to further enhance the ICZM process. Sustainable development has its genesis in the 1980 World Conservation Strategy document published by the International Union for the Conservation of Nature and Natural Resources (IUCN) (Reid 1995). Here, sustainability was proposed as a strategic approach and the associated Brundtland Report (1987) provided international recognition for the term, defining it as *“Development that meets the needs of today whilst not affecting the ability of future generations to meet their own needs.”* (WCED 1987). As means of forward planning the sustainable development concept was one of the main foci of the 1992 World Conference on Sustainable Development and the Environment and its plan of action - Agenda 21 - in which Chapter 17, on Oceans and Coasts, presented the key role of sustainable development policies in ICZM.

Barbados, as a SIDS, is trying to achieve sustainable development through better integrated management of its resources, although it is acknowledged that it is generally difficult to achieve total sustainability in SIDS, because of their limited resource base and other vulnerability characteristics (Table 2.4). However, SIDS are finite systems requiring a harmonious relationship between the human and the natural environment. Thus, the “conceptual approach of sustainable development” is always at the forefront of all major decisions associated with their coastal zone.

Vulnerability, as a major disadvantage facing SIDS (Section 2.6), was first brought to international attention during the Global Conference on Small Island Developing States in Barbados in 1994. One of the main recommendations arising from this conference is captured in paragraph 113 of the Barbados Programme of Action for SIDS³, which

³ Refer to SIDS Programme of Action ([http://community.wow.net/eclac/SIDS POA/home.html](http://community.wow.net/eclac/SIDS_POA/home.html))

identifies the need for the development of a vulnerability index to integrate ecological fragility and economic vulnerability. This resulted in the development of an Environmental Vulnerability Index (EVI) procedure for SIDS⁴ (Briguglio 1993, 1995, & 1997, United Nations 1998) (Section 3.2.1), with Pantin (1997), Crowards and Coulter (1998), and Crowards (1999) also having presented other approaches for determining economic and ecological vulnerability indicators.

Given the importance of the shoreline to SIDS, the concept of LVA also has a significant role in long-term coastal sustainable development. Although many coastal hazards are recognised and appreciated by both residents and government in Barbados (Section 2.7.4), it is proposed that, through this research, an improved understanding of littoral processes and the potential impacts of hazard events will contribute to a stronger basis for the implementation of the island's Integrated Coastal Zone Management Plan (ICZMP) (Section 9.4.2). The suggested approach, LVA (Sections 2.2.1.3, 4.2.1 and 9.2.1), will assist in prediction and response planning, ensuring the coast's protection through forward planning and management. Such work has not been attempted before in most small islands and it will be instrumental for the sustainable planning of any island's coastline.

1.3.2 Research Aims and Objectives

1.3.2.1 Aim

To investigate the development and integration of low cost LVA into the ICZM process of a SIDS – Barbados, West Indies (W.I.) - and its potential application to other small island states.

1.3.2.2 Objectives

This aim will be achieved through the following research objectives:

⁴ Refer to SOPAC (1999, 2000 & 2001) for additional details.

1 Variable Identification

To identify a minimum set of variables, which describe short-term environmental dynamics, and are proxies representing the variables on which most processes depend. The use of these variables will provide simple quantitative, qualitative and as far as possible objective tools for rapid identification and assessment of risk potential that are scientifically valid.

2 Coastal Segment Classification

To classify the coastline, subdividing it into stretches and group these based on physical and man-made characteristics. The aim is to provide a valid instrument for coastal planning and management allowing classification for single coastal segments to be then applied to the entire study area.

3 Development of a Rapid Assessment Technique that is Transferable to Other SIDS

To develop a rapid assessment technique that uses *in situ* field variables to characterise the coast. The procedure should have wide application to other small islands where similar littoral process information is limited or needs to be established.

4 Development of Littoral Vulnerability Assessment Profile Model

To construct a scientific tool (a Littoral Vulnerability Assessment Profile (LVAP) Model), based on holistic comprehensive sensitivity indices, that 1) characterises coastal stress and 2) has potential applicability in similar situations where human pressures are experienced. It comprises a series of descriptive indices (Environmental Sensitivity Indices, Coastal Vulnerability Indices and Degree of Risk Indices) representative for each coastal segment.

5 Development of Low Cost Approach to achieve Index Determination

To present a low cost methodology for index development by identifying a cost structure for equipment purchase, data acquisition and processing as well as assessing the methodology's potential application to other small islands.

6 Coastal Economic Valuation within the LVA Process

To provide a risk quantification and an economic valuation of the vulnerability of the coastline as a representation of its potential loss value from storm flooding events.

7 Public Perception Integration in the LVA Process

To demonstrate the role of public perception within the LVA process by determining beach user and coastal property owner perceptions of beach aesthetics and coastline's susceptibility to coastal hazards respectively.

8 LVAP Model Integration in the ICZM process

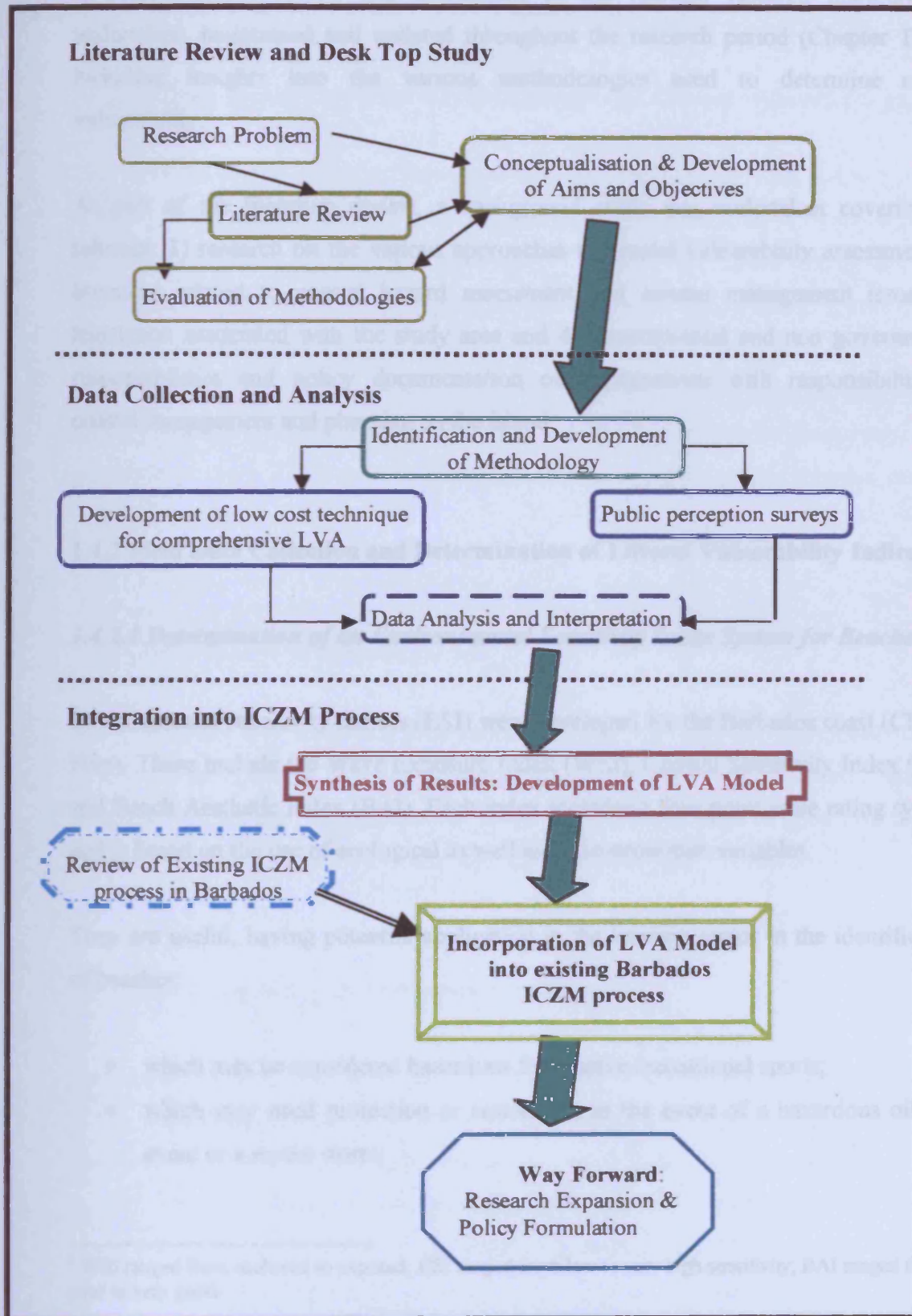
To demonstrate how the developed LVAP model could be integrated within the ICZM programme of a small island.

1.4 RESEARCH METHODOLOGY

As part of the research process a combination of qualitative and quantitative analytical techniques have been employed. The process is split into three main sections: 1) literature review and desktop study; 2) field data collection and case study investigations⁵ and 3) integration into the ICZM process, (Figure 1.3 and Table 1.1). The following subsections describe the sub-components in each of these sections.

⁵This includes public perception surveys.

Fig 1.3 The Research Process (Source: Original)



1.4.1 Literature Review and Desk Top Study

A comprehensive review and assessment of the relevant research literature was undertaken, maintained and updated throughout the research period (Chapter Three), including insights into the various methodologies used to determine coastal vulnerability.

As part of the literature review, a background study was undertaken covering the relevant: 1) research on the various approaches to coastal vulnerability assessment; 2) literature related to coastal hazard assessment and coastal management issues; 3) legislation associated with the study area and 4) governmental and non governmental responsibilities and policy documentation of organisations with responsibility for coastal management and planning on the island.

1.4.2 Field Data Collection and Determination of Littoral Vulnerability Indices

1.4.2.1 Determination of an Environmental Sensitivity Index System for Beaches

Environmental sensitivity indices (ESI) were developed for the Barbados coast (Chapter Five). These include the Wave Exposure Index (WEI), Coastal Sensitivity Index (CSI), and Beach Aesthetic Index (BAI). Each index includes a four point scale rating system⁶ and is based on the use of ecological as well as socio-economic variables.

They are useful, having potential application in the tourism sector in the identification of beaches:

- which may be considered hazardous for passive recreational sports;
- which may need protection or restoration in the event of a hazardous oil spill event or a severe storm;

⁶ WEI ranged from sheltered to exposed; CSI ranged from low to very high sensitivity; BAI ranged from poor to very good.

- which have a high quality rating and may be of popular use that may need aesthetic improvements.

1.4.2.2 Multivariate Analysis for the Development of a Coastal Vulnerability Index

The literature review (Chapter Three) demonstrates the range of measurable variables used to develop the index, and the need to collect data *in situ*. In some instances secondary data sources are useful, but often such data occurs in both quantitative and qualitative formats, contributing to inconsistency in data interpretation. It is necessary to ensure that such data can be effectively analysed. The literature (Price 1990, Dal Cin and Simeoni 1994, Amore and Randazzo 1994) demonstrates multivariate analysis as a useful analytical technique for this purpose. Chapter Six presents the developed coastal vulnerability index (CVI) and the groupings of coastal segments with common physical variables and characteristics.

1.4.3 Case Study Investigations

In this research, five case study sites have been analysed using GIS interpretation. The use and interpretation of aerial photography and coastal land valuation data are presented as alternate approaches to assist the determination of potential coastal vulnerability associated with property loss along the coastline (Chapter Seven).

1.4.4 Application of Public Perception Questionnaires

Questionnaires have been designed to capture public perception of the beaches and related coastal hazards. These are explored and discussed in Chapter Eight. The beach user questionnaires are designed to capture perception of beach amenity quality. Coastal property owners within five study areas were also surveyed to identify their perception of the risk that their properties might incur as a result of the effects of coastal erosion and flooding from storm surges.

1.5 THE RESOLUTION OF THE RESEARCH PROBLEM

As discussed further in Section 2.4, SIDS face serious disadvantages to their development because of the interplay of geographic dispersion, vulnerability to natural disasters, and limited natural resources, amongst other things. The research approach (Chapter Four) has been designed so that it could be applied generically to SIDS using basic information, which is normally available or can be easily acquired with systematic monitoring. This ensures that the method is rapid, easily applicable and flexible and can be easily adapted as more knowledge and data become available. Criteria have been developed to justify the selection of variables and the effectiveness of the proposed field methodologies. The resultant model demonstrates these factors, together with the suitability of other criteria of relevance to other SIDS, and, thus, the transferability of the LVA procedure to other SIDS.

1.6 THESIS STRUCTURE

This thesis is divided into ten chapters. Chapter Two outlines the broad concept and the importance of coastal vulnerability and its relevance to small islands, and key definitions of terms used throughout the thesis. A brief description of the case study area of Barbados, W. I. is also presented. Chapter Three interprets the current literature on various coastal classification and coastal vulnerability (CV) determination methodologies.

Chapters Four to Eight contain the research investigations and analysed results. Chapter Four presents the strategic overview of the research methodology and describes of the selection criteria used in the identification of suitable variables and methodology applications. Chapter Five describes the methodology and analysis of results used in the determination of the ESI's. Chapter Six presents the methodology and analyses of results for determining coastal segment CVIs. Chapter Seven describes the methodology and analyses of results for coastal economic vulnerability assessment using GIS

application in LVA. Chapter Eight presents the methodologies used in the application of public perception questionnaires within the study area.

Chapter Nine examines the incorporation of the LVA model into the Barbados ICZM process. It discusses the implications of these findings relative to the existing coastal management process. Recommendations and future research needs are outlined. Chapter Ten provides an overview of the thesis conclusions. A final evaluation of the LVA model and an assessment of its usefulness in achieving the research objectives are also provided.

1.7 JUSTIFICATION OF RESEARCH

Given the level of current development pressure along the Barbados coastline, there is a requirement for proactive shoreline management to ensure long-term sustainable coastal development. It is accepted that Barbados' reliance on its coastline as the main tourism attraction is one of the principle reasons for the island's successful tourism product. Despite this, high rates of coastal development within the last 20 years have occurred without consideration of the potential negative impacts associated with changing global climate and accelerated sea level rise.

This approach to LVA has not been previously applied to Barbados and therefore provides new research contributions to the literature. The combined techniques presented in this thesis provide a comprehensive approach and contribution to improved decision-making along Barbados' coastal fringe. In addition, its application will:

1. Assist decision-makers in the identification of vulnerable areas;
2. Identify coastal segments needing additional study;
3. Contribute to more proactive management of the coastline;
4. Integrate information into the existing integrated coastal zone management plan (ICZMP).

5. Simplify the issues associated with littoral vulnerability for the public as well as decision-makers to allow an understanding of what might be perceived as complex technical findings. Thus a more balanced and knowledgeable decision-making process should occur.

The following advantages arise using Barbados as a case study area:

- It is a small island with limited background data on its coastline, therefore providing an interesting stage upon which to build the research as it allows for
 - a) the identification of the primary data requirements needed to perform the littoral assessments proposed; and
 - b) it has application for SIDS with no such information or resource base upon which to establish the data variables.
- The research also develops the model for integrating the research information into the existing Barbados ICZM process.

With increased awareness of coastal vulnerability, there is increased risk to coastal infrastructure. Within SIDS, this is of great concern because economic activities concentrate near the shore; thus, damage can indirectly affect the entire country/economy (Granger 1997, Solomon and Forbes 1999). While methodologies, which are easily applicable to the developed world⁷, have been developed and applied by the wider international community, SIDS are left to suffer these natural events. Within SIDS there are often limited research funds and more importantly, very limited time series of available data on which to base effective shoreline assessment. Barbados is no exception to these financial constraints. The continued requirement for coastal development places increased pressure on limited government personnel to perform rigorous coastal evaluations. The primary aim of this research is to integrate low cost LVA techniques into the interdisciplinary ICZM process.

⁷ Refer to IPCC (1992a and 1992b), Midun and Lee (1995), Nicholls and Leatherman (1995), and El-Raey *et al.* (1995).

Chapter 2

Definitions and Background on Barbados W.I.

Chapter 2

Definitions and Background on Barbados W.I.

2.1 INTRODUCTION	15
2.1.1 VULNERABILITY – SETTING THE CONTEXT	15
2.2 DEFINITION OF TERMINOLOGY.....	16
2.2.1 VULNERABILITY	16
2.2.1.1 Vulnerability Assessment.....	18
2.2.1.2 Coastal Vulnerability Assessment	18
2.2.1.3 Littoral Vulnerability Assessment Profile.....	18
2.2.2 COASTAL ZONE	19
2.2.3 INTEGRATED COASTAL ZONE MANAGEMENT.....	19
2.3 NATURAL COASTAL HAZARD EFFECTS.....	21
2.3.1 NATURAL COASTAL HAZARDS	21
2.4 SEA LEVEL RISE AND COASTAL VULNERABILITY: A CHALLENGE FOR SMALL ISLAND STATES.....	25
2.5 THE CARIBBEAN REGION AND ITS VULNERABILITY.....	28
2.6 COASTAL DESCRIPTION OF BARBADOS	30
2.6.1 LOCATION AND COASTAL FORM.....	30
2.6.2 COASTAL HABITATS AND ECOSYSTEMS OF BARBADOS	31
2.6.3 BARBADOS’ COASTAL DEVELOPMENT ASSETS	37
2.6.3.1 Tourism, Human Settlement and Housing	37
2.6.3.2 Industry.....	38
2.6.4 BARBADOS’ NATURAL HAZARD AND VULNERABILITY ISSUES	39
2.6.4.1 Hurricanes and Tropical Storm Hazards	39
2.6.4.2 Torrential and inland Flood Hazards.....	40
2.6.4.3 Global Climate Change Hazard Mitigation.....	41
2.6.4.4 Seismic Events (Volcanic Activity, Earthquakes and Tsunami).....	42

2.6.5 THE NEED FOR SYSTEMATIC RISK AND VULNERABILITY ASSESSMENT	42
2.6.5.1 Barbados' Coastal Geohazards	43
2.7 SUMMARY	43

2.1 INTRODUCTION

This chapter focuses on the conceptual components associated with coastal vulnerability. It is divided into five sections. The first provides the definition of terms used in the research. The second presents a review of natural coastal hazards and their effects. The third reviews issues associated with sea level rise and the vulnerability of small island states. The fourth provides a description of the vulnerability of the Caribbean islands. The final section describes the research study area, Barbados W.I., and its associated coastal hazards issues.

2.1.1 Vulnerability – Setting the Context

Human society and the natural environment have become increasingly vulnerable to natural hazards. A principal challenge of CM is maximising access to coastal areas while protecting the public from natural and anthropogenic hazards. The exposure of people and property to hurricanes, storm surges and other related coastal hazards is increasing steadily because of economic growth. This is especially the case within the developing world along CZs frequently subjected to storm surge and coastal flooding. This can contribute to a rise in the potential economic loss of vulnerable coastal areas. This is important within SIDS where large differences in property damage and risk exposure may exist between islands. In addition, such differences can also be experienced between different sides or, coastal segments, on the same island.

As tourism is also the main economy for most SIDS, these issues become even more important. Particular challenges occur on recreational beaches (e.g. crowding and implications for free access; and competition between active and passive recreational activities), which are important for consideration (Hecock 1970, van Herwerden and Bally 1989a and b, Houghton 1989, James 2000). The multiplicity of hazards arising from physical features and man-made hazards (e.g. motorized watercraft) in the recreational nearshore can also be a concern. Such issues are well discussed in the

literature¹. Vulnerability, is, therefore, a multi-dimensional concept encompassing biogeophysical, economic, institutional and socio-cultural factors (Nicholls and Klein 2001)

2.2 DEFINITION OF TERMINOLOGY

Terms such as hazard, risk, vulnerability, vulnerability assessment, and risk assessment are frequently used in the assessment of coastal susceptibility to hazards and are widely used in coastal descriptive classifications. This section defines the primary terms used within the thesis (Table 2.1).

2.2.1 Vulnerability

Within existing definitions², vulnerability is frequently viewed as the exposure to risk factors and the reduction in the capacity of people's ability to cope. However, this research uses the definition presented in Table 2.1. This captures the natural, anthropogenic and socio-economic factors that can affect populations in vulnerable areas.

¹ Refer to Pethick 1984, Williams and Williams 1988 and 1991, Carter 1989, Ratcliffe 1992, Bird 1994, Pickering *et al.* 1994, Short 1995 and Pendleton 2001.

²Refer to IPCC (1992), Blaikie *et al.* (1994), Carter *et al.* (1994), Cutter (1996), Ramachandran and Eastman (1996), USAID/OAS (1996), O'Neill (1997), Bender (1999), and NOAA (1999).

Table 2.1 Definitions Used Within the Context of the Research

Terminology	Definition	Source
Vulnerability	Any condition of susceptibility to external shocks that could threaten people's lives and livelihood natural resources, properties and infrastructure, economic productivity and a region's prosperity	Uribe <i>et al.</i> (1999)
Vulnerability assessment	An operational procedure, which considers the anticipated impact of a potential hazard on a location and the available adaptation/mitigation options to minimise damage, caused by the event.	IPCC (1994)
Coastal vulnerability assessment	An operational procedure to consider a coastline's inability to cope with the anticipated impact consequences of climate change and accelerated sea level rise, and assessing the available adaptation options that can be applied to minimise any potential coastal damage.	IPCC (1994)
Coastal zone	The area along the coast that includes both the area of land subject to marine influences and the area of the sea subject to land influences.	UNEP (2000)
Integrated coastal zone management	A dynamic process in which a co-ordinated strategy is developed and implemented for the allocation of environmental, socio-cultural and sustainable multiple uses of the coastal zone.	UNEP (2000)
Hazard	Some event or object that is a potential source of harm to human life, health, income or possessions. It also includes threats to human built structures or other aspects of the biophysical environment.	McElroy (1999)
Disaster	A calamity, which befalls people, their buildings, livelihood and belongings, and/or the environment of a place because of a hazardous event.	McElroy (1999)
Risk	The combination of the probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequences of the occurrence.	DEFRA (2002)
Resilience	The coast's ability to both absorb and subsequently recover from coastal forcing pressures that cause damage to the coast.	Klein <i>et al.</i> (1998)
Coastal geohazards	These are a collective set of local geologic, environmental and morphological features found on a shoreline. They determine how the community will respond to, and recover from hazardous coastal processes.	Coburn (2002)
<i>Littoral</i>	<i>A term used to depict the interactive nature of the coast and its ecosystems and the influences of anthropogenic factors on the coast.</i>	<i>Original</i>
<i>Littoral vulnerability assessment</i>	<i>A procedure which considers the anticipated impact of a potential hazard on identified vulnerable areas of the littoral leading to the development of proactive mitigation options to minimise damage.</i>	<i>Original</i>
<i>Littoral vulnerability assessment profile</i>	<i>A rapid operational procedure using a series of indices to characterise the CZ to prioritise the effects of coastal geohazards and anthropogenic hazards on a coastline.</i>	<i>Original</i>

2.2.1.1 Vulnerability Assessment

Vulnerability assessment focuses on the mapping of areas likely to be affected by hazards e.g. storm surge inundation areas, and determining the potential threat for loss of life and damage to property (IPCC 1994, NOAA 1999, Crichton 2001). This concern is of importance, highlighting the need to ensure that such analyses are performed regularly to identify land use and population changes. This is especially significant in situations of expanded population density leading to increasing vulnerability³. Vulnerability assessment provides for the better siting of infrastructure to avoid high risk areas, and indicates appropriate mitigating measures (structural and non structural) to minimise potential damage

2.2.1.2 Coastal Vulnerability Assessment

The CVA definition presented in Table 2.1 is based on a nation's ability to cope with:

- the consequences of accelerated sea level rise (ASLR);
- the potential impacts of physical change on the socio-economic system and the ecological system; and
- the ability of the country to cope with impacts using the IPCC mitigation options (IPCC 1994).

2.2.1.3 Littoral Vulnerability Assessment Profile

The littoral vulnerability assessment profile (LVAP) represents the collection of appropriate littoral data, which when illustratively presented provides a descriptive profile of the littoral zone. LVAP can be defined as a rapid operational procedure to characterise the littoral zone to prioritise the effects of coastal geohazards and anthropogenic hazards on a coastline.

³ NOAA (1999) has used such procedures in the development of a seven stage Community Vulnerability Assessment Tool.

2.2.2 Coastal Zone

The literature is replete with CZ definitions⁴, which try to capture the special ecological and socio-economic character, and significance of the area. Table 2.1 presents the CZ definition used in this research. More detailed functional definitions are site or region specific (Fig. 2.1).

In Barbados, the CZ extends between A and C on Fig. 2.1. In zones A – B, the government exercises rights of control. In zone B – C, the government control relates to physical development and recreational zoning but the majority of the shore lands are in private ownership and property rights of the owners predominate.

2.2.3 Integrated Coastal Zone Management

Integrated Coastal Zone Management (ICZM) can be thought of as a special planning process within the complex and dynamic CZ. Several definitions exist in the literature⁵, but for this research, the ICZM definition, presented in Table 2.1 is employed. Its essential features can be summarised as:

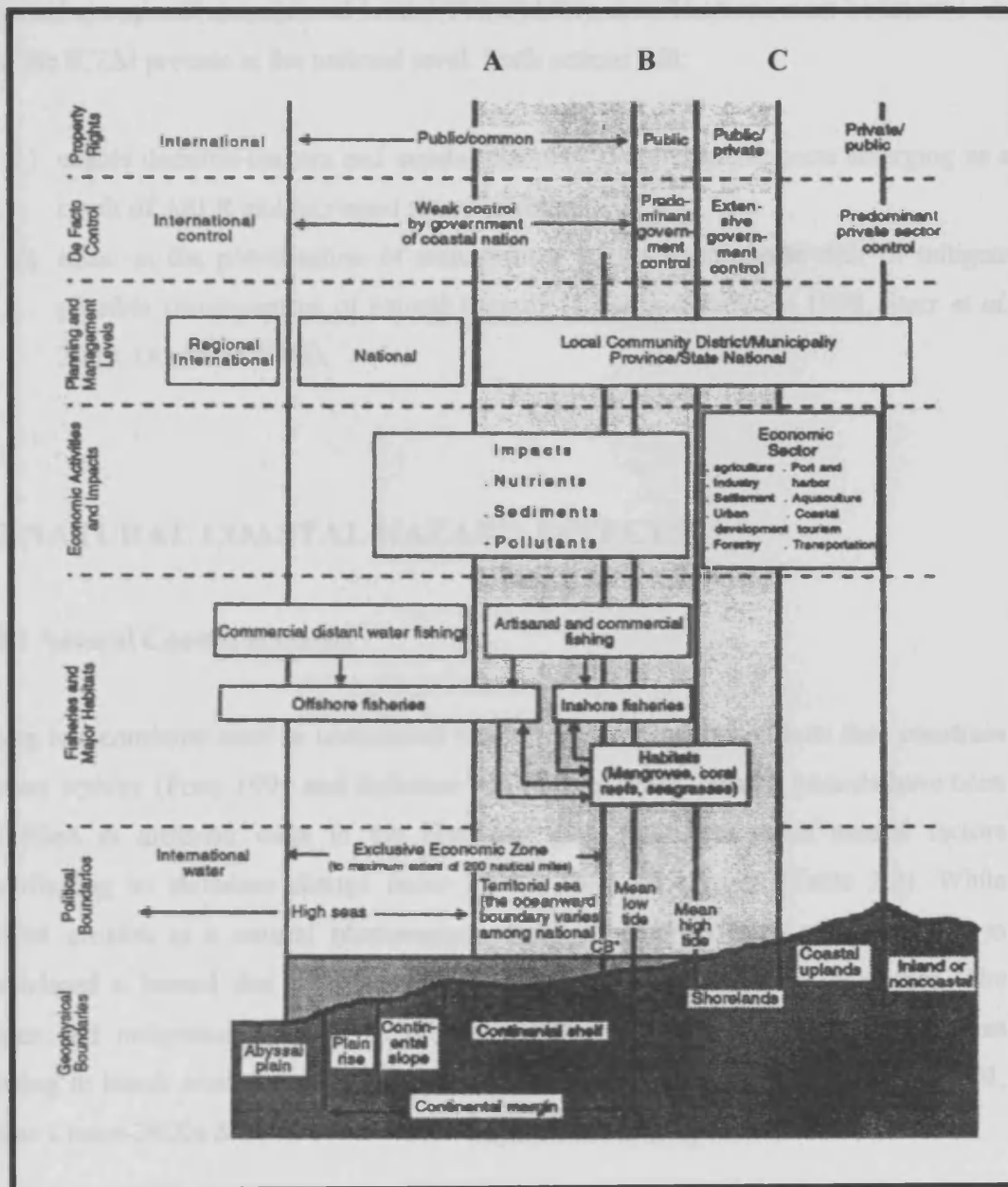
- the need for co-ordination between and among groups in the public and private sectors;
- balancing and distributing use and the access to the resources found within the zone; and finally
- the preservation of the coastal zone while preserving its form and function for the future (Gubbay 1990).

⁴ Refer to Fricker and Forbes (1988), Cendrero (1989), Carter (1989), Bartlett and Carter (1991), Viles (1991), Scura *et al.* (1992), Awosika *et al.* (1993), UNEP (1996), Clark (1997), Sorensen (1997), Cicin-Sain and Knecht (1998), Yanez-Arancibia (1999).

⁵ Refer to definitions presented by CAMPNET (1989), Clarke (1992), Sorensen (1993), Vallejo (1993), CEPNET (1993), Awosika *et al.* (1993), Knecht and Archer (1993), UNEP (1996), Clarke (1996), IOC-UNESCO (1997), UNEP (2000), Salm and Clark (2000), and Henocque and Denis (2001).

Fig. 2.1 The Coastal Zone (with overlapping jurisdictional and other boundaries).

(Source: Scura *et al.* 1992)



Where CB* in the figure is the coastal baseline.

The ICZM process gained global attention at UNCED (1992) and more recently at the Oceans and Coasts at Rio +10 Conference (2001). At the former, it was identified as one of the priority actions for all coastal states⁶. In the latter, its implementation status was reported at regional and national levels. Vulnerability considerations must be interwoven into the ICZM process at the national level. Such actions will:

- 1) enable decision-makers and coastal planners to anticipate impacts emerging as a result of ASLR and increased storm intensity;
- 2) assist in the prioritisation of management efforts to minimise risk, or mitigate possible consequences of natural hazards (Klein and Nicholls 1998, Sterr *et al.* 2000, Doukakis 2003).

2.3 NATURAL COASTAL HAZARD EFFECTS

2.3.1 Natural Coastal Hazards

There is a continual need to understand natural coastal hazards and how they constrain human activity (Potts 1999 and Solomon and Forbes 1999). Natural hazards have been classified in different ways in the literature⁷ (Fig. 2.2). The main natural factors contributing to shoreline change occur mainly from geohazards (Table 2.2). While coastal erosion is a natural phenomenon, from an anthropogenic perspective, it is considered a hazard due to its interaction with coastal development processes. The issues and mitigation options, including shoreline stabilisation/protection initiatives relating to beach erosion, are well documented (Kohsiek *et al.* 1987, Titus *et al.* 1991, Heinz Centre 2000a & b, Parsons & Powell, 2001 and Ofiara & Psuty 2001).

The vulnerability of coastal properties and coastal communities to these chronic and infrequent catastrophic forces is important to both users and coastal planners/managers.

⁶ Refer to Chapter 17, Agenda 21 (UNCED 1992)

⁷ Refer to Whittow (1980), Tank (1983), U. S. Army Corps of Engineers (1984), Wolf (1985), OAS (1990), Bennett (1991), Clark (1992), Smith (1994), California Coastal Commission (1995), Viles and Spencer (1996), Berger and Iams (1996), CIRIA (1996), Island Resources Foundation (1996), UNEP (1997), Pethick (1997), Haslett (2000), Heinz Centre (2000), ODLCD (2001), Smith (2001) and WCU (2001).

There are special concerns for general public safety and the welfare for coastal communities and their associated infrastructure, in addition to considerations for the trade-off conflict between the need for conservation of coastal ecosystems and the need for development (Wolf 1985 and Bennett 1991).

Fig. 2.2 Coastal Geohazard Descriptors (Source: Potts 1999)

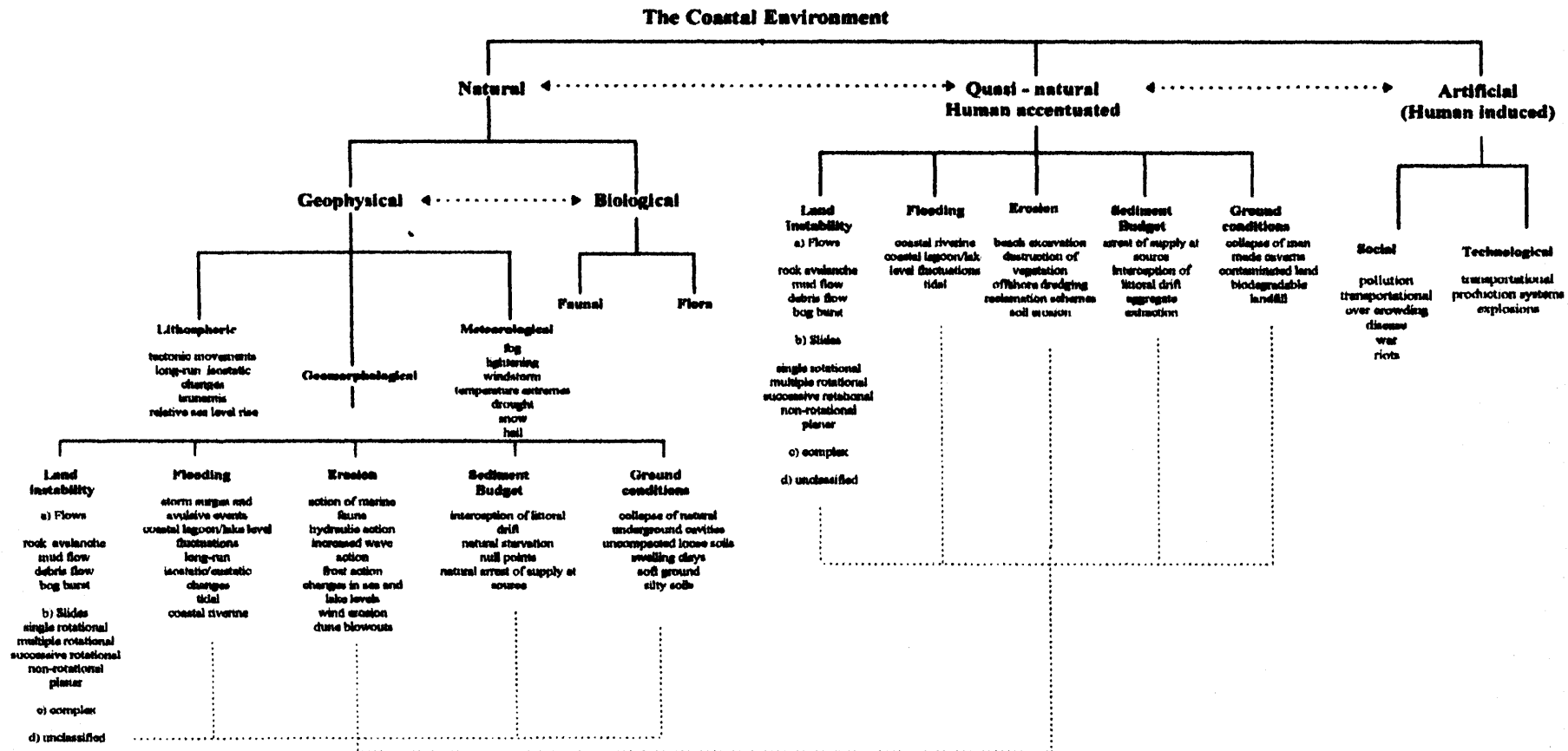


Table 2.2: Summary of Natural Factors Affecting Shoreline Change
(Source National Research Council 1990 cited Heinz Centre 2000)

Factor	Effect	Time scale	Comments
Sediment supply (source and sinks)	Accretion/ erosion	Decades to millennia	Natural supply from inland or shore face and inner shelf sources can contribute to shoreline stability or accretion
Sea level rise	Erosion	Centuries to millennia	Relative sea level rise
Sea level change	Erosion	Months to years	Causes poorly understood
Storm surge	Erosion	Hours to days	Very critical to erosion magnitude
Large wave height	Erosion	Hours to months	Individual storms or seasonal effects
Short wave period	Erosion	Hours to months	Individual storms or season effects
Waves of small steepness	Accretion	Hours to months	Summer conditions
longshore currents	Accretion, no change, or erosion	Hours to millennia	Discontinuities (updrift/downdrift) and nodal points
Rip currents	Erosion	Hours to months	Narrow seaward flowing , near bottom currents may transport significant quantities of sediment during coastal storms
Underflow	Erosion	Hours to days	Seaward flowing, near- bottom currents may transport significant quantities of sediment during coastal storms
Inlet presence	Net erosion; high instability	Years to centuries	Inlet-adjacent shorelines tend to be unstable because of fluctuations or migrations in inlet position; net effect of inlets is erosional owing to the sand storage in tidal shoals
Overwash	Erosional	Hours to days	High tides and waves cause sand transport over barrier beaches
Wind	Erosional	Hours to centuries	Sand blown inland from beach
Subsidence, compaction	Erosion	Years to millennia	Natural or human induced withdrawal of subsurface fluids
Subsidence, tectonic	Erosion/ accretion	Instantaneous, centuries to millennia	Earthquakes; elevation or subsidence of plates; tsunami generation

2.4 SEA LEVEL RISE AND COASTAL VULNERABILITY: A CHALLENGE FOR SMALL ISLAND STATES

Small island states, typically less than 10,000 km² in area with approximately five hundred thousand or fewer residents, vary by geography, social composition, political influence, economic priorities, physical makeup and climatic conditions (Hess 1990). The common thread binding all small islands together is the current threat of global climate change and the resulting threat of ASLR⁸. The hazard risk factors associated with small islands⁹ have been well-documented (UNESCO 1994, UN-CSD 1996, Primo 1997, and Solomon and Forbes 1999). These factors are best exemplified by conditions currently being experienced in the Maldives, Marshall Islands, Tuvalu and Kiribati, to list a few.

The characteristics of SIDS present several constraints for sustainable development (Maul 1996). Leatherman and Beller-Simms (1997) suggested that SIDS will continue to experience increased vulnerability to natural hazards because of man-made influences¹⁰, and an overall decline of the resources that are often the main stay of their economies (i.e. tourism and associated amenities). In addition, the effects of coastal flooding from ASLR may have contributory effects (Table 2.3), well discussed in the literature (National Research Council 1987, IPCC 1990, Nicholls *et al.* 1995, Sterr *et al.* 2000, and Douglas *et al.* 2001).

⁸ As discussed in Roy and Connell (1991), Jagalersma *et al.* (1993), Nicholls and Leatherman (1995), Leatherman & Beller-Simms (1997).

⁹ These include single island states and especially coral atoll nations that lie almost entirely within three meters of current sea level and have no land at higher elevations to relocate populations and economic activities.

¹⁰ Such as over development, high population growth rates, over exploitation of resources and pollution problems associated with development and the decline of their natural resources.

Table 2.3 Effects of Coastal Flooding due to Accelerated Sea Level Rise
(Source: Various)

Impact Source	Result
Accelerated Sea Level Rise	<ul style="list-style-type: none"> • Provides a higher base for storm surge build up resulting in more frequent flood events¹¹.
Destruction or over wash of barrier islands by increases in sea level	<ul style="list-style-type: none"> • Destruction of ocean front property and leaving inland properties vulnerable to storm waves¹².
Higher water levels would reduce coastal drainage gradients	<ul style="list-style-type: none"> • Would increase flooding attributable to rainstorm. • Could promote salt water intrusion into coastal aquifers. • May cause groundwater tables at the coastal margin to rise¹³.
Possible rising water tables and salt water intrusion	<ul style="list-style-type: none"> • Impacts on coastal aquifers used for drinking water purposes as well as irrigation of coastal agricultural lands¹⁴.

While scientists have made progress in predicting the potential for global climate change and its associated effects, much of this information is not readily applicable to or even available to the developing world particularly SIDS. However, small island nations still need to be prepared for the effects of climate change and to develop adaptation or alternative strategies (Sections 1.4 and 1.7) to minimise the potentially devastating effects on economic and population growth (Ragoonaden 1997, Kaluwin & Smith 1997, USAID/OAS 1997).

The United Nations General Assembly (1993) defined a list of characteristics that described the vulnerability of small island states (Table 2.4). Other authors (Micallef 1997, ECLAC 2000) have also presented specific characteristics for SIDS based on their economic and environmental sustainable development options. A description for Barbados identifying its characteristics as a SIDS has been similarly developed and presented (Table 2.4).

¹¹ See Leatherman (1994) and Hoozemans *et al.* (1993).

¹² See Kraft *et al.* (1987) cited Daniels (1992).

¹³ See Daniels (1992) and Sterr *et al.* (2000).

¹⁴ See Sterr *et al.* (2000).

Table 2.4 Vulnerability Characteristics of Small Island Developing States (Source: Original)

Hess (1990)	United Nations General Assembly (1993)	Micallef (1997)	Economic Commission for Latin America and the Caribbean (2000)	Barbados Characteristics (Source: Original)¹⁵
Physical character.	Small size.	Small size.	Small size.	<i>Small size.</i>
	Limited range of natural resources and fragile resource base.	Small scale economic development options results in an inability to provide basic local infrastructure and services.	Limited land resources and difficulties in waste disposal management.	<i>Limited land resources and difficulties in waste disposal management.</i>
Climatic conditions.	Susceptibility of natural hazards (e.g. hurricanes and tsunamis).	Susceptible to wave attack from all directions.	High exposure to natural hazards.	<i>High exposure to natural hazards & susceptible to wave attack from all directions.</i>
	Little biological diversity.	High numbers of endemic species.	Environmental/ecological vulnerability.	<i>Ecological vulnerability from development pressures.</i>
Geography.	Relative isolation and great distance to other markets.	Geographic remoteness makes communication and transport difficult with external markets.	Geographic remoteness and isolation.	<i>Great distance to regional and other external markets.</i>
	Extensive land/sea interface per unit area which makes protective measures extremely expensive.		Special social vulnerabilities.	<i>Extensive land/sea interface per unit area which makes protective measures extremely expensive.</i>
Economic priorities.	Extreme openness of economies and susceptibility to external shocks.	Unable to undergo fast economic adaptation by local economic sectors.	Limited diversification and open economies.	<i>Economic priorities.</i>
Political influence.	Low resilience of a subsistence economy.			<i>Political influence.</i>
Social composition.	Narrow range of skills and lack of educated specialists.	Scarcity of human resources.	Weak institutional capacity and high costs of basic infrastructure.	<i>Weak institutional capacity and high costs of basic infrastructure.</i>

¹⁵ The characteristics presented here are this author's opinion of the principal issues of concern to Barbados as a SIDS.

2.5 THE CARIBBEAN REGION AND ITS VULNERABILITY.

The Wider Caribbean Region, comprising 33 countries (and dependent territories) (UNEP 1996) (Fig. 2.3), is the largest concentration of small developing countries in the world. The region is diverse in character and form, but all coasts face similar climate change issues and associated problems. The resource base, especially within the insular region, is limited in scale and scope, but it is highly diverse in terms of ecosystem complexity and biological productivity.

For many of these countries and dependent territories, coastal tourism is the main revenue earner¹⁶, and is inextricably linked to the environment and its quality (Rodriguez 1981, Kosiek *et al.* 1987, Gable *et al.* 1990 and Simmons and Associates 1994). Within the Wider Caribbean Region the main coastal hazards are hurricanes and tropical storms, floods, landslides and mud slides (Oostdam and Billeter 1995, and Charveriat 2000). The vulnerability of Caribbean countries to major hazards is presented in Table 2.5.

Fig. 2.3 Map of Wider Caribbean Region (Source: UNEP 1996)



¹⁶ This has been the predominant form of tourism for most of the Caribbean countries since the 1960's. However beach tourism has significant impacts on coastal zones (IRF 1996, UNEP 1989, 1994 and 1994a, 1997, Conlin 1995, Hoagland *et al.* 1995, Cambers 1996, Auer 1991, Blommestein 1985 and 1995).

Table 2.5: Vulnerability to Natural Hazards of Caribbean Countries
(Source: UNEP 2002)

Country	Natural Hazard Type				
	Hurricanes	Earthquakes/ Tsunami	Volcanoes	Floods	Drought
<i>Barbados</i>	σ	σ	τ	υ	τ
Other Caribbean Islands					
<i>Antigua & Barbuda</i>	σ	σ	τ	υ	σ
<i>Bahamas</i>	σ	τ	τ	υ	τ
<i>Cuba</i>	σ	σ	τ	σ	σ
<i>Dominica</i>	σ	σ	σ	σ	τ
<i>Dominican Republic</i>	σ	σ	τ	σ	υ
<i>Grenada</i>	σ	σ	σ	υ	υ
<i>Haiti</i>	σ	σ	τ	υ	σ
<i>Jamaica</i>	σ	σ	τ	σ	σ
<i>St Kitts & Nevis</i>	σ	σ	σ	υ	τ
<i>St Lucia</i>	σ	σ	σ	σ	τ
<i>St Vincent & the Grenadines</i>	σ	σ	σ	υ	τ
<i>Trinidad & Tobago</i>	υ	σ	σ	υ	τ

Table Notes:

Where σ = High vulnerability; υ = Moderate vulnerability; τ = Low vulnerability.

- 11 km sedimentary slopes (Northwest and East Southwest coasts), and
- approximately 10 km igneous structures (mainly on the West and South coasts) (Camber 1979, Truett and Ruffin 1984, TCPO 1982)

¹² The island's physiographic form is described as a succession of upfolded coral reef terraces on the leeward side of the island, the remnants of such terraces on the windward side and the presence of a strait, which act as outlets of drainage channels across the island.

2.6 COASTAL DESCRIPTION OF BARBADOS

Having established the regional context of the research, the following section provides a brief description of Barbados, the research study area.

2.6.1 Location and Coastal Form

Barbados, at latitude 13°N and longitude 59°W, is the most easterly of the Lesser Antilles Islands chain (Fig. 2.3). It is 34 km long and 24 km wide, having a total area of 432 sq. km. Its greatest elevation is 337m. It is bounded on its eastern coast by the Atlantic Ocean and on its western coast by the Caribbean Sea. The island is predominantly Pleistocene coral limestone (80%), averaging some 70 m in thickness. The island's physiographic form has been reviewed¹⁷ (Barker and Poole 1982, Town and Country Planning Department (Barbados) 1988, Radtke & Grun 1990, Speed 2001 and Schellmann & Radtke 2002).

The coastline is regular with no deep indentations. There are only two major bays (Carlisle Bay and Oistins Bay), both on the south coast. The coastline itself is approximately 97 km long (Fig. 2.3), comprising:

- 32 km coral sand (west and south coasts);
- 32 km limestone cliffs (North, Southeast coasts and some parts of the West coast);
- 11 km silica sand (East coast);
- 11 km sedimentary slopes (Northeast and East Southeast coasts); and
- approximately 10 km man-made structures (mainly on the West and South coasts) (Cambers 1979, Proctor and Redfern 1984, TCPO 1988).

¹⁷ The island's physiographic form is identified as a succession of uplifted coral reef terraces on the leeward side of the island, the absence of such terracing on the windward side and the presence of watercourses, which act as natural drainage channels across the island.

2.6.2 Coastal Habitats and Ecosystems of Barbados

Nearshore tropical marine communities are of great socio-economic and biological importance, being essential to coastal ecosystem maintenance. Around Barbados, the main coastal ecosystems are coral reefs, seagrass beds and coral rubble habitats (Fig. 2.4). These ecosystems suffer many common problems presented in the literature (Clarke 1992, IRF 1996a, Procter and Redfern 1984, Delcan 1994, Halcrow 1998, Brewster and Mwansa 2000). Barbados' coastal habitats, usage and associated issues are summarised in Table 2.6.

Fig 2.4 Map of Barbados Coastal Physiographic Form (Source: Original)

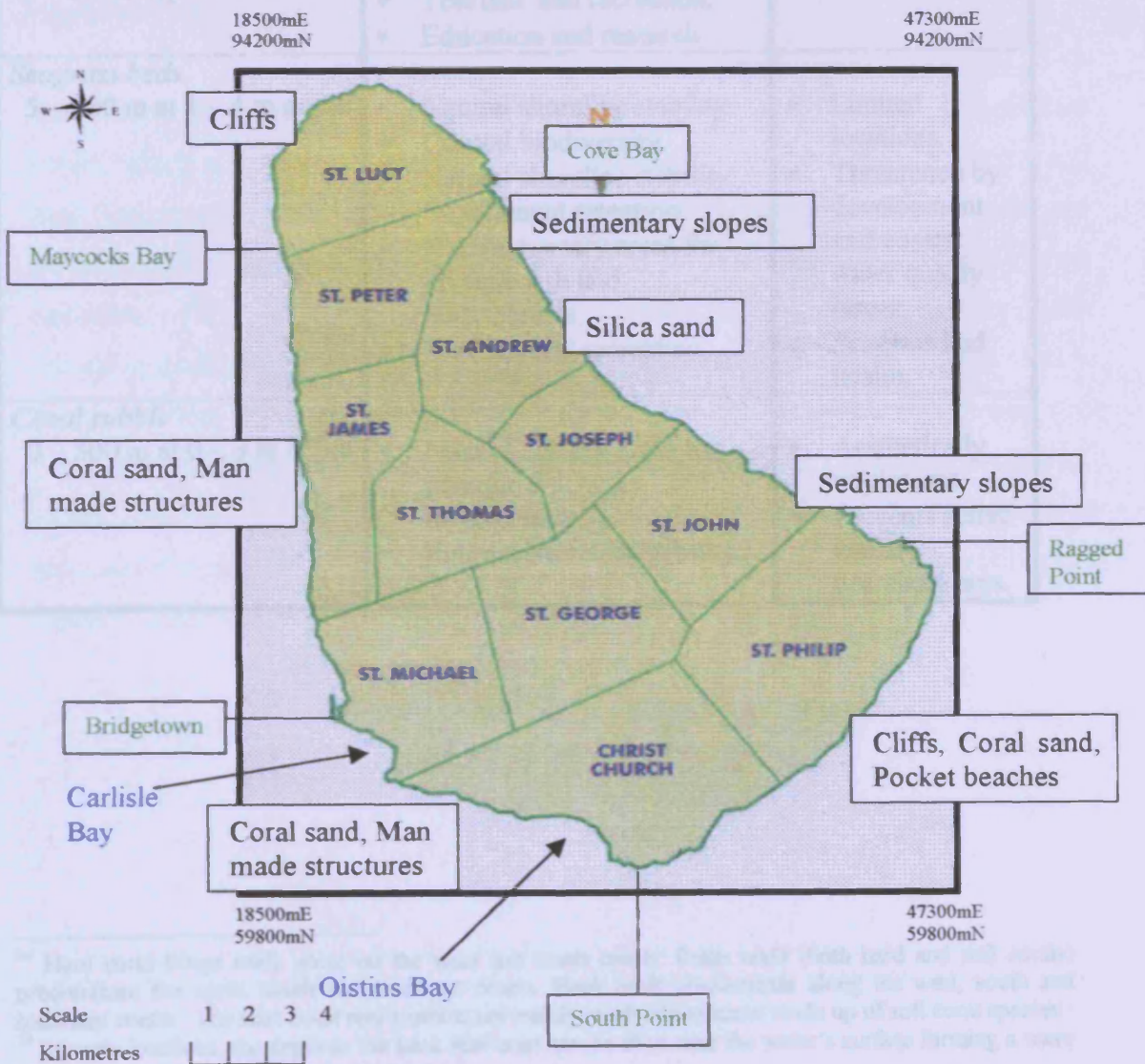


Table 2.6 Main Marine Coastal Habitat Systems of Barbados (Source: Original)

Habitat type and distance from shore	Usage	Issues
<p><i>Coral reefs</i>¹⁸ (Fringe, Patch and Bank reefs)</p> <p>Fringe: 0 – 200 m at 0 – 10 m depth</p> <p>Patch: 0 – 200 m at 4 – 40 m depth</p> <p>-</p> <p>Bank: 500 – 1200 m at 15 – 30 m depth¹⁹</p>	<ul style="list-style-type: none"> • Support artisanal fisheries. • Natural nursery areas for juvenile fish and invertebrates. • Natural production of beach sand. • Coastal biodiversity. • Natural coastal protection • Natural shoreline stability by sediment retention. • Tourism and recreation. • Education and research. 	<ul style="list-style-type: none"> • Pollution and land runoff due to proximity to coastline. • Anchor damage from recreational vessels. • Reef health.
<p><i>Seagrass beds</i> 5 – 100 m at 1 – 4 m depth</p>	<ul style="list-style-type: none"> • Natural shoreline stability. • Coastal biodiversity. • Natural shoreline stability by sediment retention. • Natural nursery areas for juvenile fish and invertebrates. • Tourism and recreation. 	<ul style="list-style-type: none"> • Limited locations. • Threatened by development and coastal water quality issues. • Seagrass bed health.
<p><i>Coral rubble</i> 0 – 300 m at 0 – 3 m depth</p>	<ul style="list-style-type: none"> • Natural nursery areas for juvenile fish and invertebrates. • Indirect shoreline stability. 	<ul style="list-style-type: none"> • Aesthetically unpleasant. • Prevents active use of nearshore area.

¹⁸ Hard coral fringe reefs occur on the west and south coasts. Patch reefs (both hard and soft corals) predominate the north, south and southeast coasts. Bank reefs predominate along the west, south and southeast coasts. The East coast reef systems are mainly patch reef systems made up of soft coral species.

¹⁹ In some locations, the depth to the bank reef crest can be at or near the water's surface forming a wave break - exemplified on the southeast coast.

2.6.2.1 Bathymetry and its Influence on the Coastline

Barbados' offshore bathymetry (Fig. 2.5) demonstrates a very narrow shelf ranging between 1.5 to 3 km offshore except at its southwest corner near Needham's Point where, because of a narrow tongue like bulge, the shelf is about 6 km wide (Delcan 1995). Thereafter, it slopes off rapidly into deep water. This is consistent with the geologic origin of the island, which is a peak on the Barbados Ridge²⁰ (Speed 2001). Parallel for much of the coast, but, especially along the West and South coasts, is a series of parallel bank reefs that are between 10 and 25 m below the sea surface. Fringe reefs are found at most headland locations along much of the west coast, acting as natural wave barriers and beach sediment anchors, retaining beach sands within the respective beach cells.

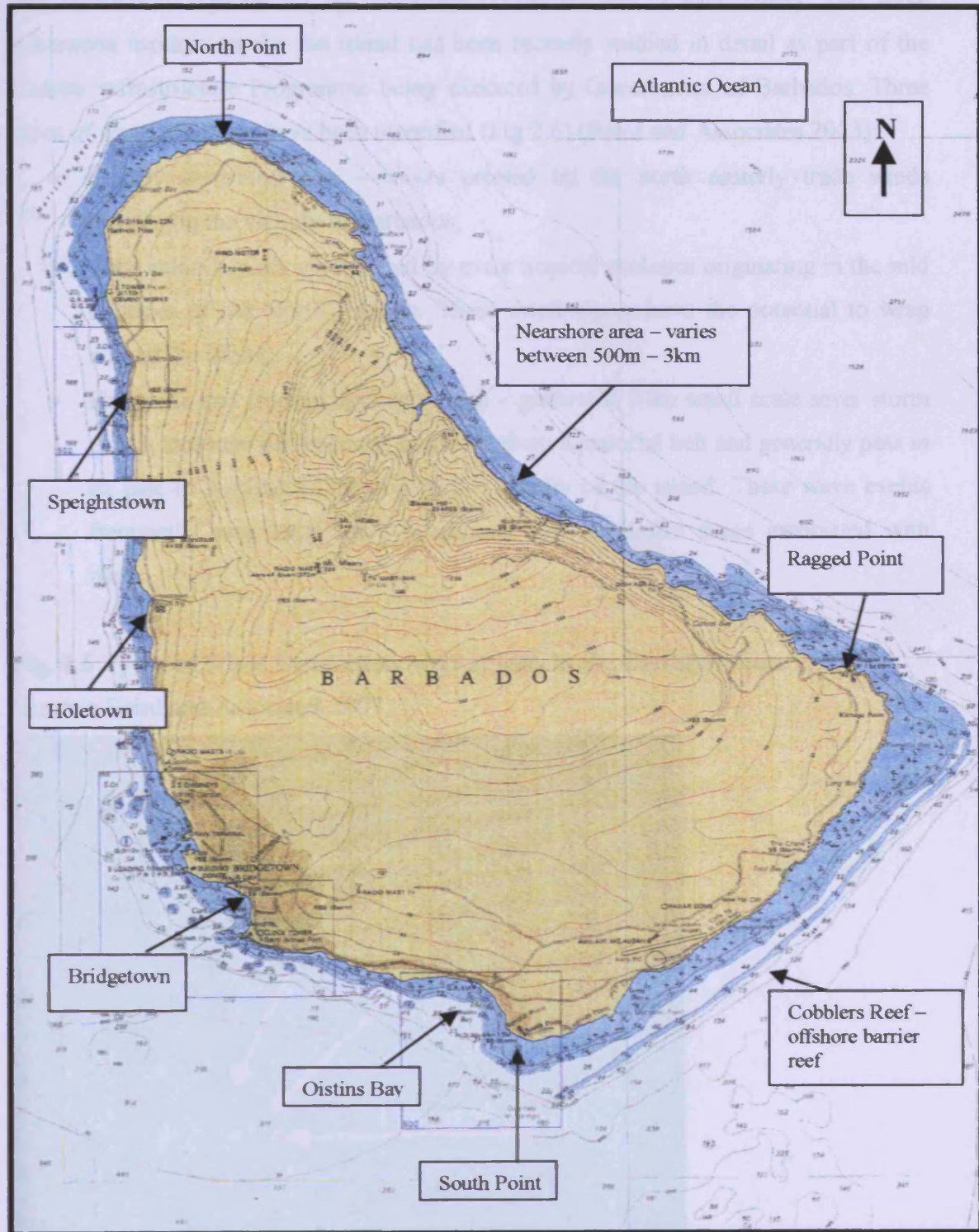
Shelf and coastal processes around the island are dominated by trade wind-generated waves, which are consistent for most of the year increasing in intensity in January and June (Delcan 1993). The waves refract over the nearshore reefs and transport beach and nearshore sediments along the coastline according to the prevailing longshore current direction. There is known to be seasonal variation in this, with current reversals occurring during the summer months from a north - south direction to a south - north direction (Proctor & Redfern 1983, Delcan 1994). Periodically, between December and April, the coastline is subject to swell waves generated in the far north western Atlantic Ocean. These swell events normally have durations of 1 – 4 weeks but have been known to exceed this, depending on the extent of penetration of the cold front experience in the Atlantic Ocean (Colin Depradine *pers. comm.*).

²⁰ According to Speed (2001) the Barbados Ridge is an extensive sub-sea mountain range between Tobago and a point east of Martinique. The Barbados island peak is the only peak on the ridge currently above sea level. The Barbados Ridge descends eastward to the deep Atlantic Abyssal plain. To the west the ridge descends less steeply as it is bordered by the Tobago Trough.

Fig. 2.5 Offshore Bathymetry of Barbados (Source: Admiralty Chart 2485 (1987)).

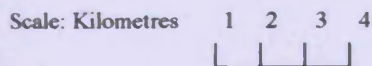
18500mE
94200mN

47300mE
94200mN



18500mE
59800mN

47300mE
59800mN



There is a critical link between the wave energy experienced on the coast and the actual impact on the shore. This is controlled by the extent of wave refraction of the seabed and diffraction experienced by headlands (USACE 1984, Carter 1989). The wave generation mechanism for the island has been recently studied in detail as part of the Coastal Infrastructure Programme being executed by Government of Barbados. Three types of wave condition have been identified (Fig 2.6) (Baird and Associates 2003):

- Locally generated seas – waves created by the north easterly trade winds blowing in the vicinity of Barbados;
- Long period swells – generated by extra tropical cyclones originating in the mid latitudes of the North Atlantic. These swell waves have the potential to wrap around the island;
- Hurricane and tropical cyclone waves – generated from small scale sever storm events that may be generated in the northern equatorial belt and generally pass in an east to northwest direction in the vicinity of the island. These wave events frequently have large wave conditions and significant surge associated with them.

Fig. 2.6 Types of Wave Generation Mechanisms in the Caribbean Sea

(Source: Baird and Associates 2003).



Figure 2.7 show a point rose plot of individual hourly wave heights as a function of wave direction. A comparison of Figure 2.7 with Figure 2.8 shows the largest number of waves approach from the North East but the waves with the largest wave heights tend to occur form the North-Northwest (Baird and Associates 2003).

Fig. 2.7 Plot of Hourly Wave Heights as a Function of Wave Direction (Source: Baird and Associates 2003).

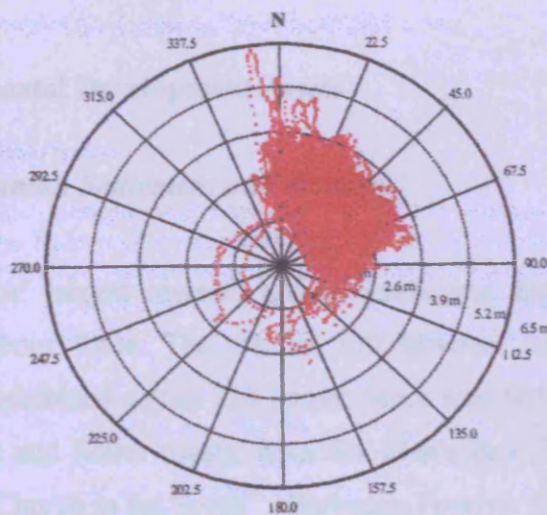
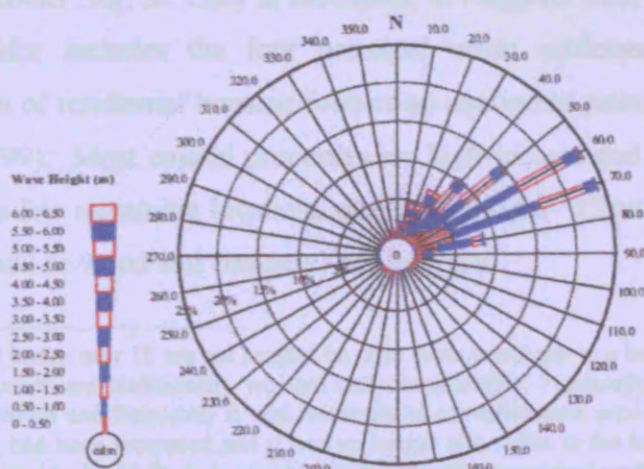


Fig. 2.8 Wave Height Rose Offshore Barbados (Source: Baird and Associates 2003).



ICZM requires application of both planning and model usage in a range of conditions from average to storm events. The average wave climate conditions have been used in this research as the storm events are generally of low frequency and low magnitude in terms of damage done to the coast. Recovery normally is seen within 2 – 4 weeks. This does not negate the potential devastating effects tropical depression or hurricane waves can impact on the coast. When such storms events are affecting the coast, there is no active use of the recreational nearshore, given the high waves and associated energy and their potential dangers.

2.6.3 Barbados' Coastal Development Assets

2.6.3.1 Tourism, Human Settlement and Housing

Tourism is Barbados' largest revenue earner, employing approximately 25% of the current available labour force. The tourism infrastructure consists of approximately 6000 hotel rooms distributed across 150 hotels. More than 90% of this infrastructure is located on the West and South coasts, from Six Men's Bay, St. Peter in the North, to South Point, Christ Church in the South²¹ (Barbados Tourism Authority 2001).

Currently in excess of 40% of the island's 276,000 population, live within 2 km of the coast. The population is concentrated in a continuous linear urban corridor, extending from Maycocks Bay, St. Lucy in the North, to Ragged Point, St. Philip in the Southeast. This corridor includes the four principal urban settlement nodes (Fig. 2.9). The distribution of residential housing follows an equivalent pattern to that of the population (TCPO 1999). Most coastal properties are high-income and very expensive real estate, with only a few remaining locations where traditional "Chattel style" housing²² (houses built of wood or wood and concrete) can be found.

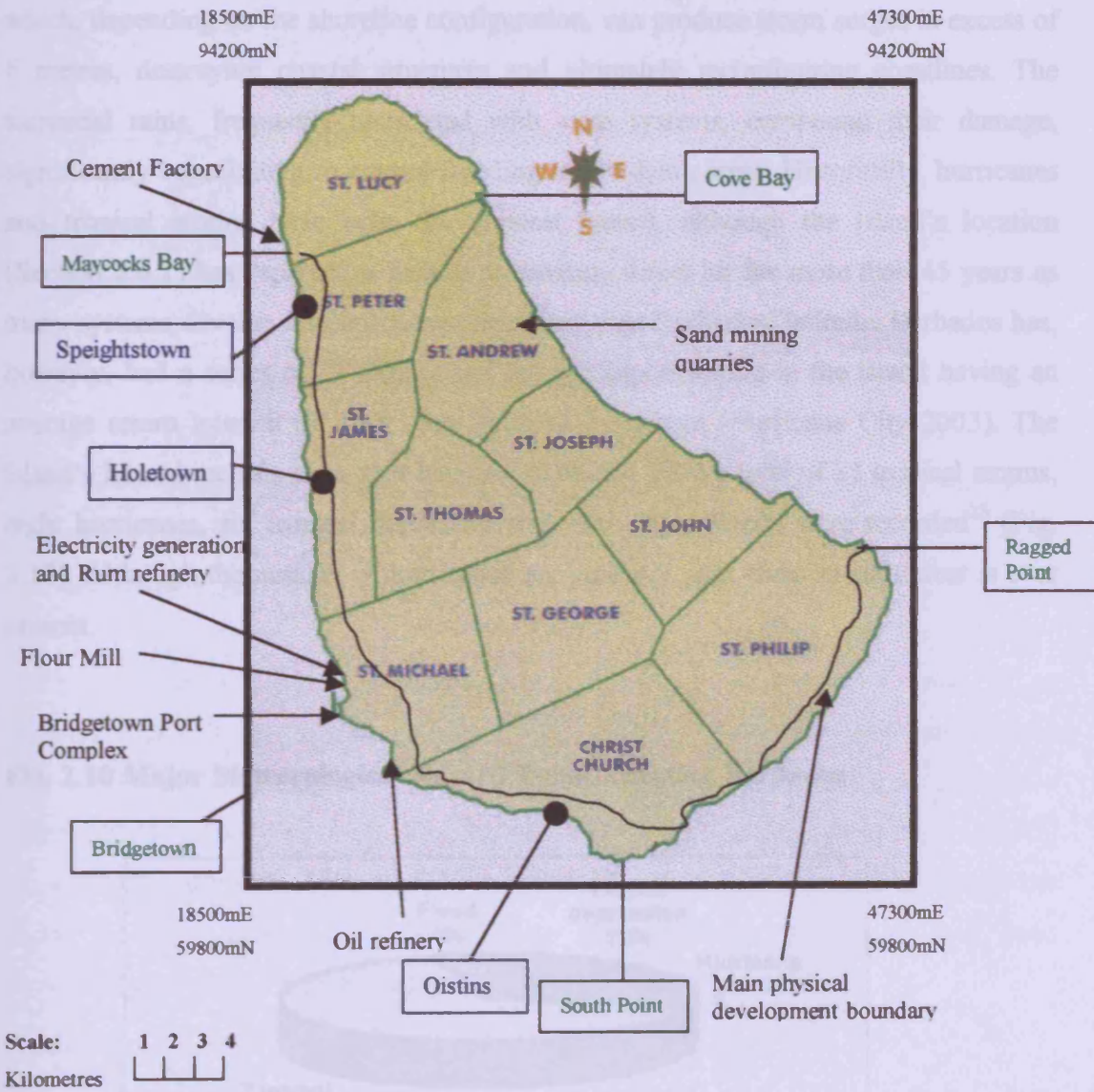
²¹ Of the 150 hotels only 12 are not located on or in close proximity to a beach or coastline resource.

²² Chattel houses are traditionally wooden and transportable. Previously, homeowners used to rent the land they lived on and frequently it was necessary to move/relocate once the land lease had expired or if the land rent had been increased and it was no longer affordable to the land occupant. These house types were constructed to be easily and quickly dismantled and transported on the back of a flat bed truck to the new land location. There they would be reassembled. The process would normally take a day.

2.6.3.2 Industry

Most coastal industrial facilities are located in and around the Greater Bridgetown Area (Fig. 2.9).

Fig. 2.9 Map of Coastal Industry Locations (Source: Original)



The four urban settlement nodes are Speightstown, St. Peter, Holetown, St. James, Bridgetown, St. Michael and Oistins, Christ Church.

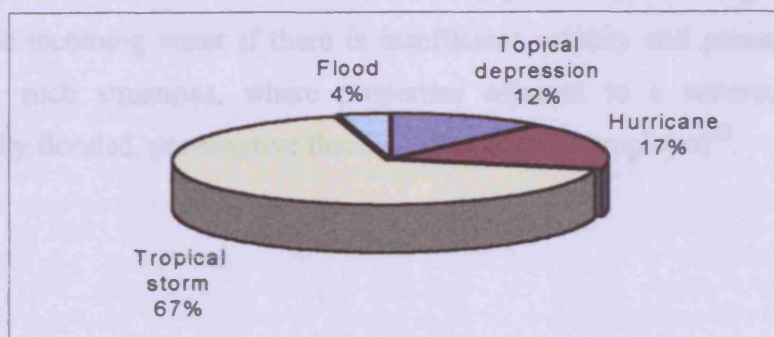
2.6.4 Barbados' Natural Hazard and Vulnerability Issues

The following section outlines the major natural hazards experienced in Barbados.

2.6.4.1 Hurricanes and Tropical Storm Hazards

The destructive nature of these hazards is associated with their extensive high winds, which, depending on the shoreline configuration, can produce storm surges in excess of 6 metres, destroying coastal structures and ultimately reconfiguring coastlines. The torrential rains, frequently associated with such systems, compound their damage, significantly contributing to coastal flooding in low-lying areas. Historically, hurricanes and tropical storms have been the greatest hazard, although the island's location (Section 2.6.1) has "spared" it from a devastating direct hit for more than 45 years as many systems develop into hurricanes once they pass Barbados' latitude. Barbados has, however, had a series of "brushes" and indirect hits resulting in the island having an average return interval of 3.07 years between hurricanes (Hurricane City 2003). The island's hazard records show that between 1898 and 2002 a total of 35 tropical storms, eight hurricanes, six tropical depression and two major floods were recorded²³ (Fig. 2.10). Although the number of hurricanes per year can vary, their annual threat is ever present.

Fig. 2.10 Major Meteorological Hazard Types Affecting Barbados



N = 51

²³ See Appendix 2.

It is generally acknowledged that climate change can influence the overall intensity of hurricanes. Granger (1997) reported that since Hurricane David and Allen in 1979, the major hurricanes with a Category 4 or 5 classifications (e.g. Gilbert, Hugo, Andrew, Frederick, Luis, Marilyn and Opal) have consistently had highly significant sustained wind speeds, central pressures and storm surge heights. They have consistently resulted in coastal inundation, loss of life and extensive damage to residential, commercial and industrial infrastructure, and general devastation to the agricultural sector.

2.6.4.2 Torrential and inland Flood Hazards

Heavy rains, characteristic of the tropical Caribbean rainy season, are most prominent in the hurricane season (June to November)²⁴. Landslides in some locations on the East coast (St Joseph) and Northwest coast (St. Peter) have been also associated with such events (Clive Lorde, *pers. comm.* 2001). They often arise from torrential rains flowing through the island's gully systems and encountering illegally disposed solid waste items, causing blockages within watercourses. Dependant on flood severity, secondary hazards such as mass wasting can also occur (e.g. east coast of the island). The result is frequent property damage, loss of services, and occasionally, loss of life.

Additionally, where watercourses cross under a road, the culvert is often of an inadequate size to handle the volume of water. This results in significant watercourse and culvert over spill, and the flooding of adjacent properties. Similarly, at watercourse egress points on beaches, the sand berm, blocking the water discharge point, frequently retains the incoming water if there is insufficient velocity and pressure to breach the berm. In such situations, where properties adjacent to a watercourse have been periodically flooded, pre-emptive flooding strategies are employed²⁵.

²⁴ Three hundred millimeter rainfall events as recorded in the 1995 floods have been reported (Central Emergency Relief Organization (CERO) 1999).

²⁵ In order to avoid these occurrences, watercourse discharge points that are known to be prone to flooding have their berms mechanically breached, prior to known episodes of heavy rainfall.

2.6.4.3 Global Climate Change Hazard Mitigation

The Barbados government has been proactively addressing this issue, being actively involved in the Caribbean Planned Adaptation to Climate Change (CPACC)²⁶ project monitoring programmes (Box 2.1).

Box 2.1 Project Components for CPACC Project (Source: IRF 1996, CPACC 1998)

1. Design and establishment of sea level and climate monitoring network
2. Establishment of databases and information systems
3. Inventory of coastal resources and use
4. Coral reef monitoring *
5. Coastal vulnerability and risk assessment*
6. Formulation of a policy framework for coastal and marine management
- 7 Economic valuation of coastal and marine resources *
- 8 Economic regulatory proposals for adaptation to climate change*

Where those * marked are the pilot projects that participating countries need to select from and unmarked are the regional components that all countries participate in automatically.

Barbados is currently involved in project components 1 and 5 as a result of the potential implications of sea level rise (SLR) on natural hazard management. Even with the

²⁶ This project has a series of subcomponents specifically aimed at the improved preparedness of the Wider Caribbean Region for the possible eventuality of global climate change, through the establishment of various monitoring programmes. Given the important long-term implications that climate change can have for the future of the region, the Caribbean Community (CARICOM) member states raised their concerns on the climate change issues at the United Nations (UN) sponsored SIDS conference in Barbados 1994. The project is intended to balance the climate change interests and concerns of CARICOM countries, the mandates of regional and international agencies and the opportunities created by the availability of grant funding (IRF 1996). The concerted support by all participating regional governments shows the individual government's commitment to preparing for global climate change concerns. CPACC is funded by the GEF and World Bank and being executed by the Organisation of American States (OAS). See <http://www.cpacc.org/>.

stabilisation of greenhouse gases, projected temperatures are expected to continue to increase (Collymore 1992). In addition, it is envisaged that there will be an increased frequency of storminess with the production of larger and more severe storms and hurricanes because of latent ocean heat (Gable & Aubrey 1990, Burton 1997, Chen 1997, Hudgens 1999, and Doukakis 2003).

2.6.4.4 Seismic Events (Volcanic Activity, Earthquakes and Tsunami)

Generally, Barbados does not suffer from these hazard types, as it is neither close to a fault line nor volcanic in origin. However, it has suffered from ash deposition from volcanic eruptions in 1979 (the Soufriere Volcano in St Vincent), and 1998 (the Soufriere Volcano in Montserrat) (Gibbs 2002). Over the last 8 years, the latter volcano has been highly active. The submarine volcano Kick 'em Jenny, located to the north of Grenada, however, poses the greatest tsunami threat to the island²⁷.

2.6.5 The Need for Systematic Risk and Vulnerability Assessment

Having highlighted Barbados' main natural hazards, there is a need for the incorporation of comprehensive natural hazards assessment into the general planning of the island. Relevant government departments (e.g. Central Emergency Relief Organisation, CERO) are exploring some of these concerns, but plans are still in their infancy. As suggested by the Island Resources Foundation (IRF) (1995), the development of systematic risk assessment studies may allow for an improved understanding of insurance costs and active mitigation efforts for future planning. As part of this, it is necessary to recognise that no coastal location is safe from coastal hazards and the instability effects introduced by human activity (Young *et al.* 1996, Berger and Iams 1996, Heinz Centre 2000a & b). Consideration has to be given to the coastal communities and their differing abilities to respond. The best way of achieving this is through the development of hazard mitigation strategies and plans which consider

²⁷ The summit of the volcano is growing at a rate of approximately 4m per annum. See Appendix 2 for potential impacts of Kick 'em Jenny on Barbados.

coastal geohazards²⁸ (IRF 1995, USAID/OAS 1997, UN-IDNDR 1997, and NOAA 1999).

2.6.5.1 Barbados' Coastal Geohazards

Figure 2.11 presents the hazard ecology of Barbados²⁹. The primary contributors to the island's coastal geohazards are biophysical and human use factors. Each geohazard is summarised with regard to the existing coastal conditions, potential causes of the hazards effect, and the general coastal susceptibility and resilience to the hazard effects. Identified geohazards can assist in the development of CVA maps which, when including information on the ecosystems present within the CZ, proffer a representation of the littoral zone.

2.7 SUMMARY

Chapter Two has examined the conceptual components associated with coastal vulnerability. It has provided a review of the main terminology frequently used in CVA and a rationale for vulnerability assessment. It has shown that, with the predicted effects of climate change, shorelines will continue to be under threat. To encourage proactive responses, coastal systems analysis is required to identify those locations at risk and to determine possible prevention or mitigation strategies. CVA, when integrated into ICZM can help prioritise such management efforts. This chapter has

²⁸ Coastal geohazards and geoindicators are a set of local geologic, environmental and morphologic features that determine the type extent and degree of impact that coastal hazards can have on a coastline (Coburn 2002, Berger 1996, Forbes and Liverman 1996). Coastal geohazards determine how a community will respond to and recover from hazardous coastal processes. Because of their influence geohazards are used to help assess vulnerability and identify potential mitigation options in a coastal community (Coch 1995).

²⁹ Source for erosion and accretion information as well as littoral regime information: Delcan (1995). Source for sea level rise information: Nurse (1989). Source for coastal/inland flooding information: Cumming Cockburn Ltd (1996). Source for information on soil erosion and land slippage: Halcrow (1998).

identified the context for the recognition of the coastal hazard issues affecting the coastline and has presented the case study area on which this research is to be applied.

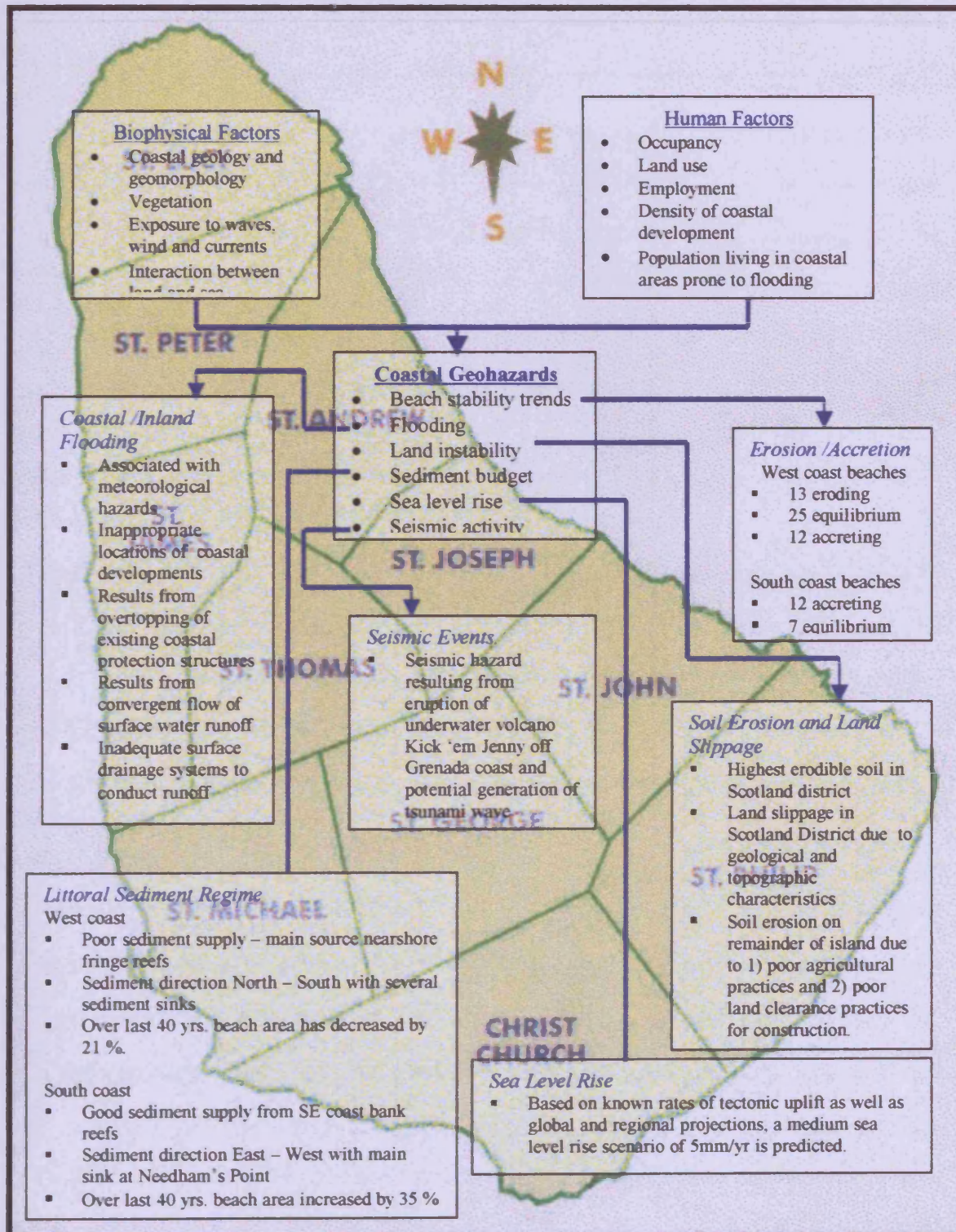
Fig. 2.11 The Hazard Ecology of Barbados (Source: Original)

18500mE

94200mN

47300mE

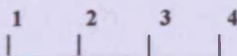
94200mN



18500mE

59800mN

Scale:
Kilometres



47300mE

59800mN

Chapter 3
Literature Analysis of Coastal Classification
And Coastal Vulnerability Indices

Chapter 3
Literature Analysis of Coastal Classification
And Coastal Vulnerability Indices

3.1 INTRODUCTION	46
3.2 GENERAL DEVELOPMENT OF COASTAL VULNERABILITY ASSESSMENT CLASSIFICATION SCHEME.....	47
3.2.1 APPROACHES TO COASTAL VULNERABILITY ASSESSMENT	48
3.2.2 RAPID ASSESSMENT PROCEDURES IN COASTAL MANAGEMENT	51
3.3 PURPOSE OF COASTAL VULNERABILITY ANALYSIS.....	52
3.3.1 PURPOSE OF CVI DEVELOPMENT AND APPLICATION.....	52
3.3.1.1 The Use of CVA and CVIs	53
3.3.2 APPLICATION PURPOSE OF CVI	55
3.3.2.1 Academic or Practical Application of the CVI.....	55
3.4 SCALE OF APPLICATION	57
3.4.1 APPLICATION TO BARBADOS	61
3.5 REVIEW OF VARIABLES USED TO DOCUMENT COASTAL CLASSIFICATION AND COASTAL VULNERABILITY INDICES.....	62
3.5.1 VARIABLE SELECTION.....	62
3.5.2 NUMBER AND RANGE OF VARIABLES.....	63
3.5.3 SPECIFIC CATEGORIES.....	64
3.5.4 APPLICATION TO BARBADOS	66
3.6 DATA COLLECTION PROCEDURES USED.....	69
3.6.1 APPLICATION TO BARBADOS	69
3.7 SCORING AND RANKING PROCESSES.....	71
3.7.1 QUALITATIVE MEASUREMENTS	71
3.7.2 QUANTITATIVE AND SEMI-QUANTITATIVE MEASUREMENTS.	72
3.8 DATA ANALYSIS.....	73

3.8.1 CONCERNS ARISING FROM THE REVIEWED DATA ANALYSIS TECHNIQUES	74
3.8.2 APPLICATION TO BARBADOS	75
3.9 PRESENTATION FORMAT	75
3.9.1 APPLICATION TO BARBADOS	76
3.10 SUGGESTIONS FOR FURTHER STUDY	76
3.10.1 APPLICATION TO BARBADOS	77
3.11 CONCLUSION	78

3.1 INTRODUCTION

This chapter analyses the extent to which the available literature has addressed issues related to coastal classification (CC) and the development of coastal vulnerability indices (CVIs), and the techniques used in the determination of the vulnerability indices. It provides a synthesised and structured evaluation of CC and coastal vulnerability (CV), helping set the research context. The review initially spanned a period of 11 months in which available relevant journal articles, published documents and literature were sourced and reviewed. Thereafter, it was systematically updated as part of the ongoing research¹.

This chapter is structured into ten sections:

- The first commences with a brief rationale for developing CC systems and CVIs.
- The second section reviews the general CVA scheme.
- The third reviews the purpose of CVA.
- The fourth presents scale considerations in developing a CVI;
- The fifth reviews the variables used by the authors to assist in the determination of CVA.
- The sixth provides a critical review of the data collection procedures used.
- The seventh reviews the scoring and ranking processes used.
- The eighth presents the data analysis techniques used.
- The ninth part reviews the presentation formats used.
- The final part reviews the suggested areas for further study in the literature.

These themes provide the underlying framework for identifying the relevant variables used in developing the LVA, presented in Chapter 4.

¹ A summary of those methodologies considered of most relevance to this research is presented at Appendix 3.

3.2 GENERAL DEVELOPMENT OF COASTAL VULNERABILITY ASSESSMENT CLASSIFICATION SCHEME

Coastal geomorphology is controlled by a wide range of geologic factors and processes operating at various scales (Pethick 1984, Shaw *et al.* 1998, Young *et al.* 1996, Forbes and Liverman 1996). Young *et al.* (1996) and Coburn (2002) contended that the frequency, intensity and location of such active physical processes are controlled by regional, local, and site-specific factors or the coastal geohazards encountered therein². No coastal location or community can be considered truly safe from hurricanes, floods, winds, waves and erosion³. The concept that different parts of a community can respond differently to similar coastal processes is fundamental to the development of any hazard mitigation strategy (NOAA 1999, Heinz 2000b, and Coburn 2002). There is a need therefore, to reduce the effects of such events at potentially high-risk coastal locations through proper coastal planning and management.

The use of a coastline classification (CC) scheme is important for ICZM. It groups the coastline into segments that demonstrate the natural processes (e.g. hydrographic, hydraulic, oceanographic, ecological and sedimentological) operating therein. This aids the recognition of different shoreline types and simplifies their description, making it possible to transfer knowledge between separate coastlines of the same type. CC and its application are well discussed in the literature (e.g. King 1974, Davis 1980, Sunamura 1992, Bird 2000, Finkl and Khalil 2000, Fairbridge 2004, Finkl 2004) and has currently evolved to be based on a comprehensive classification system based directly observable attributes and on geomorphological mapping at meaningful scales (Fairbridge 2004 and Finkl 2004). Such approaches will be useful in their relevant application to this research.

² Region factors e.g. plate tectonic setting or latitude; local factors e.g. coastal configuration and protective breakwaters and site specific setting e.g. site elevation and vegetation.

³ Their effects can have significant negative ramifications on communities.

3.2.1 Approaches to Coastal Vulnerability Assessment

Recognition of physical, ecological, and human-use characteristics along coastal areas has prompted efforts to classify coastlines using multidisciplinary information (LOICZ 1995). Such classifications have been associated with risk assessment and CM and have been greatly aided by their capability to store and examine relationships between multidisciplinary data sets in a digital format, typically using a Geographic Information System (GIS) and/or using computer assisted multivariate analysis (Cooper and McLaughlin 1998).

This section introduces the main approaches used in CVA - the Common Methodology (IPCC 1991) and the Environmental Vulnerability Index (SOPAC 1999). The former has been applied with varying success in both developed and developing nations, while the latter, applied initially to the SIDS of the South Pacific Ocean (UNEP 1999a, Kaly *et al.* 1999, SOPAC 2000), was expanded to other SIDS in 2001 (Briguglio & Kaly 1999, Pratt *et al.* 2001).

(1) Global Vulnerability Assessment and the Common Methodology

Since 1990, various guidelines and methodologies have been developed to assess CV to ASLR. Of these, the first edition of the “Global Vulnerability Assessment: Vulnerability Assessment for Population Coastal Wetlands and Rice Production on a Global Scale”, published in May 1992 (Hoozeman *et al.* 1993) is noteworthy. This aimed to generate some initial vulnerability results on a global and regional scale related to: 1) people living along the world’s coasts; 2) the vulnerable coastal ecosystems; and 3) significant rice production in low-lying regions. The result was the collection of detailed global information on the distribution, density and state of resources, and impacting hazardous events. This was presented at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992.

In 1992, the Seven Step Common Methodology for assessing the vulnerability of coastal areas to SLR (IPCC 1992) was proposed by the former IPCC CZM subgroup. This methodology has been instrumental in assisting coastal states with the

identification and assessment of potential coastal impacts from SLR, although with varying degrees of success⁴.

In addition to the Common Methodology, the original IPCC technical guidelines for assessing climate change impacts and adaptations have been developed (Carter *et al.* 1994, Sterr *et al.* 2000). Klein and Nicholls (1998) have further enhanced these particularly for coastal regions. It should be noted that although both procedures use a seven-step approach, there are some basic differences (Table 3.1⁵), which arise as a result of their contrasting applications, (the Common Methodology for coastal zones and the Technical Guidelines for application as a generic guideline for natural or socio-economic systems) (Sterr *et al.* 2000).

Table 3.1 A Comparison between the Stages of the Common Methodology and the Technical Guidelines.

IPCC Common Methodology for Assessing Vulnerability to Sea Level Rise		IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations	
Delineate case study area	1	1	Define problem
Inventory study area characteristics	2	2	Select method
Identify relevant development factors	3	3	Test method/sensitivity
Assess physical changes	4	4	Select scenarios
Formulate response strategies	5	5	Assess impacts
Assess vulnerability profile	6	6	Assess autonomous adjustments
Identify future needs	7	7	Evaluate adaptation strategies

⁴ See Journal of Coastal Research, Special Issue 14.

⁵ Variation in the procedures can be observed where Stages 1 and 2 of the Technical Guidelines (problem definition and method selection) are not reflected in the Common Methodology. Additionally, testing of the methodology is not included as an explicit step in the Common Methodology. The assessment of autonomous adjustments is considered in the Technical Guidelines but not in the Common Methodology. The evaluation of adaptation strategies as presented in the Technical Guidelines equates to the 3 final stages of the Common Methodology.

The Common Methodology has allowed for preliminary vulnerability assessments by coastal states. Its drawback, however, has been the limited information available within the developing countries to perform such assessments.

(2) The Environmental Vulnerability Index (EVI)

One of the main outcomes from the UNCED Conference in 1992 was the formal recognition of the high vulnerability of SIDS to global economic conditions. There was also global agreement for an equivalent conference to focus on SIDS. The result was the Global Summit on Small Island Developing States held in Barbados in 1994 (Section 1.3.1). It was at this conference that there was a recognised need for the development of an appropriate index that could be applied to SIDS to determine their overall environmental vulnerability.

The Environmental Vulnerability Index (EVI), one of the more comprehensive vulnerability indices to date, is particularly applicable to SIDS. It is based on the integration of economic (Briguglio 1993, 1995, 1997), and ecological/environmental vulnerabilities into a single index value (Atkins *et al.* 1998, Pantin 1997, and Kaly *et al.* 1998). Its focus, on the environmental vulnerability to both human and natural hazards, captures the effects on the biophysical aspects of ecosystem, diversity, populations or organism communities and species.

The EVI is consistent with the 1994 Barbados Plan of Action⁶ of the Global Summit on Small Island Developing States. The EVI has been reported to provide a more realistic representation of the issues faced by SIDS, where the entire island system can be considered a CZ. This is especially important because of the relatively short time required for any negative perturbations to be visible and/or effectively experienced on the coastline of most small islands.

Kaly *et al.* (1998) have recommended this approach in an attempt to identify data gaps and capture the fragility of island states, especially those which rely on external

⁶ The SIDS conference action document that presented proposals for the way forward for implementing many of the recommendations arising out of the conference working sessions.

economic forces. However, once the following concerns are addressed, the index is considered highly applicable for SIDS for vulnerability determination:

- The lack of available data for some of the variables;
- Information on variables may exist, but it may take considerable time to find, procure or be put into a readily useable format; and
- Data quality - as there could be conflicting information found from different source agencies or literature.
- Potential misuse through:
 - a) Political Motive - based on those who are against treating SIDS as special considerations at the international level;
 - b) Inexperience - application by inexperienced researchers who attempt to complicate the construction of the indices; and
 - c) Ignorance - relating to the researchers understanding of what the index is meant to measure (Briguglio 1998).

3.2.2 Rapid Assessment Procedures in Coastal Management

Rapid assessment methodologies have been used in other situations⁷, particularly to fast track the assessments of environmental resource systems through the active participation of communities. Pido (1995) encourages the use of this sort of technique as it allows for the generation of additional information about problems and opportunities in the CZ, establishing monitoring indicators to determine the impacts of future development and determining subjects of further research. The advantages of this type of methodology have been identified (Box 3.1). As presented by Salm and Clark (2000), the value of the data produced using this technique is dependent on the skill and judgment of person(s) performing the rapid assessment as well as the style of assessment used. One of the main objectives of this thesis is to develop a rapid technique for littoral assessment - the LVAP model (Fig. 4.1 and Chapter Nine).

⁷ Rapid assessment techniques have been used as part of informal resource management approaches in the developing world to assist with the management of community level resources - refer to Price (1990), Pido and Chua (1992), Pido (1995), Pido *et al.* (1997), Price *et al.* (2000) and Mahon *et al.* (2003).

Box 3.1 Advantages of Rapid Assessment Techniques (Source: Pabla *et al.* 1993)

- They are cost effective.
- Sampling errors and bias are reduced⁸.
- There is flexibility in making adjustment during fieldwork.
- The use of the participatory approach highlights the needs and concerns of stakeholders.
- Discussion with communities and community groups are enhanced.
- Information gathered can be easily mapped and presented for further discussion.
- More local knowledge can be applied to the data collected.

3.3 PURPOSE OF COASTAL VULNERABILITY ANALYSIS

3.3.1 Purpose of CVI Development and Application

CVA is often performed for a distinct purpose. Observations on 1) natural biophysical characteristics, and 2) human interventions that bring about more changes in the natural system, are useful because they provide an encompassing view of the littoral system. For a large stretch of coast⁹ (>100 km), coastal databases developed based on these characteristics have contributed to the development of different indices to determine the vulnerability or sensitivity of a coastline to hydrodynamic, climatic or anthropogenic threats. CVA contributes to the CM process through its integration in ICZMPs and associated initiatives. The CVA provides a priority setting for specific coastal areas and economic sectors from a coastal hazard perspective and indicates the effects of development of the coastal zone on such vulnerability (IPCC 1991).

⁸ Sampling errors and bias can be reduced by the cumulative collection of information presented in group settings which can be verified by stakeholders at the time of discussion, or provide points of information which can be verified by consultation with relevant government departments or other agencies which may be known to collect the data in question.

⁹ From the literature, scale application for coastal lengths can vary between several hundred kilometres to less than several hundred meters. Within this context, coastal length is equivalent to several hundred meters.

3.3.1.1 The Use of CVA and CVIs.

It is recognised that the response requirements to address coastal hazards often result in the development of CM objectives based on the coastal geomorphology. The literature has been shown to primarily focus on the concept of CVA related to *inter alia*:

- 1) The impacts from climate change and natural hazards on a coastline (Gornitz and Kanciruk 1989, Gornitz & White 1991, Gornitz *et al.* 1994, Zeidler 1995, Rotnicki *et al.* 1995, El-Raey 1997, Chemane *et al.* 1997, Gornitz *et al.* 1997, OAS/ USAID 1997, OAS 1999, and McLaughlin 2001).
- 2) The sensitivity of the coast to oil spill damage (Gundlach and Hayes 1978, RPI 1993, Al-Bakri 1996, Abdel-Kader *et al.* 1998, NOAA 1999, Nansingh and Jurawan 1999, and Price *et al.* 2000).
- 3) Development and management along the coastline (Dal Cin and Simeoni 1989, 1991 and 1994, Amore and Randazzo 1994, Bainbridge and Rust 1995, Al-Bakri 1996, Daniels *et al.* 1996, Young *et al.* 1996, Simeoni *et al.* 1997, Cambers 1998, Bush *et al.* 1999).
- 4) Sensitivity of the coast to erosion (Dal Cin and Simeoni 1989, 1991, and 1994, Amore and Randazzo 1994, Simeoni *et al.* 1997, O'Riain 1999, Heinz Centre 2000).
- 5) Socio-economic assessments for vulnerability (El-Raey *et al.* 1995 and 1997, Daniels *et al.* 1996, OAS 1999, Malvarez-Garcia *et al.* 2000, Estnard *et al.* 2000, Greve *et al.* 2000, McLaughlin *et al.* 2002, Carvalho 2002).
- 6) Flood hazard assessment (NOAA 1999, Finkl 2001, DEFRA 2002, Ramsbottom *et al.* 2002, Meadowcroft *et al.* 2002).
- 7) For use as a data storage and data management tool to assist in the creation of shoreline management plans and ICZM plans (Gornitz & White 1992, Gornitz *et al.* 1994 and 1997, and Malvarez-Garcia *et al.* 2000).

Based on this list, the following have been developed as part of this research: oil spill sensitivity characterisation of the coasts (Section 5.3); coastal development and management characterisations (Sections 6.2, 6.4 and 9.2); socio-economic vulnerability

characterisations (Section 7.3 and 7.4) and the research model, developed for integration into the Barbados ICZM process to aid data management (Section 9.4.2).

The primary use of a coastal index is to classify and divide the coastline into segments of similar form, exhibiting equivalent characteristics. The literature suggests that the use of a single index value can be representative for coastal segments (Gornitz and Kanciruk 1989, Gornitz *et al.* 1991 and 1994). It also suggests that the classification procedure should reduce the need for detailed studies, and reduce the cost of monitoring at site specific locations, allowing the findings from well studied locations to be transferred to other less studied locations (Dal Cin and Simeoni 1994 and Cooper and McLaughlin 1998). Hughes and Brundrit (1992) identify that the justified development of CVIs and risk analysis procedures help coastal planners/managers and developers in realising their professional responsibility in addressing appropriate responses to future climate change issues. A CVI, therefore, aids the implementation of protective and preventative management strategies, in advance of probable impact.

The review, however, has shown that there has been little recommendation for the incorporation of proposed approaches to index development into the coastal planning and management process. Further, many indices appear to be purely for academic purposes. Exceptions to this would be those countries, which performed and reported their status of CV as part of the IPCC reporting procedure using the Aerial Videotaped Vulnerability Assessment (AVVA) technique¹⁰. While reported in a scientific journal, there is no indication that the information will be routinely updated. Furthermore, many of these assessments were performed with special funding and, in several instances, by the same co-authors. Hence, while the work has been research led, it does raise the question as to the level of in-house training and technology transfer achieved, and

¹⁰Leatherman *et al.* (1996) demonstrated how effective the use of aerial videography was when combined with economic data for coastlines. The use of this technique showed the natural progression from aerial photographs and remote sensing techniques (although the latter technique still has considerable scope, once resolution and scaling issues are resolved for the country in question). Additionally, the technique allows for large quantities of data to be collected in a relatively short space of time. It was therefore considered to be a very cost effective technique that could be of significant relevance to countries that have been unable to meet the continued cost of long term monitoring programmes, aimed at establishing long term databases. The use of the video image also meant that the interpreter could get an almost physical feeling for the coastline at the instant when the video was flown – a feature not always effectively captured by still photographs (see Journal of Coastal Resources Special Edition 14).

remaining within the country upon completion of the project assessments, required for systematic updating of information.

3.3.2 Application Purpose of CVI

3.3.2.1 Academic or Practical Application of the CVI

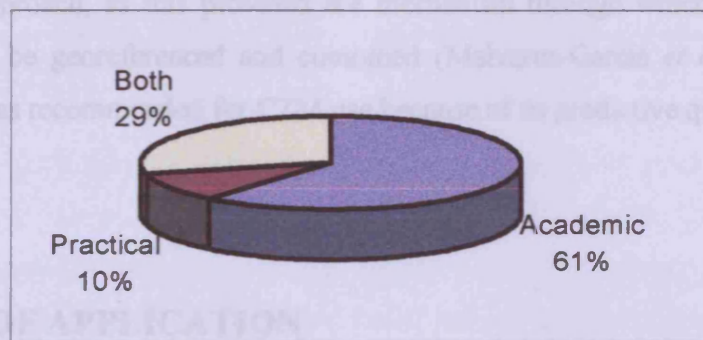
As part of this review, the academic or practical application of each procedure has been determined, to decide its usefulness in CVA methodology within the context of this research. The term “academic” is taken to mean a paper that has been published to improve the scientific knowledge of the subject area; while the term “practical” means a paper published demonstrating the performance of the methodology and its application for use in coastline designation. Appendix 3.2 Table I(i) subdivides papers into international, regional and local applications reviewed into academic or practical papers based on this author’s judgement. In some cases, papers have been classified as both. The rationale behind this has been to establish the applied regularity of purpose for the research. It also provided some indication as to the reliance of secondary data.

Appendix 3.2 Table I(i) shows that most applications are academic (61%), with only 10% having direct practical application (Fig 3.1). The latter are primarily qualitative in their methodology, using semi-quantitative analytical procedures. Academic applications demonstrate the effectiveness of the procedures and the possible implications of potential future work. They demonstrate that the methods presented can be considered an appropriate alternative to other procedures. The review also demonstrates that academic papers seldom made recommendations for their incorporation into the ICZM process.

The academic papers cover all application scales (international, regional and local). Several were purely scientific, reviewing some of the controls governing process-response relationships on coastlines (e.g. Jackson and Nordstrom 1992, Anthony 1994). Others followed prescriptive guidelines to assess the potential impacts of sea level rise on coastal study areas (e.g. El Raey 1996 and 1997, Rotnicki *et al.* 1995 and Chemane

et al. 1997). Of special significance are the papers by Dal Cin and Simeoni (1989a and b and 1994) and Amore and Randazzo (1994) who published on the use of hydrodynamic, textural, sedimentological, and evolutionary features for determining the classification, vulnerability and risk of coastlines. These procedures resulted in the identification of areas of similar classification, and the development of site-specific maps.

Fig. 3.1 Applied Use of CVIs Found in the Literature



N=70

There are few practical papers. Those that exist are generally of a highly descriptive nature involving field-based observations using checklists. However, unlike the academic papers, all have been proposed for use in the CZM process (Bush *et al.* 1999 and Young *et al.* 1996). Of particular note is the work by Cambers (1998) who developed a checklist based on Young *et al.* (1996) for use in the Caribbean. This was to be applied to site-specific coastal property locations as part of a site evaluation process for the effects of erosion on the coastline.

An alternative approach, utilised by both Williams *et al.* (1993a) and Alveirinho-Dias (1994), focused on the vulnerability of sand dune systems. While this methodology has been presented for academic purposes, it clearly has practical potential. The authors' note that the variables can be modified, to suit site-specific situations, (especially relating to the pressure of use and recent protection measures categories).

Other methods have been effectively used in the development of risk maps through CVI mapping of the coastal areas and the incorporation of the CVI into a GIS (Gornitz and White 1992, Gornitz *et al.* 1994 & 1997, Thieler and Hammar-Klose 1999 & 2000). While highly academic (requiring vast quantities of historical data and considerable aptitude data processing), the results are presented in a format, which allows for transfer to other areas.

Malvarez-Garcia *et al.* (2000) implemented a procedure examining the origin and management of development stress along their study area. As part of the process, a CVI was developed based on variables used by Gornitz (1990). This was done primarily using a GIS approach, as this provided the mechanism through which heterogeneous variables could be georeferenced and combined (Malvarez-Garcia *et al.* 2000). The methodology was recommended for CZM use because of its predictive quality¹¹.

3.4 SCALE OF APPLICATION

Townend and Fleming (1994) note that the scalar extent of coastlines is highly varied (metres to hundreds of kilometres), and the effects experienced at a site-specific location are related to existing coastal resources and man-made structures therein. Additionally, the effective management of a coastline depends primarily on the role the relevant management agency plays. Hence, the coastal process information to be presented and interpreted has to be summarised and represented in a useful format, at a scale best suited for management purposes. It is suggested that the most effective scale to achieve this should be only a few kilometres in length (Townend and Fleming 1994).

The literature analysis revealed four scales (Table 3.2)¹².

¹¹ It could combine the existing long-term stability of shoreline and marine conditions with elements of population growth and urbanisation that could be subject to rapid change.

Table 3.2 Application Scales derived from the Literature (Source: Original)

Scale Category	Geographic Application Coverage	Coastal Segment Length
General Guidelines	Not Applicable ¹³	General application
Global/ International/ Interregional	Global/international application 1:5,000,000 or larger	>1500km
	Global to very large: > 1:5,000,000 and > 1:2,000,000	> 1000 km
	International and interregional level ¹⁴ 1:1,000,000,	1000 km and >500 km
Regional	Large area: < 1:5,000,000 and > 1:2,000,000	>1000 km
	Medium area < 1:1,000,000 and > 1:10,000	< 1000 km and > 100 km
Local	Small area < 1:10,000 ¹⁵	< 100 km

The review has demonstrated that the scale of application is of primary significance when considering the proposed use of a CC and an associated CVI. The scale¹⁶ (global/international/interregional, regional, and local) depends on the CC requirements of the identified study area. Classifications and indices proposed for large areas, of course, lack considerable detail and resolution, and result in generalisations of coastal types and responses (Marques and Julia 1987, Fricker and Forbes 1988, Jelgersma *et al.* 1993 and Richmond *et al.* 2001).

Some authors (Bainbridge and Rust 1994, Gornitz 1990, Gornitz *et al.* 1994), however, have attempted to use detailed indices at a smaller resolution. The variations in spatial resolution included:

- A few metres (Cambers 1998),

¹² Refer to Appendix 3.1 Table Ia, for the number of authors in the respective categories.

¹³ Several proposals put forward at the international and intergovernmental levels relating to general procedures for coastal vulnerability and sensitivity assessment, providing a basic starting point from which all countries determine at least a preliminary assessment of the vulnerability of their coastline.

¹⁴ Applied to adjacent countries and dissimilar countries with similar coastline classifications were identified.

¹⁵ This category is important since it is the scale that can be best applied to most SIDS or a localised or site-specific stretch of coastline.

¹⁶ These application scale categories have been developed by this author to determine, based on the review, the most effective methodologies that can be applied within a SIDS context.

- A few hundred metres (Bush *et al.* 1999, Young *et al.* 1996);
- 500 m by 500 m (Price 1990 and Price *et al.* 2000, Shepherd and Ormond 1987);
- A few kilometres in length (Dal Cin & Simeoni 1989 and 1994, Al-Bakri 1996 and El-Raey 1997);
- 5° latitude and 5° longitude (Gornitz *et al.* 1990, Gornitz *et al.* 1993, Thieler *et al.* 1999).

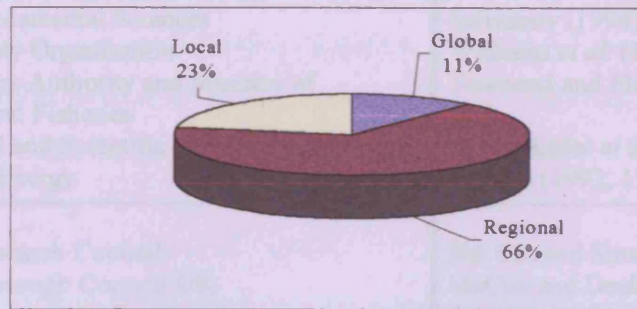
Scale consideration is also relevant as it can hide important differences in coastal form. This was observed by Jelgersma *et al.* (1993) where the noticeable variations, at ground level in some low lying areas, were not accurately reflected in the final map outputs.

Global and interregional scales are important in the formulation of international and interregional policies, and where appropriate, national CM policy guidelines. However, generalised global methods are still highly limited in their application at the local levels. Where this has been attempted it has been possible to develop a preliminary general analysis of vulnerability to SLR and other risk issues (e.g. Leatherman and Nicholls 1995, Nicholls and Leatherman 1995). It has, however, been able to identify data gaps, in order that additional detailed national studies can be performed. This also identified the need for independent local modification, especially if they are to be applied within a SIDS context. Further modification considerations are still required to capture SIDS issues. As identified by Otter and Capobianco (2000), the use of GIS has increased the capacity of analysis of spatial data and, thus, contributed to improved quantification techniques and manipulation possibilities, including modelling (Engelen *et al.* 1995, Martin 1996).

The analysis has shown that most research, has occurred at the regional level (Fig. 3.2), possibly because it is often led by institutions that have an interest in this area of research and/or have direct coastal or environmental management responsibility or remit, at a regional or national scale. In some instances, index development has been funded by research organisations and other agencies with no direct CM responsibility (e.g. Anglian Water 1989, Nature Conservancy Council & National Rivers Authority 1993, Commission of the EC and Directorate for Science, Research and Development 1998, UN FAO 1993). The recognition by these agencies of the need to develop CVIs

suggests that there is a common appreciation of their importance and potential value to the CM process. Funding agencies involved in index development are exemplified in Table 3.3.

Fig 3.2 Applied Scales of Multidisciplinary Approaches to CVA found in the Literature Review



N =70

The development of CVIs for local application has also been very limited. However, this is the scale at which the greatest appreciation of the direct effects of shoreline vulnerability can be determined. The review highlighted the need for a rapid assessment approach using semi-quantitative analytical methods. However, authors such as Young *et al.* (1996), Berger (1996) and Bush *et al.* (1999) noted the need for low cost approaches to assist developing coastal states in assessing their high-risk coastal area. This was necessary since the research required the development of new fine resolution indices that might be too expensive for local management structures.

At the local level the main sources of funding originate from academic and national research organisations (Appendix 3 Table 3.1). While it may be difficult to determine the specific reasons for this, the paucity of local scale applications demonstrates a lack of appreciation of the value of such approaches at this level. It has been shown that regional approaches have been applied in preference to local applications, primarily to ensure cost effectiveness by the funding agencies while simultaneously raising awareness about CM issues.

Table 3.3 Examples Funding Sources for CVI Development¹⁷ (Source: Original)

Scale Level and Funding Agency	Authors
<u>International Level</u> United Nations Food and Agricultural Organisation (FAO) US Department of Energy Commission of European Communities	Gommes <i>et al.</i> (1998) and Jelgersma <i>et al.</i> (1993) Gornitz and Kanciruk (1989) Queleynec (1989)
<u>Regional Level</u> Central European University and the Russian Foundation for Fundamental Sciences North Atlantic Treaty Organisation U.K. National Rivers Authority and Ministry of Agriculture Food and Fisheries Islamic Educational and Scientific Organisation US Department of Energy	Selivanov (1994) Williams <i>et al.</i> (1993) Townend and Fleming (1994) Abdel-Kader <i>et al.</i> (1998) Gornitz (1992, 1994 and 1997)
<u>Local Level</u> Italian National Research Council Great Yarmouth Borough Council UK United Nations Environment Programme	Dal Cin and Simeoni (1994) McCue and Deakin (1995) Simeoni <i>et al.</i> (1997)

3.4.1 Application to Barbados

The local scale is best suited for application within this research as it applies indices and classification schemes to small areas, with the lower limit being a functionally manageable size, permitting the equivalent of local and site-specific interpretation to be performed with some degree of accuracy. As Barbados is small independent island, the local scale has to be applied at a national level to capture any noticeable variations within the CZ. Additionally, based on the developed literature scale ranges, the island fits in the “local scale” designation. The local scale provides sufficient adaptable yet applicable detail for SIDS whereby a broad cross-sectoral representation can be made, which through systematic application can result in the implementation of planning policies to avert coastal geohazard effects.

¹⁷ See Appendix 3.

3.5 REVIEW OF VARIABLES USED TO DOCUMENT COASTAL CLASSIFICATION AND COASTAL VULNERABILITY INDICES.

3.5.1 Variable Selection

The selection of variables¹⁸, which characterise the methodology used in the LVA development process are used as determining features of the coastline (Section 4.2.1.1). In 1993, the OECD proposed a set of “pressure-state-response” indicators for national use. This framework has been widely accepted because of its simple form and adaptability for application on any scale (Izzo 1996). Since then, the OECD system has been modified by different agencies, as exemplified by USEPA (1994) and Wiering (1995).

The literature demonstrates that coastal monitoring can be performed in several ways (e.g. JCR Vol. 13 No. 4)¹⁹. The criteria chosen to assist in indicator selection, provide guidelines that assist in the decision-making process, ensuring the variable or methodology under consideration is suitable for inclusion in the monitoring programme.

The US Environmental Protection Agency (USEPA) and US Geological Survey (USGS) (2002) identified the need for standardisation of selection criteria to:

- (a) Streamline the selection process;
- (b) Reduce cost;
- (c) Prevent duplication of effort;
- (d) Provide consistency in the data collection and interpretation;
- (e) Allow for cross programme comparisons.

Owen (2002) identified a total of 26 criteria requirements frequently used in the performance of a good risk assessment and sensitivity analysis (Appendix 4). However,

¹⁸ Indicator variables are defined as tools for enhancing reporting, communication, transparency, effectiveness and accountability with policy makers and the general public on environmental assessment, in terms of the state and pressure derived from human activities and affecting the environment (Izzo 1996, Cendrero & Fischer 1997, Ferreira 2000, Garcia *et al.* 2000).

¹⁹ See also Crowell *et al.* (1991), Shoshany and Degani (1992), Morton *et al.* (1993), Thieler and Danforth (1994a & b), Burke-Pollock (1995), Larson *et al.* (1997), Gorman *et al.* (1997), Morang *et al.* (1997a & b), Mitchell (1997), Everitt *et al.* (1999), Mason *et al.* (2000) and Moore (2000).

the author pointed out that the criteria should be selected for the specific needs of the assessment and on the data quality and its accessibility.

Hyder (1999a & b) identified eight criteria on which to assess applied methodologies²⁰. These requirements are captured to a large extent by the criteria listing presented by USEPA/USGS (2002). These identified three selection criteria groupings (Table 3.4):

- 1 Scientific Validity - this determines if data can be compared with reference conditions or other sites. The technology used here should not be too complex or costly to be applied. The ability to use the criteria is also important to allow for comparisons on temporal and spatial levels.
- 2 Practical Considerations – consistent data have to be collected in order for the results to be effective. This is directly related to the practical application of the methodology. Included here are monitoring costs, availability of personnel and the practical application of the technology.
- 3 Programmatic considerations – this reflects the design of the applied monitoring programme to attain the desired objectives of the research/data collection.

Therefore, in order to ensure the acceptability of research the variables need to be evaluated. According to Robinson (1995) (cited Owen 2002), evaluations should be an integral component of any study, but should also contribute to the improvement of what is being evaluated. This evaluation is presented in Section 3.5.2

3.5.2 Number and Range of Variables

The analysis demonstrates the selection and number of variables used in the different classifications relate directly to study aims (e.g. McGregor and Green 1989, Jelgersma *et al.* 1993, Anthony 1994, Dal Cin & Simeoni 1994, Selivanov 1994, Bainbridge and

²⁰These are: (1) applicability to project type (2) applicability to environmental conditions (3) applicability to European assessment systems (4) adaptability, (5) cost effectiveness (6) international acceptability (7) complexity and (8) utility to the practitioner.

Rust 1995, Williams and Bennett 1996, Ferreira and Alveirinho-Dias 1998, Cambers 1998 and McCue 2000). In the case of Townend and Fleming (1994), the variables were spatially disparate and were specifically associated with defined areas - some areas of the hinterland (e.g. landscape), beach (e.g. backshore and foreshore width) or the sea floor (e.g. subsurface sediments). These variables were important in describing how the variables changed between different coastal locations.

It was noted that the same author often has changed the variables used, when applying the indices to different areas of the same coastline. This is exemplified by Gornitz *et al.* (1992 and 1994²¹), where in the 1994 application, the extensive variable combinations used, incorporated several socio-economic factors and environmental variables that could have a direct effect on the highly vulnerable low lying study area regarding its level of risk to SLR. This highlights the importance of methodology flexibility to achieve the required aim - even on the same scale.

3.5.3 Specific Categories

Within the last decade the analysis of multidisciplinary data sets using GIS and or computer assisted multivariate analysis for index development and CC has been applied to several coastal areas²². In most cases, the classification procedures involved the use of secondary data sets (Cooper and McLaughlin 1998). The following considers the variables used in the derivation of CVIs. The variables are grouped under subheadings to demonstrate the key variable areas for consideration. Appendix 3 Table III (ii) presents a listing of all the documented variables located in the literature review. The variable category groupings (and associated brief explanations) are presented in Table 3.5²³.

²¹ The 1994 application retained the original variables used in 1992 but added additional variables to the process.

²² Such applications have been demonstrated by Gornitz and Kanciruk (1989), Gornitz and White (1992 and 1997), Gornitz *et al.* (1994), Daniels *et al.* (1996), Thieler and Hammar-Klose (1999), O'Riain (1999), Malvarez-Garcia *et al.* (2000), Finkl (2000), Price *et al.* (2000), Dobosiewicz (2001) McLaughlin (2002) and Finkl (2004).

²³ Titles and variables categories 12 and 13 were derived from Williams *et al.* (1993) and Alveirinho-Dias (1994). The decision for their inclusion specifically related to issues affecting the vulnerability of sand dunes as unique littoral terrestrial habitats.

Table 3.4 Summary of Some Indicator Selection Criteria

(Based on combined Criteria Guidelines drawn from the USEPA and different US government agencies) (USGS 2002.)

Criteria/Quality	Definition (s)
Scientific Validity (Technical considerations)	
*Measurable/quantitative [#]	Feature of environment measurable over time has defined numerical scale and can be quantified simply.
*Sensitivity [#]	Responds to a broad range of conditions or perturbations within an appropriate time frame and geographic scale, and is sensitive to potential impacts being evaluated.
Resolution/discriminatory power [#]	Ability to discriminate meaningful differences in environmental condition with a high degree of resolution (high signal to noise ratio).
Integrates effects/exposure	Integrates effects or exposure over time and space
*Validity/accuracy	Variable is true measure of some environmental conditions within constraints of existing science. Related or linked unambiguously to an endpoint in an assessment process.
*Reproducible	Reproducible with defined and acceptable limits for data collection over time and space.
Representative	Changes in variable/species indicate trends in other indicators which they are selected to represent.
*Scope/applicability	Responds to changes on a geographic and temporal scale, appropriate to the goal or issue.
Reference value [#]	Has reference condition or benchmark against which to measure progress.
Data comparability	Can be compared to current or available data sets/past conditions.
Anticipatory	Provides an early warning of changes.
Practical Considerations	
*Cost/cost effective	Information is available or can be obtained with reasonable cost/efforts. High information returns per cost.
*Level of difficulty	Ability to obtain expertise to monitor. Ability to find, identify and interpret chemical indicators, biological species, or habitat variable. Easily detected. Generally accepted method available. Sampling produces minimal environmental impact.
Programmatic considerations	
*Relevance [#]	Relevant to desired goal, issue, or agency mission; e.g. species or recreational or commercial value.
*Program coverage	Program uses suite of indicators that encompass major components of the ecosystem over the range of environmental conditions that can be expected.
*Understandable	Indicator is or can be transformed into a format that target audience can understand.

Table note: Where * = Criteria selected to correspond with those applied in this research; [#] = Criteria identified by OECD²⁴ (Izzo 1996).

²⁴ Izzo (1996) indicated that the European Union applied the following criteria to assist in the identification of indicators: 1) Relevance to the coastal zone; 2) Relevance to European policy; 3) Measurability/data availability; 4) Exclusion of natural fluctuation; 5) Spatial fluctuation; and 6) General.

As part of the review, it was considered important to identify the authors using the same classification variables. Generally, there are a few instances where a variable has only been used by one author (e.g. Jelgersma *et al.* 1993, Bainbridge and Rust 1995, and Townend and Fleming 1994). Where multiple authors are identified, these have used the same methodology to develop their classification system and indices. The works of Gornitz *et al.* (1991, 1993, and 1997), Thieler *et al.* (1999), and Malvarez-Garcia *et al.* (2000) exemplify this. In contrast, different authors (Dal Cin and Simeoni 1994, Amore and Randazzo 1994, Al-Bakri 1996, Simeoni *et al.* 1997, Cambers 1998 and Bush *et al.* 1999), using different methodologies employed the same variables (e.g. coastal shape, beach orientation, wave period and wind speed, beach size, and accretion erosion rate, climate and sediment type).

It was also considered important to identify variables most suited for CC, especially if different authors, using different methodologies for analysis, chose the same specific variables. In these results the individual variables have been related to their respective authors (Appendix 3 Table III (i)). However, there is still need for a clearer definable mechanism for variable selection. Such a procedure has been described and applied in Section 4.3.

3.5.4 Application to Barbados

The review demonstrates variable classification categories depend on the primary aim of the vulnerability or sensitivity index. The literature points to caution needing to be taken in variable selection, as some variables may exert similar effects, or the use of irrelevant variables might mask the importance of other response variables. Within this research, the collection of data on several variables is considered the more appropriate approach, as they provide a useful foundation on which to build a comprehensive descriptive dataset for coastlines where little information previously existed.

Table 3.5 Variable Groupings Identified from Literature Review (Source: Original)

Variable Category Grouping	Explanation
<i>1. General variables</i>	To provide general information on the coastal area.
<i>2. Interior variables</i>	To provide information on the area landward of the study area. From the reviewed documents, the inland extent varied between a few metres to several kilometres, depending on the scale of study application. At the regional level, the description of the interior variables did not extend landward of the predicted point of greatest inundation from storm surge or sea level rise.
<i>3. Human intervention /impact variables</i>	To provide information on major coastline anthropogenic impacts identified in the literature. Within this category, broad variable types that primarily indicated the effects of coastal engineering structures on the coast, have been used.
<i>4. Littoral habitats variables</i>	To provide information on littoral habitats within the coastal zone. These variables have been based mainly on abundance and diversity values, together with identification descriptors of the habitat types.
<i>5. Nearshore variables</i>	To provide information on the form of the nearshore and offshore shelf. These have been determined by this author to be outside the category used to identify the physical variables of littoral processes.
<i>6. Inlet variables</i>	To provide information on the variables used to identify inlet effects on shorelines.
<i>7. Physical variables of littoral processes</i>	To provide information on those variables that influence the littoral processes acting on coastlines.
<i>8. Shoreline variables</i>	To provide information on those variables which qualitatively and quantitatively describe the coastline.
<i>9. Evolutionary variables</i>	To provide information on those variables depicting shoreline change over predetermined time periods.
<i>10. Morphology and sedimentology of the beach variables</i>	To provide information on variables that determines the composition of the beach sediments and the backshore area.
<i>11. Morphology and sedimentology of the sea floor</i>	To provide information on the variables that determine the sea floor characteristics associated with sediment composition and sea floor shape.

Table 3.5 Variable Groupings Identified from Literature Review (cont'd)

Variable Category Grouping	Explanation
<i>12. Pressure of use</i>	To provide information on those variables that describe the level of public use pressure on sand dune systems.
<i>13. Recent protection measures</i>	To provide information on those variables that describe the levels of protection applied sand dune systems.
<i>14. Sand dune morphology and condition</i>	To provide information on those variables describing resilience of dune system and the site-specific factors that influences their resilience.
<i>15. Other</i>	Those variables that that have been identified by authors but do not fit in with the other category titles listed above. They are presented have for completeness of the list review but they are difficult to be incorporated into the variable list.

3.6 DATA COLLECTION PROCEDURES USED

An assessment was made of the most useful data collection procedures used for each variable. The variables have been divided into three categories based on the data being either field acquisition related (i.e. requiring *in situ* data collection) or desk-top study related (i.e. requiring secondary source information) or both²⁵. This assessment aided the identification of generic costing implications associated with the low cost assessment process developed in this research (Chapters Five and Six).

Table 3.6 summarises the approaches used for data collection according to the number of reviewed authors using the variables. This shows that the littoral habitat variables are primarily field determined (63% field). In contrast, those variables relating to physical littoral processes require secondary source data mainly (55% desk). The shoreline variables are predominantly field-oriented, requiring onsite descriptions and measurements, where appropriate (67% field). The beach morphology variables also require all *in situ* data collection, while the morphology of the shoreline, required access to both field data and historical or documented information (88%).

3.6.1 Application to Barbados

This analysis provides an initial guideline for determining the source of information on variables. This has implications on the time required to collect, collate and analyse the data. Based on the reviewed variables, those describing oceanographic conditions, the shoreline and nearshore morphology and bathymetry, beach and nearshore sedimentology, coastal land use characteristics and shoreline protections structures have the widest application for Barbados and have been selected for use in this research. However, the variables have had to be refined. The selection process is presented in

²⁵ Some variables could be considered as adequately fitting both desktop and field survey classification types. However, the use of field designation indicates the need for direct *in situ* measurements describing site characteristics at the present time, rather than historic information. This is especially important since the information derived from a desktop study reflects the data collected at the time when the study was performed.

Section 4.3. The development of the field-monitoring component of the research is presented in Chapter Five.

Table 3.6 Summary of Data Collection Procedures for Variable Types²⁶
(Source: Original)

Variable Type	Number of Data Collection Procedures Used in Literature			
	Field	Desk	Both	Total
<i>1. General variables</i>	4	4	2	10
<i>2. Interior variables</i>	2	5	3	10
<i>3. Human intervention /impact variables</i>	2	1	1	4
<i>4. Littoral habitats variables</i>	5	0	3	8
<i>5. Nearshore variables</i>	3	2	1	6
<i>6. Inlet variables</i>	3	0	0	3
<i>7. Physical variables of littoral processes</i>	7	12	3	22
<i>8. Shoreline variables</i>	29	5	9	43
<i>9. Evolutionary variables</i>	0	2	0	2
<i>10. Morphology and sedimentology of the beach variables</i>	4	0	0	4
<i>11. Morphology and sedimentology of the sea floor</i>	6	4	0	10
<i>12. Pressure of use</i>	6	3	4	13
<i>13. Recent protection measures</i>	5	3	3	11
<i>14. Sand dune morphology and condition</i>	14	3	5	22

²⁶ Complete table is found in Appendix 3.

3.7 SCORING AND RANKING PROCESSES

Appendix 3.3 Tables I and II²⁷, were developed to provide a succinct presentation of the author values and descriptive terms used in their scoring and ranking process, respectively. The variables have been presented with their measurement units in both tables to help understand the applied range of field measurements. This representation further assists in the interpretation of applied scale ranges and their applicability for littoral zones of SIDS. The review is divided into those applications that used qualitative measurements and those that used quantitative or semi-quantitative measurements.

3.7.1 Qualitative Measurements

These rely on a combination of general descriptive field observations (including some direct measurements) and interpretation of the information to apply a ranking score. It is observed (Appendix 3.3 Table I) that scoring system descriptions generally used a three or five scale subjective scoring scheme (i.e. scales from 1 to 3 and 1 to 5). The ranking associated with the scores of 1 to 5 were descriptive, often covering very low, low, moderate, high and very high. Gornitz *et al.* (1992, 1994, and 1997), Thielier *et al.* (1999 & 2000) and Malvarez-Garcia *et al.* (2000) have used this system. Cambers (1998), however, used a scale of 1 to 3, where the descriptive ranking ranged from low to high to reflect that high scores correlate to a high level of risk vulnerability.

While it would be expected that the ranking score would increase numerically with increasing risk, this was not always so (e.g. Bush *et al.* 1999 and Young *et al.* 1996). These authors used the ranking system 1 to 3, with descriptive descending rankings of high, moderate and low respectively. Such equivalent descriptive classifications have been used in the development of the environmental sensitivity indices presented in Chapter Five.

²⁷ These show the qualitative and quantitative variables used by the reviewed authors.

3.7.2 Quantitative and Semi-Quantitative Measurements.

These descriptions rely mainly on measured field observations. It is observed (Appendix 3.3 Table II) that clearly quantifiable measurements were used to determine the variables. Most variables had a scoring range associated with them. However, in some instances only the measurement units were used, indicating the need to collect actual data on variables. Several scoring systems (e.g. Gornitz *et al.* (1992, 1994, and 1997 and Thieler 1999) were used to assign values of risk, (ranging from 1 to 5 in ascending ranking order of very low, low, moderate, high and very high). In contrast, Nansingh and Jurawan (1999) used a scoring of 1 to 3 with a descending order of risk (high, medium and low). Thus, high scores in such variables as wind speed, wave height, wave period, and long shore current indicate a low risk ranking.

The quantitative and semi quantitative measurements used in the literature also reveal that two authors (Townend and Fleming 1994 and Price 1990) chose not to apply risk ranking to some variables, but instead applied values and a scoring system determined from the compiled data.

Some authors (Dal Cin and Simeoni 1989 and 1994, Amore and Randazzo 1994) relied on the actual measurements of some variables as part of the quantitative assessment process for the evaluation of morphological and sedimentological variables for the beach and sea floor. A similar trend was also observed for variables used in the physical variables of littoral processes (Jackson and Nordstrom 1992 and Nansingh and Jurawan 1999). In comparison, it was found that variables used in describing the shoreline often had score ranges and risk rankings associated with each variable.

Others (Gornitz *et al.* 1991, Malvarez-Garcia *et al.* 2000, Bush *et al.* 1999 Young *et al.* 1996 and Cambers 1998) using the semi-quantitative checklist approach were considered to be more application-oriented. These authors provided a mechanism for which either technical approaches (the first 2) or non-technical approaches (the latter 3) could be used to ascertain the level of shoreline vulnerability.

3.8 DATA ANALYSIS

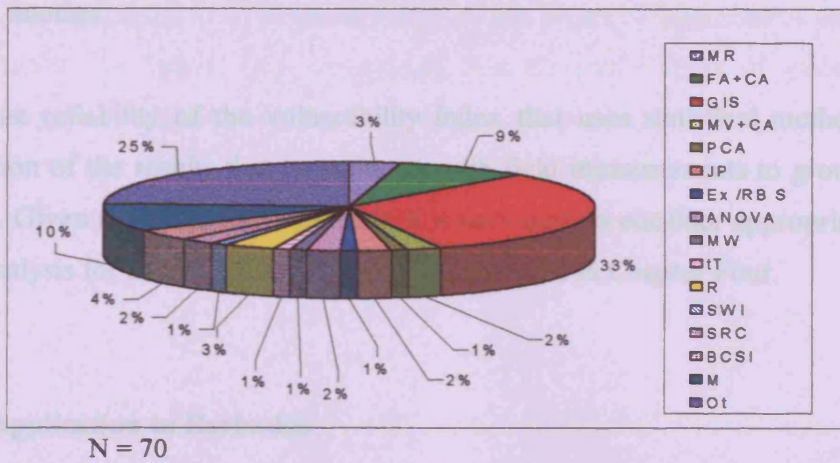
Most methods used to derive CVI were relatively simple statistical tests mainly involving the grouping of variables of similar effect/weighting with some authors focused on database development rather than the further refinement of the data.

Multivariate analysis²⁸ was the most frequently used analytical method for data analysis (Fig. 3.3). The use of cluster analysis enables reduction and grouping of large numbers of variables, which have similar effects on the coast. Various authors used these types of groupings (e.g. Dal Cin and Simeoni 1989 & 1994, Jelgersma *et al.* 1993, Nansingh and Jurawan 1999 and Young *et al.* 1996). Multivariate analysis also highlighted those variables that are more significant in explaining the variability within a given coastal stretch (Cooper and McLaughlin 1998).

Most papers (34%) made use of GIS for data interpretation (Fig 3.3), with other frequently used alternatives including manual methods for CVI calculation (15%) and factor and cluster analysis (9%). However, all the combined multivariate analyses only represent 20% of the methodologies. The level of detailed application varied according to the required output (e.g. El-Raey 1997, Gornitz *et al.* 1989, 1994 & 1997).

²⁸ In the forms of multivariate analysis, factor analysis, principle component analysis, and cluster analysis.

Fig. 3.3 Analysis Methods used to Determine CC and CVIs



Where the analysis methods identified are:

MR = Multiple Regression; FA+ CA = Factor and Cluster Analysis; GIS = Geographic Information Systems; MV+ CA = Multivariate and Cluster Analysis; PCA = Principle Component Analysis; JP = Joint Probability Analysis; Ex/RB S = Expert Shell / Rule Based System; ANOVA = Analysis of Variance; MW = Mann Whitney Test; tT = t Test, R = Ratio; SWI = Shannon Weiner Index; SRC = Spearman Rank Correlation; BCSI = Bray-Curtis Similarity Index; M = Manual; Ot =Other

3.8.1 Concerns Arising from the Reviewed Data Analysis Techniques

Many papers gave little consideration to the validity of the variables. Few examined the interrelationship between variables and the statistical basis for their inclusion/exclusion. The danger of such an approach is that the capacity for improper manipulation of the data may not be recognised by a coastal manager. Other concerns identified include:

- Data analysis reliability from the applied statistical tests depends on the accuracy with which the data were collected and the applicability of the statistical tests chosen and the interpretation of the results.
- For indices to be beneficial in time, the databases need to be updated with current information. As there were seldom reports of the procedures being integrated into the ICZM process, it is unlikely that such information has been updated.

- Problems also arise in that the development of a single index for vulnerability as it may obscure the relative strengths of certain individual variables from one another.

The true reliability of the vulnerability index that uses statistical methods is in the validation of the results that it produces, with field measurements to ground truth the results. Given the aim of this research, it is necessary to consider appropriate means of data analysis for the methodology. This is developed in Chapter Four.

3.8.2 Application to Barbados

It is concluded that most authors used multi-disciplinary approaches for data analysis in the development of classification systems. Such techniques can distill large numbers of variables to highlight those that are the most significant in explaining coastal variability. However, they should be used with care. It can be expected that this will not be a single task because of the lack of physical, demographic and economic data of the areas most likely to be affected. Additionally, thematic and appropriate topographic maps, at scales most applicable to performing the vulnerability analysis, are not often available in the developing world. This research applies a combination of multivariate analyses to determine the general coastal segment associations and to identify their vulnerability levels (Chapter Six). Additionally, GIS analyses are applied to determine the socio-economic levels of risk for coastal segments (Chapter Seven).

3.9 PRESENTATION FORMAT

Generally, the literature presented a map as the final presentation format for analysed data. Several were presented in the form of hard copy maps²⁹, or as digital maps generated by GIS³⁰ or as “Kite Diagrams³¹”.

²⁹ Refer to Price (1990), Jelgersma *et al.* (1993), Al-Bakri (1996), Nansingh and Jurawan (1999).

Dal Cin and Simeoni (1989, 1991, and 1994) used pie charts to depict the varying levels of vulnerability along coastal segments. The investigations were also carried further by relating the calculated level of vulnerability to the extent of urbanisation along the first 200m behind the beach. They determined that the combination of vulnerability and urbanisation provided a relative estimate of the coastal risk. A few authors (Price 1990, Jelgersma *et al.* 1993, Gornitz and Kanciruk 1989) also made reference to the importance of map scale and its applicability in the identification of vulnerable coastal areas.

3.9.1 Application to Barbados

The final presentation format must be easily applicable to the required output, with the information being presented in a clear easily understood format. The use of digital maps has the added advantage of being easy to update, an important consideration for this author's research methodology (Chapter Four).

3.10 SUGGESTIONS FOR FURTHER STUDY

Several authors indicated that improvements could be made to their classification methodology (Fig. 3.4). It was repeatedly noted that further detailed studies were needed (17%), as well as the inclusion of information on anthropogenic (12%), socio-economic and economic factors (9% each). Several authors acknowledge the specific need for including socio-economic variables (e.g. Yohe 1990, Rivas and Cendrero 1994, Estnard *et al.* 2000, Taussik *et al.* 2001, McLaughlin *et al.* 2002). El-Raey (1997) proposed that additional information on the land, its infrastructure, culture, ecological, and historical significance of the area should be also represented. Similar

³⁰ Exemplified by Queennec (1989), Fleming and Townend (1989), McCue and Deakin (1995), Gornitz *et al.* (1989, 1990, 1991, 1994, & 1997), Thieler and Hammar-Klose (1999), El-Raey (1997), and Townend and Fleming (1994).

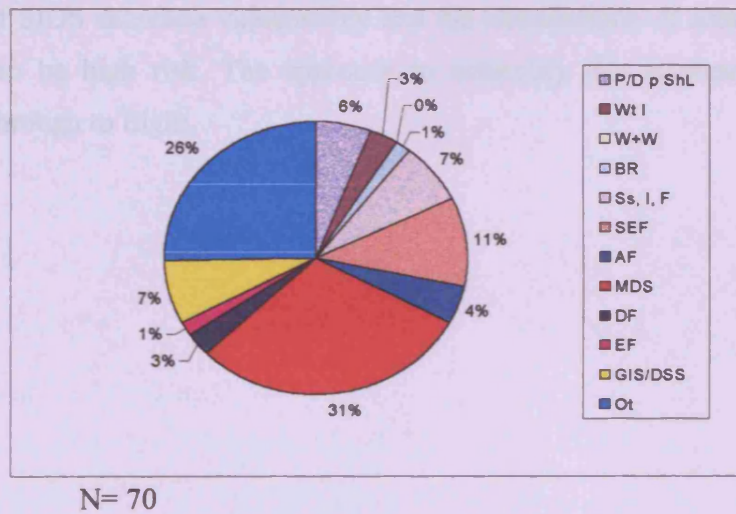
³¹ See Williams *et al.* (1993) and Alveirinho-Dias *et al.* (1994). Here the diagrams were used to interpret a measure of the management response to dune vulnerability and its index of vulnerability/protection measures.

considerations were also recognised as important at the general guideline level (e.g. Leatherman *et al.* 1994, Benioff *et al.* 1996, and Harvey *et al.* 1999).

3.10.1 Application to Barbados

It can be concluded that socio-economic and particularly coastal community considerations are integral to CVA, although rarely included. This deficit may imply that a lack of involvement from the human sciences in the consultation process for developing indices. The review has demonstrated little focus on public perception of coastal hazards with most research focusing on public amenity values of coastlines. This, therefore, presents a gap, which has to be explored, as public participation is a major requirement of the ICZM process. This is addressed in Chapter Eight.

Fig 3.4 Proposed Future Data Requirements for incorporation into CVIs



Where the abbreviations for future data requirements are:

- P/D p ShL = Population/Demographics per shoreline length; Wt I = Weighted index;
- W+W = Wind and Wave data; BR = Biological Resources; SEF = Socio-economic factors;
- Ss, I, F = Storm surge, Intensity, Frequency; AF = Anthropogenic Factors;
- MDS = More Detailed Study; DF = Demographic factors; EF = Economic factors;
- GIS/DSS = Geographic Information System/ Decision Support System; Ot = Other

3.11 CONCLUSION

The applied use of multidisciplinary data sets, combined through multivariate analysis or through procedures designed to reduce such information to a simplified form of measurement of coastal attributes, has emerged in the literature as a potentially useful tool in CM. These issues provided the platform from which the research aims were developed. It has been illustrated that the scale of index application is of the greatest importance together with the relevance of the funding and its sources.

The review has found that several approaches have been used in the development of the vulnerability indices, with most research occurring in the last decade. However, the applications of the CVIs within a small island context have been highly limited, being highly dependent on their national priorities, and further illustrating the need for an appropriate technique that can assist in the determination of their shoreline vulnerability issues. It is this author's opinion, that the literature demonstrates that there is still a need for the development of an index methodology that is quick, inexpensive and practical in its evaluation of SIDS shoreline vulnerability and the identification of areas which can be considered to be high risk. The approach to achieving this is presented in the Chapters Four through to Eight.

Chapter 4

Strategic Overview of LVA Methodology

Chapter 4:

Strategic Overview of LVA Methodology

4.1 INTRODUCTION	79
4.2 LITTORAL VULNERABILITY ASSESSMENT METHODOLOGY	80
4.2.1 LVA METHODOLOGY DESCRIPTION	80
4.2.1.1 Variable Category and Subcategory Designation	84
4.2.1.2 Developed Indices.....	86
4.2.1.3 Littoral Vulnerability Assessment Profile	87
4.2.1.4 Data Inter-relatedness.....	88
4.2.1.5 LVAP Updating	88
4.2.2 APPLIED METHODOLOGY AND ANALYSIS	88
4.3 METHODOLOGY USED IN THE SELECTION OF VARIABLES.....	89
4.4 COASTAL ZONING METHODOLOGY	90
4.4.1 COASTAL BOUNDARIES DEFINITION	91
4.4.1.1 Identification of Study area	92
4.4.2 COASTAL HAZARD ZONE	93
4.4.3 SHORELINE DESCRIPTIONS	93
4.4.3.1 Selection of Case Study Areas.....	94
4.5 CASE STUDY AREA DESCRIPTIONS	98
4.5.1 WEST COAST LOCATIONS.....	100
4.5.1.1 Weston, St. James to Porters, St. James.....	100
4.5.1.2 Holetown, St James to Sandy Lane Bay, St. James.....	102
4.5.1.3 Fresh Water Bay, St. Michael to Brandons, St Michael	104
4.5.2 SOUTH COAST	106
4.5.2.1 Hastings Rocks, Christ Church to Rockley, Christ Church.....	106
4.5.2.2 Casuarina Beach, Christ Church to Oistins, Christ Church.....	108
4.6 DESIGN OF FIELD SAMPLING PROGRAM.....	110
4.6.1 SELECTION AND LOCATION OF SITES	110

4.6.2 DATA COLLECTION PROCEDURES.....	111
4.6.2.1 Physical Oceanographic Indicators.....	111
4.6.2.2 Degree of Urbanisation	112
4.6.3 DATA RECORDING PROCEDURES	113
4.7 SUMMARY.....	116

4.1 INTRODUCTION

The second part of this thesis describes the methodologies used to develop a Littoral Vulnerability Assessment Profile (LVAP), the data processing of the results and their interpretation. Table 4.1 presents the respective chapter titles found in this part of the thesis.

Table 4.1 Methodology and Results Chapters.

Chapter	Title
4	Strategic Overview of LVA Methodology.
5	Development of Environmental Sensitivity Indices for Littoral Vulnerability Assessment.
6	The Determination of the Coastal Vulnerability Index.
7	Quantification of Coastal Risk using GIS.
8	Public Perception and LVA.

This chapter introduces the concept of LVA. While such assessments have been performed as part of the “broader context of the CVA process”¹ (specifically designed for their project requirements), they have been undertaken on an independent basis, with no consideration for cross linkages of the collected data. In order to consider the littoral zone, it is necessary to recognise the linkage associations between the assessments identified in Section 3.3.2. This chapter also provides a strategic overview of the general methodology applied in the collection and analysis of the field data². It is divided into four sections detailing the procedures used:

1. The methodology developed to determine the LVAP model for coastlines.
2. The selection criteria applied to the overall methodologies used in this research.

¹ The assessments are described as CVA since the affected areas are impinging onto the CZ.

² Data collected for the west and south coasts of the island.

3. The general coastal zonation methodology.
4. The design of the field-sampling programme to be used in the data collection process.

As explained in Section 4.2.1, this research application is an alternative rapid methodology, in which the collected data are based on a minimum number of variables (Tables 4.3a & b, pages 115 & 116) that describe the risk potential of a coastline to various coastal hazards. The resultant output is the construction of a holistic sensitivity index profile for a coastline (Chapters Five and Six).

4.2 LITTORAL VULNERABILITY ASSESSMENT METHODOLOGY

This section addresses the issue of LVA, considering the littoral zone from an environmental and socio-economic perspective. The individual methodologies and their applied variables are detailed in Chapters Five through to Eight (Fig.4.1).

4.2.1 LVA Methodology Description

Figure 4.1 shows the main components of the methodology and highlights its three main stages:

- i) Subcategory identification and variable category allocation (Section 4.2.1.1).

First, subcategories are determined in which to place the grouped variables. In the next step, they are further subdivided into representative variable groupings leading to the development of the various index outputs.

- ii) Index development (Section 4.2.1.2).

Here the developed indices are used to describe the coastal segment. These are then presented to illustrate the LVAP for coastal segments.

iii) LVAP development (Chapter 9).

The final step is the incorporation of the LVAP into the ICZM process.

The methodology builds on the literature review stage (Figs. 1.3 and 4.1) and the identification of the comprehensive listing of CVA variables (Section 3.5). Thereafter, those variables best suited to describe the littoral zone are selected (Section 3.6). As some SIDS may be at varying stages of ICZM development, it is appropriate to demonstrate how the LVAP can be incorporated into generic ICZM procedures (Chapter Nine).

The methodology (Fig. 4.1) identified three broad categories that can be used to describe coastal features, and their associated variable subcategories. Each subcategory is further subdivided according to the type of data required to encapsulate it. The methodology requires the use of both *in situ* data collection and desktop analysis of secondary data. The field data collection procedures are summarised in Section 4.6, but are explained in detail in Chapters Five and Six.

The methodology uses 28 variables³ (Table 4.2), the selection procedure for which is presented in Section 4.3. Although it appears that some level of “double banking⁴” of the variables is occurring using this approach, this is not the case. The data are used independently for different applications in the research (Section 5.2 and Chapter Six). They, therefore, constitute independent components of the LVA process.

³As has been presented in the literature, the number of variables can be as few as seven to fifteen (e.g. Gornitz *et al.* 1989, 1991 and 1994, Dal Cin & Simeoni 1991 & 1994) or up to fifty-four (e.g. Alveirinho-Dias *et al.* 1994).

⁴Double banking would occur where data used from different variables might have contributory influence in the determination of an end product calculation as exemplified in some coastal process calculations where a single end value is being calculated (refer to US ACE 1984). In this research, the data are applied in a multiple use, source data context, for the calculation of the respective indices that comprise the LVA process.

Fig. 4.1 Proposed Methodology for Determining A Littoral Vulnerability Assessment Profile (Source: Original)

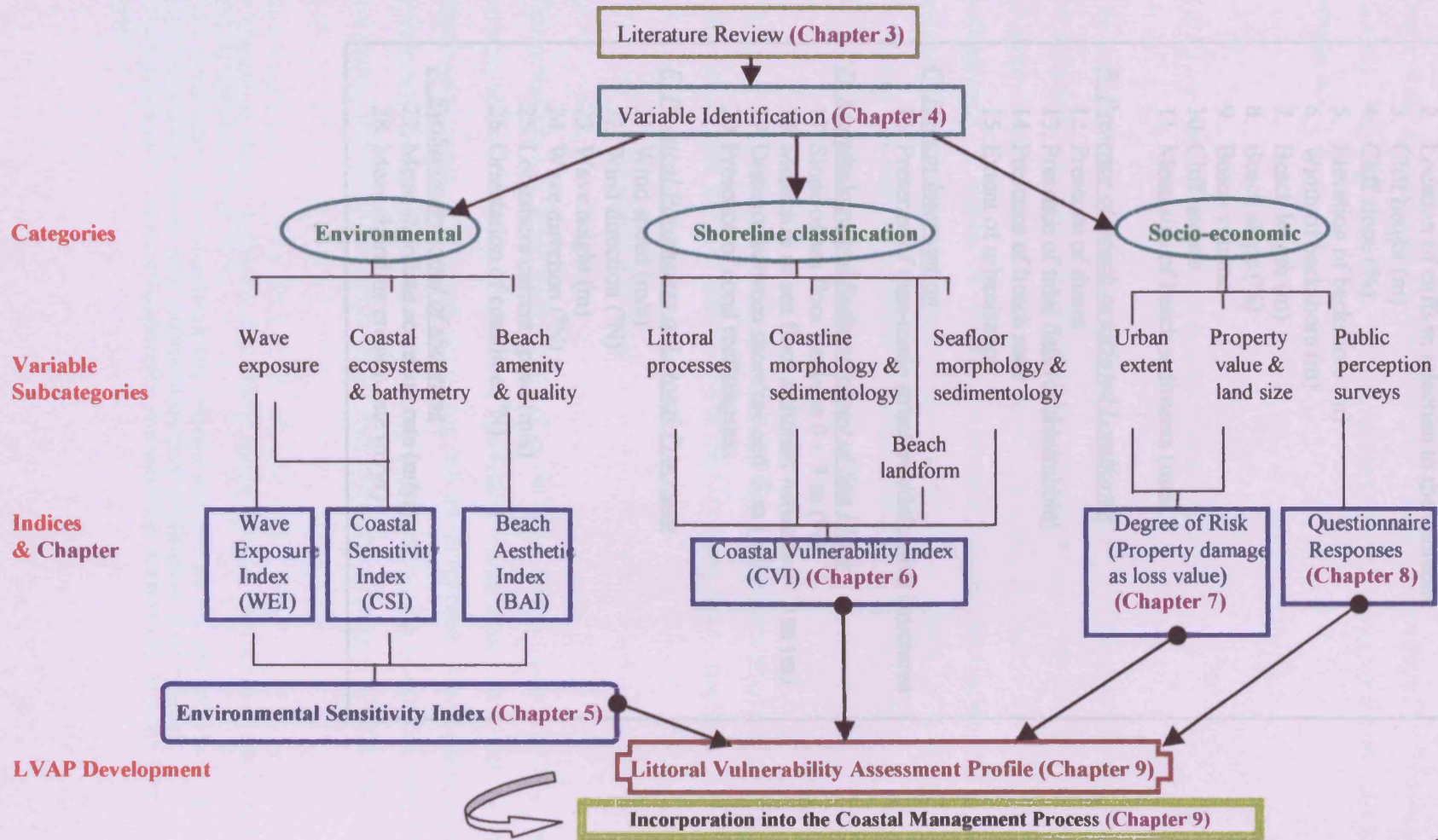


Table 4.2 Variables used in LVAP Category Descriptions (Source: Original)

A. Morphology and sedimentology of coastline

1. Presence of small scarps with maximum height of 2m
2. Location of cliffs in selection to the shoreline
3. Cliff height (m)
4. Cliff slope (%)
5. Elevation of backshore (m)
6. Width of backshore (m)
7. Beach length (m)
8. Beach slope (%)
9. Beach volume
10. Cliff texture
11. Mean size of beach sediments (mm)

B. Presence of Beach associated Landforms

12. Presence of dunes
13. Presence of tidal flats (cobble/rubble)
14. Presence of beach rock
15. Extent of urbanisation

C. Human Intervention

16. Presence of man-made structures/defensive structures

D. Morphology and Sedimentology of Sea Floor

17. Slope of sea floor between 0 - 3 m (%)
18. Mean size of sea floor sediment between 0- 3 m (m)
19. Distance between shoreline and 3 m (m)
20. Presence of coral reef/seagrass

E. Physical Parameters of Littoral Processes

21. Wind speed (m/s)
22. Wind direction (°N)
23. Wave height (m)
24. Wave direction (°N)
25. Longshore current speed (m/s)
26. Orientation of coastline (°N)

F. Evolutionary trend of shoreline

27. Mean shoreline accretion rate (m/yr)
28. Mean shoreline erosion rate (m/yr)

The pre-selection of variables is important, as most SIDS do not have the necessary in-house capacity⁵ to start with in-depth coastal monitoring programmes unless they are project-driven, and funded by multilateral or other international financial institutions. These, however, often result in a wide variety of data being collected to describe coastal conditions⁶ during the project, with an absence of monitoring continuity after project completion.

4.2.1.1 Variable Category and Subcategory Designation

The categories are used to differentiate the three components of the littoral – environmental, shoreline classification and socio-economic. They also provide a means of grouping the variables identified from the literature review for use within the methodology. A system of variables is required for the production of information relevant to Barbados' coastal policy, and to assist in the assessment of the island's CZ. To identify the subcategory issues relating to data gathering, the guidelines established by SOPAC (2000) have been used⁷.

The categories are further subdivided into variable subcategory descriptions, identifying those data that are field-oriented and those relying on secondary sources.

(a) Environmental Category

This category has three subsections (Fig. 4.1) in which collected field data on oceanographic processes, types of nearshore ecosystems and beach quality characteristics are represented, providing an environmental characterisation of the littoral. This process is achieved through the quantitative and qualitative analysis of *in situ* data. Their detailed methodologies are presented in Sections 5.2, 5.3, and 5.4. The

⁵ Capacity here relates to institutional responsibility, human resources, and dedicated financial resources (ECLAC 2000 and SOPAC 2000).

⁶ This further justifies the need to have a wide variety of data collected in a rapid yet accurate manner which can be used to provide easily understood interpretive assessments of the coastline.

⁷ These criteria are 1) data source identification; 2) accessibility; 3) availability; 4) quality and 5) capacity.

environmental category results in three indices⁸ that constitute the ESI for a given coastal segment.

(b) Shoreline Classification Category

As Fig 4.1 shows, this category has four subsections, capturing the character of the coastal morphology, the nearshore morphology, the beach landform and the oceanographic processes. The shoreline classification variables use the field data for the ESI determination (Section 4.2.1.4). However, for completeness some variables require secondary source information.

In this procedure, the field data is processed using multivariate analysis to identify specific coastal segment characteristics with similar characteristics. This approach provides the CVI for the coastal segments. The detailed methodology is presented in Chapter Six.

(c) Socio-economic Category

This category is divided into three (Fig. 4.1), with variables relating to coastal property information and level of coastal development. Each subsection is analysed using desktop studies, requiring data from relevant agencies or information repositories. Unlike Sections 4.2.1.1a and b, this component of the methodology is based on a case study assessment of five coastal segments. The procedure involves calculating the extent of urbanisation and land use classification as well as associated property and land values along the coastal segments. The collected data are processed using Geographic Information Systems (GIS) to determine the spatial extent of potential losses. The detailed methodology is presented in Chapter Seven. The result is the identification of the degree (or extent) of current economic risk of potentially property loss in the area.

The public perception variables, although lying outside of the mainstream socio-economic⁹ considerations of the CVI, have been included here to illustrate the socio-

⁸ The indices are Wave Exposure index (WEI), Coastal Sensitivity Index (CSI) and Beach Aesthetic Index (BAI).

cultural components contributing to ICZM. The perception surveys (Chapter 8) provide a mechanism to gather information a) on beach user perceptions of the beaches and their aesthetic quality; and b) as property owners' concerns.

4.2.1.2 Developed Indices

The literature (Section 3.2.1 and 3.3.1.1) demonstrates that a single index value can be derived from a series of variables (e.g. Gornitz 1990, Gornitz *et al.* 1991, Gornitz and White 1992, Daniels *et al.* 1996, Gornitz *et al.* 1997, McLaughlin 2001, Thieler and Hammar-Klose 1999 and 2000, and McLaughlin *et al.* 2002). However, a decision was taken not to incorporate the individual indices into a single index value in this study. This was decided because:

- (1) There is a need for a rapid means of recognising the littoral vulnerability issues of coastal segments for effective coastal planning and management.
- (2) The procedure provides a snapshot coastal profile that has application in other fields (e.g. oil spill contingency planning, public recreational planning¹⁰).
- (3) The procedure provides for systematic updating of the data, which improves the model¹¹.
- (4) The use of a single index value might conceal difference in the relative strengths of individual variables within and between coastal segments (Gornitz *et al.* 1994 and McLaughlin *et al.* 2002).

The remaining indices are kept separate so that each index component value is known. This can ease interpretation by the end user, allowing for easy and rapid data updating and contributing to the LVAP (Fig. 4.1 and Section 4.2.1.3).

A four point ranking system was developed for each index. This approach has been successfully demonstrated in the literature¹². The calculated scores for respective

⁹ Socio-economic considerations normally involve land use, housing and services, population, commercial sectors, infrastructure, and employment.

¹⁰ This includes shoreline safety and public notification.

¹¹ Each index can be updated independently where necessary.

indices have been subdivided based on quartile ranges, in order to ensure consistency in index interpretation as demonstrated by Thieler and Hammar-Klose (1999 and 2000). This system helps prioritise the coastal segments and beaches, as well as providing a rapid means for location comparison, interpretation and evaluation for priority setting.

As only case study sites were used under the socio-economic subcategory, indices have not been developed. If the entire coast had been used, it would have been possible to develop an index. However, for the study areas, vulnerability has been presented as a quantification of the degree of risk for potential property damage (Section 6.4.5 and Section 7.3 respectively, where vulnerability considerations have been presented as potential loss).

4.2.1.3 Littoral Vulnerability Assessment Profile

The resultant indices are represented on maps in the form of LVAPs. They provide distinct index descriptions for specific considerations (wave exposure, coastal sensitivity, beach amenity and coastal vulnerability). This contributes to much easier incorporation of LVA information within ICZM. In addition, the LVAP has to be presented for easy interpretation to planners and decision-makers. The developed profile highlighted coastal areas of priority concern, providing:

- A framework for future follow up work;
- The expansion of key themes and issues within the island's ICZM process.
- The building blocks for the development of an ICZMP, in situations where such documentation does not exist in other SIDS.

The model developed to demonstrate the effective integration of the research process into the existing ICZM process for Barbados is presented in Chapter Nine.

¹² Refer to Thieler and Hammar-Klose (1999 & 2000), Greve *et al.* (2000), Finkl (2000), Lizarraga-Arciniega *et al.* (2001) and Bush *et al.* (2001).

4.2.1.4 Data Inter-relatedness

Some variables (Table 4.2) have multiple applications within the methodology, with the environmental variables providing the main components used for coastal description (Section 4.2.1.1). These can be directly related to several of the CC subcategories (e.g. data from the wave exposure and beach amenity provide some information for the littoral processes, coastal morphology and beach landform characterisation variables).

A standardised field data sheet has been developed (Table 4.5), which allows for the collection of data in one site visit. The interrelated nature of the variables describing the ESI allows the rapid completion of the field sheet and contributes to the assessment of potential coastal hazard effects. This is useful, providing good representation of issues for future monitoring. The application also allows for each sub-component to be performed independently, in the event that an incremental process to CM is proposed.

4.2.1.5 LVAP Updating

The flexibility of the methodology allows for the establishment of coastal monitoring programmes in SIDS, where they do not exist. It also provides a mechanism for systematic updating of information from existing coastal monitoring programmes. In addition, the method is flexible enough to incorporate new variables and replace/substitute variables with new ones. This modification ability is important especially as more funding, equipment and training becomes available, contributing to a more accurate description of the coastline.

4.2.2 Applied Methodology and Analysis

Two approaches are combined to provide a definitive profile for LVA coastal representation: the first is a low cost technique and the second makes use of available land use and land valuation data to apply an actual economic cost to coastal segments considered vulnerable to potential loss.

4.3 METHODOLOGY USED IN THE SELECTION OF VARIABLES

Figure 4.2 shows the methodology used in determining the most appropriate variables. Based on the literature (Section 3.5), 28 variables have been compiled. General guidelines related to the applicability of the selection criteria have also been developed in order to assess the selected variables. They also included the following considerations:

- Their adaptability to different coastal conditions;
- Their reliability in terms of their scientific interpretation;
- Their cost effectiveness for measuring them.

The best-suited variables were then applied to the research process.

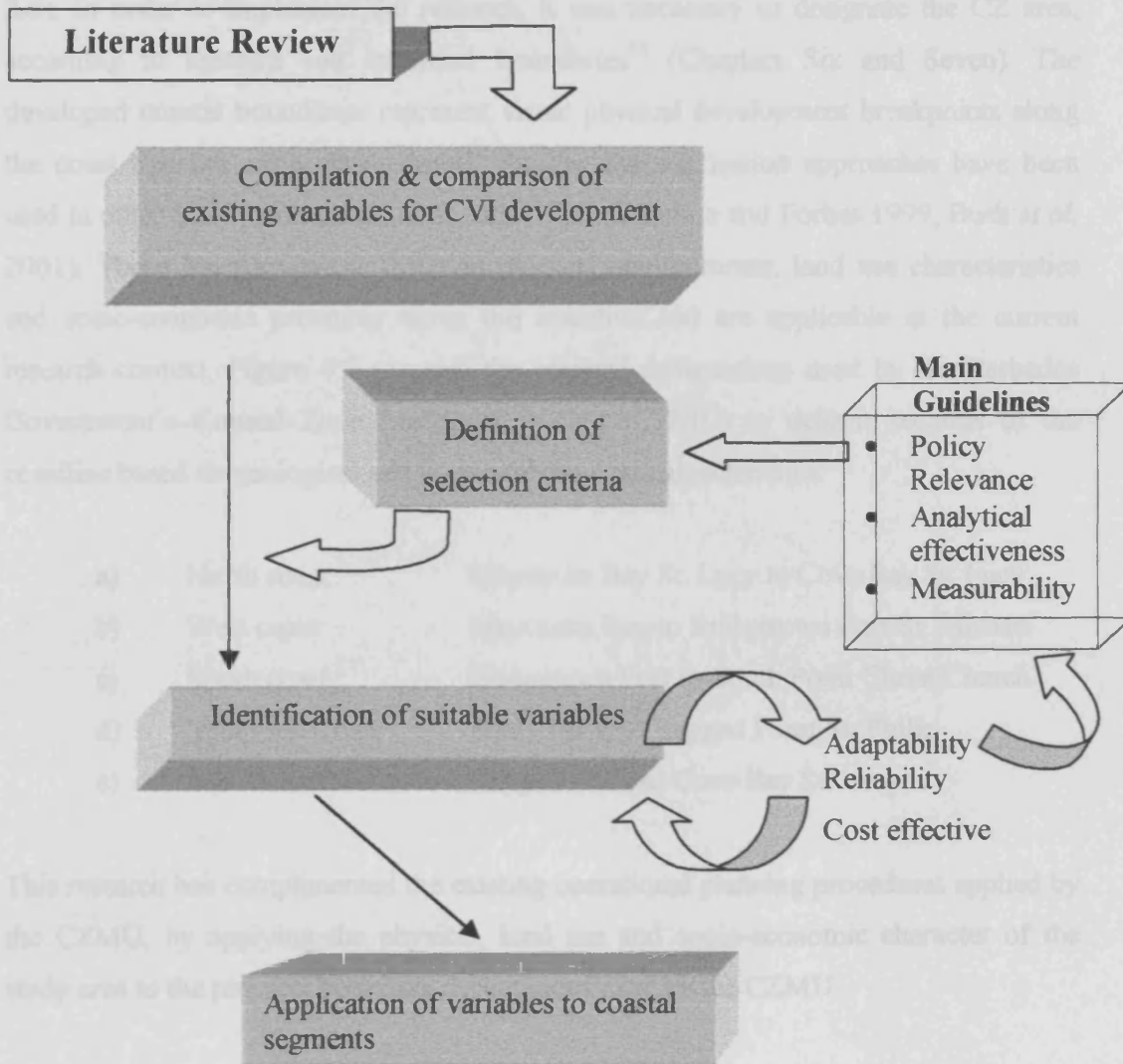
The criteria¹³ therefore, to be used in the overall assessment of the methodologies are based on the following considerations:

1. Technically sound approach (scientifically valid).
2. Reliable consistent data source (accurate)
3. The procedure used is replicable in /transferable to other locations
4. Wide variety of criteria (comprehensiveness) and concise
5. Flexibility (easily modified)
6. Low cost
7. Easily understandable
8. Systematic and interdisciplinary
9. Sensitivity
10. Criteria specific for purpose of assessment (relevance).

A discussion of the assessment of the methodologies selected is presented in Section 9.2.4.

¹³ See Appendix 4.2 for the explanatory criteria tables.

Fig. 4.2 Variables and Criteria Selection Process. (Source: Original)



4.4 COASTAL ZONING METHODOLOGY

This section describes the limits of the study area and presents the selection methodology for the five case study areas along with brief coastal descriptions for each area.

4.4.1 Coastal Boundaries Definition

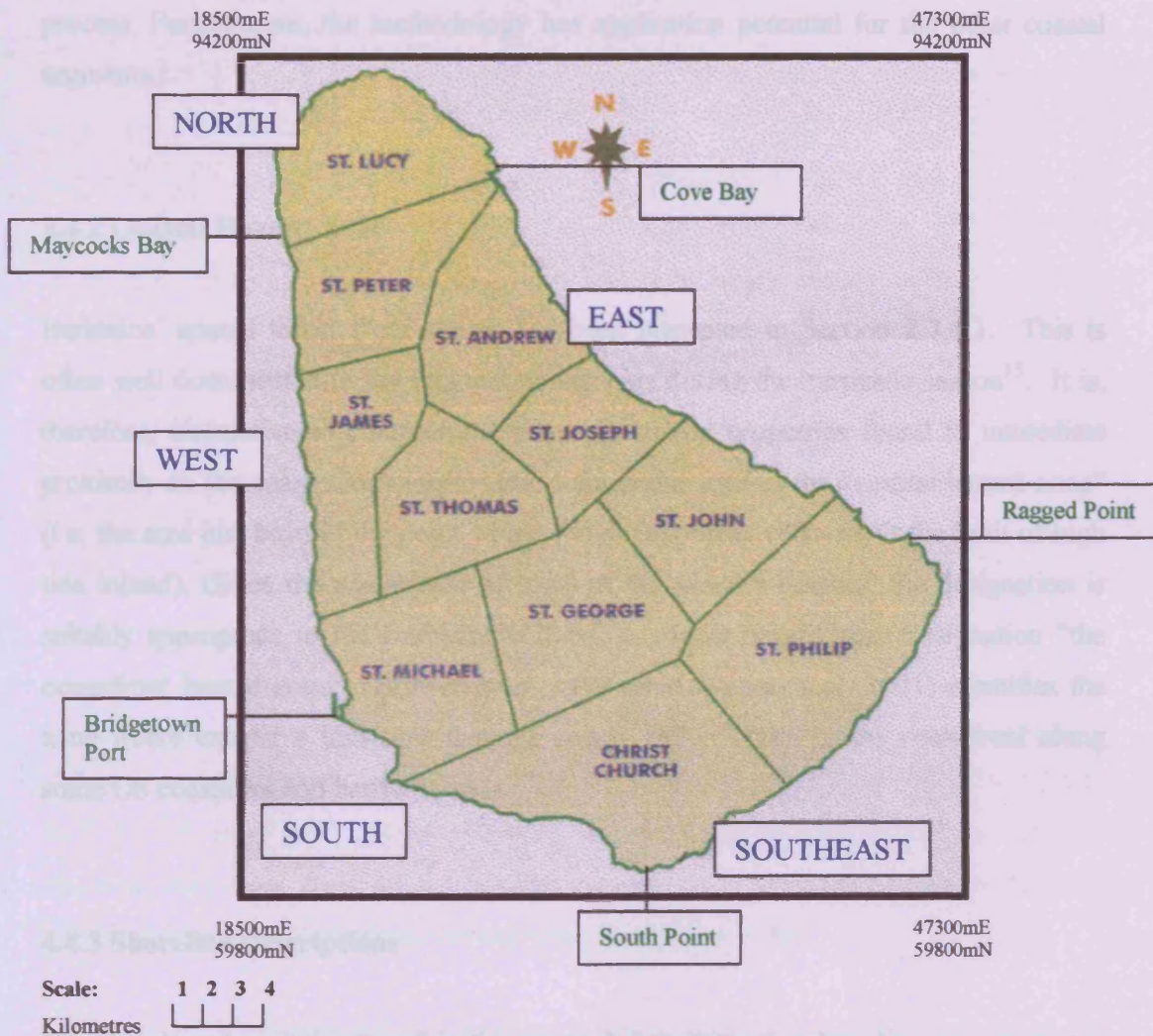
This research has described the general character of the Barbados coastline (Section 2.6). In order to implement the research, it was necessary to designate the CZ area, according to seaward and landward boundaries¹⁴ (Chapters Six and Seven). The developed coastal boundaries represent visual physical development breakpoints along the coast that are easily recognisable. Similar characterisation approaches have been used in other SIDS contexts (Weerakkody 1997, Solomon and Forbes 1999, Bush *et al.* 2001). These incorporate the different physical environments, land use characteristics and socio-economic pressures along the coastline and are applicable in the current research context. Figure 4.3 presents the cardinal designations used by the Barbados Government's Coastal Zone Management Unit (CZMU) to delimit sections of the coastline based on geological and geomorphological characteristics:

- | | | |
|----|-----------------|--|
| a) | North coast | Maycocks Bay St. Lucy to Cove Bay St. Lucy |
| b) | West coast | Maycocks Bay to Bridgetown Port St. Michael |
| c) | South coast | Bridgetown Port to South Point Christ Church |
| d) | Southeast Coast | South Point to Ragged Point St. Philip |
| e) | East Coast | Ragged Point to Cove Bay St. Lucy. |

This research has complimented the existing operational planning procedures applied by the CZMU, by applying the physical, land use and socio-economic character of the study area to the physical boundary designations used by the CZMU.

¹⁴ The seaward boundary is the 3m depth contour and the land ward boundary is 200m landward of high water mark.

Fig. 4.3 Coastal Boundaries used in thesis (Source: CZMU 2000)



4.4.1.1 Identification of Study area

The study areas for this research constitute the island’s developed West and South coasts. They illustrate the diverse multiple use of the CZ and include areas that have been intensively studied as part of the island’s coastal conservation programme (Section 9.3.2). Additionally, they provide functional boundary applications, separating changes in the physical development of the coastline. The retention of these designations

demonstrates how the LVA process can be integrated within the island's current ICZM process. Furthermore, the methodology has application potential for the other coastal segments.

4.4.2 Coastal Hazard Zone

Barbados' annual threat from storms has been presented in Section 2.7.4.1. This is often well documented in the national newspapers during the hurricane season¹⁵. It is, therefore, instructive to consider the threat to coastal properties found in immediate proximity to the coast. Coch (1995) has defined this area as the "coastal hazard zone" (i.e. the area just beyond the point where waves first break offshore to the limit of high tide inland). Given the narrowness of most of the island's beaches, the designation is suitably appropriate to the Barbados context. A similar hazard zone designation "the oceanfront hazard zone", (Brower *et al.* 1998 cited Esnard *et al.* 2001) identifies the zone where extensive hurricane damage occurs within 100m of the oceanfront along some US coastlines and barrier islands.

4.4.3 Shoreline Descriptions

The shoreline descriptions used in this research have been developed as a succinct way for representing the main coastal features along the West and South coasts. A table was generated from field surveys carried out in 2000 and from secondary information sources (e.g. available literature, consultants' reports, maps, government documents). The identified locations have been separated based on the main coastal geomorphological features. Twelve descriptive criteria assisted in the identification and selection of the case study areas. These criteria and their components (with descriptive explanations as appropriate), developed for application along the entire West and South coasts, are described in Appendix 4.

¹⁵ This occurs annually between June and November inclusive.

4.4.3.1 Selection of Case Study Areas

Case studies are used in situations where the comprehensive assessment of an entire area cannot be performed within a given time frame. Selected locations are chosen to represent the cross section of the area under consideration. According to Yin (1989 and 1993) they need to be representative and of significant importance to the overall research of the study area. The rationale for study area selection is to provide the research with a selection of coastlines, which are similar in terms of:

- (1) their human environment, and biophysical environment;
- (2) a similarity in the diversity of the coastal development they experienced;
- (3) a divergence in the type of development found along some locations;
- (4) capturing the wide range of coastal development infrastructure that is prone to the effects of erosion and potential storm wave inundation.

Based on the characteristics identified in Appendix 4, the areas were chosen reflecting different coastal characteristics and developmental conditions. The locations numbered 3, 7, 11, 15, and 18 in Table 4.4a reflect different infrastructure settings and land use characteristics along the West and South coasts, and provide an example of the potential risk in intensively urbanized and industrialized coastal sections.

The study areas can be summarised as highly urbanised with developed frontages and in some locations, “misfits”¹⁶ have occurred. There is generally extensive shoreline protection:

- 1) as the natural beaches have been lost and/or replaced by coral rubble in the nearshore; and
- 2) to prevent the further loss of coastal land in the event of storm wave activity.

¹⁶ “Misfits” constitute areas where conflicting land use policies have arisen from the systematic encroachment of the areas, as a result of expanding urban development requirements. They normally have an inadequate development buffer distance between them. This exemplified by the Brandons to Paradise location, where residential properties and tourism development surround industrial developments.

Table 4.3 Coastal Descriptions for Selected Case Study Areas (Source: Original)

Coastal Environment Details	Coastal Locations				
	3 Welches – Casuarina Beach	7 Cacrabank – Coconut Court	11 Brighton – Batts Rock	15 Paynes Bay – Almond Beach Club	18 Royal Pavilion – Tropicana (Reads Bay)
Main coastal type	D	A, D, F	D	D	D
Coastal segment	3	4	8	9	10
Major economic sector usage	A, D	A, D	A, B, D	B, H, C	A, B
Main land use	A, B, C, G, E, H	A, B, C, D, G, H	A, H, C, F	B, C, H	A, B, C, H
Main nearshore characteristics (to – 10m depth)	H, A, C, F, G	A, C, E, F	A, B, H	A, B, H	A, B
Coastal engineering structures along coast	A, B, C, F	A, E, C	A, C, B,	B, C, D, E	C, E
Access type	B, A, D	A, E, D	D, F	D, C, B	A, D, F
Erosion accretion indicators	D, C, E	I, E	I, K	I, J	E, A
Scenic potential	A, B	A	D	B	A
Swimming potential	A, B	B	A	B	A, B
Main coastal hazards	C, G, H, B	B, C, G, H	B, C, H, I	C, G, E, H	B, H, I
Similarity of coastal zone management plan issues	A, B, F, C	B, D, F, A,	D, A	H, B, A, D,	F, A, B, C

The following key to Table 4.3 provides a summary of the descriptions, which apply to the selected locations:

Box 4.1 Key to Table 4.3 (refer to Appendix 4 for a complete listing)

(Source: Original)

- **Main coastal type:** cliffed coast = A, beach backed by lowland = D, beach backed by lowland and inland relic cliff = F.
- **Coastal segment:** Number corresponds to sector of coast in which the segment is found.
- **Economic sector:** tourism = A, fishing = B, industrial = C, commercial = D.
- **Main land use:** houses = A, hotels = B, roads = C, parks = D, natural vegetation = E, industrial = F, commercial = G, villas = H.
- **Nearshore characteristics:** sand = A, fringe reef = B, patch reef = C, coral rubble = E, coral rubble and sand = F, coral rubble and seagrass = G, beach rock = H.
- **Engineering structures:** A = groyne, B = seawall, C = revetment, D = gabions, E = breakwater, F = culvert and drain.
- **Access:** informal pedestrian = A, formal pedestrian = B, driveable track = C, road access only = D, road access and parking = E, Boat access = F
- **Erosion accretion indicators:** undercut cliffs = A, beach rock = C, waves reach building = D, coastal structures = E, well established vegetation = I, wide beach = J, none of the above = K.
- **Scenic potential:** excellent = A, very good = B, good = C, moderate = D.
- **Swim potential:** safe for all bathers = A, safe but coral rubble in nearshore = B.
- **Coastal hazards:** moderate erosion = B, moderate accretion = C, significant flooding from inland runoff = E, limited flooding from inland runoff = G, potential storm surge flooding of property = H, potential storm surge flooding of land seaward of property = I.
- **Coastal zone management plan issues:** setback concerns = A, access = B, beach use management = C, effectiveness of coastal engineering structures = D, coastal development = F, nearshore water quality improvement = H.

In considering these variables, it is recognised that no one section of the coastline can be considered totally representative of the entire coast and its assorted features. The locations have not only been chosen for their basic similarities, but more importantly for their different levels of development. The following key aspects are included within the study sites:



- a multiple use function of the land and marine areas and their associated activities;
- a variety of hazard types (both natural and man made) and their associated risk to coastal property and society;
- a range of geomorphological similarities;
- development control issues that have arisen as a result of:

- 1) Property owners building in positions too close to the sea.
- 2) The use of protective engineering works as a means of property protection, with negative effects on the adjacent coastal areas.
- 3) Locations that over time have resulted in properties becoming susceptible to the effects of wave action.

The case study locations are presented in Table 4.4 and Figs. 4.4 & 4.5.

Table 4.4 Case Study Locations

Location & Segment Name	Segment Boundaries (Parish)	Case Study Number
<i>West Coast (Fig. 4.5a(i & ii))</i>		
Royal Pavilion Segment	Weston to Porters (St. James)	1
Holetown Segment	Holetown to Sandy Lane Bay (St. James)	2
Brighton Segment	Fresh Water Bay to Brandons (St. Michael)	3
<i>South Coast (Fig. 4.5b)</i>		
Rockley Segment	Hastings Rocks to Rockley (Christ Church)	4
Casuarina Segment	Casuarina Beach to Oistins (Christ Church)	5

4.5 CASE STUDY AREA DESCRIPTIONS

The following section provides a general description of the areas chosen, their nearshore and offshore conditions together with their general level and type of coastal development. The segment length for each shoreline area is of approximately equivalent size for ease of comparison.

Fig. 4.4 Map of West Coast Case Study Location (Based on original 1:50000 scale)

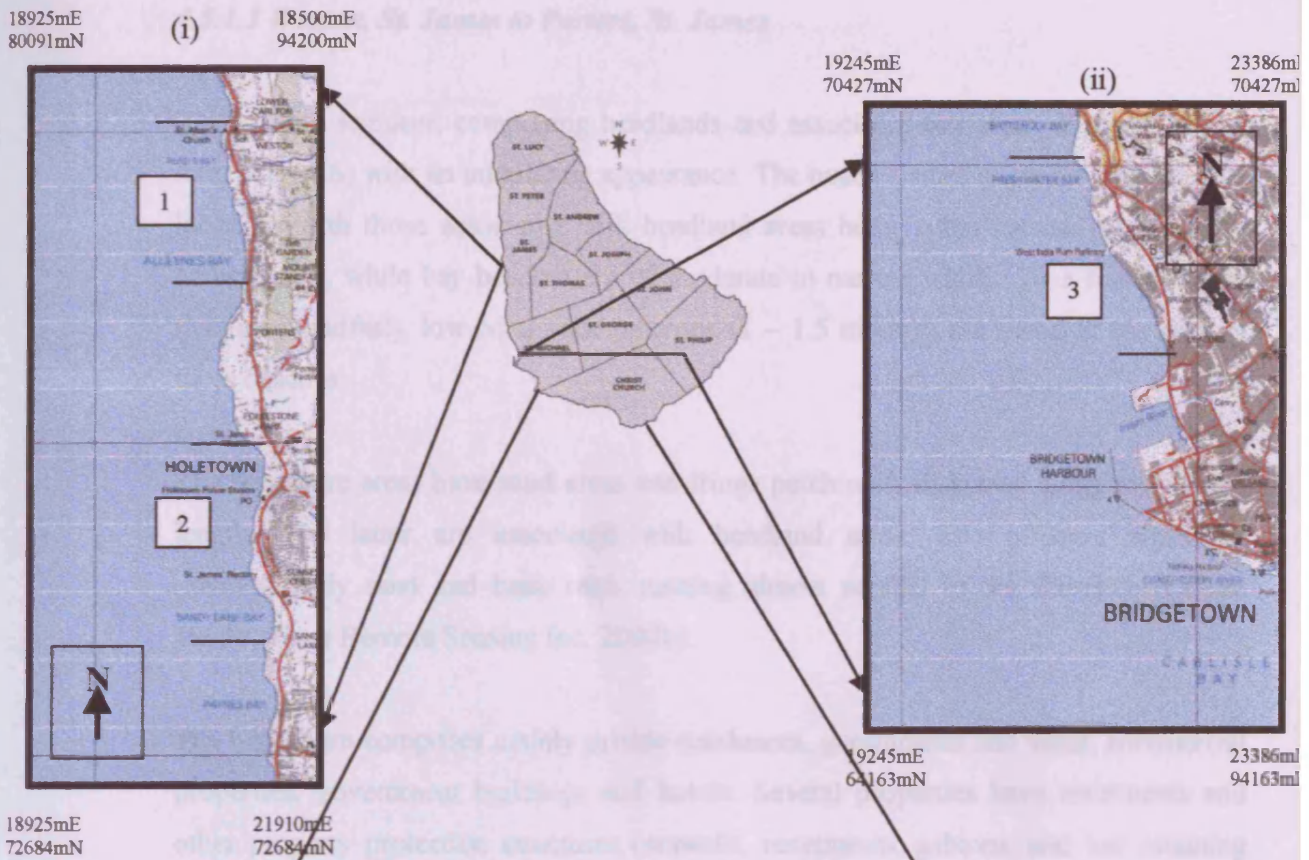
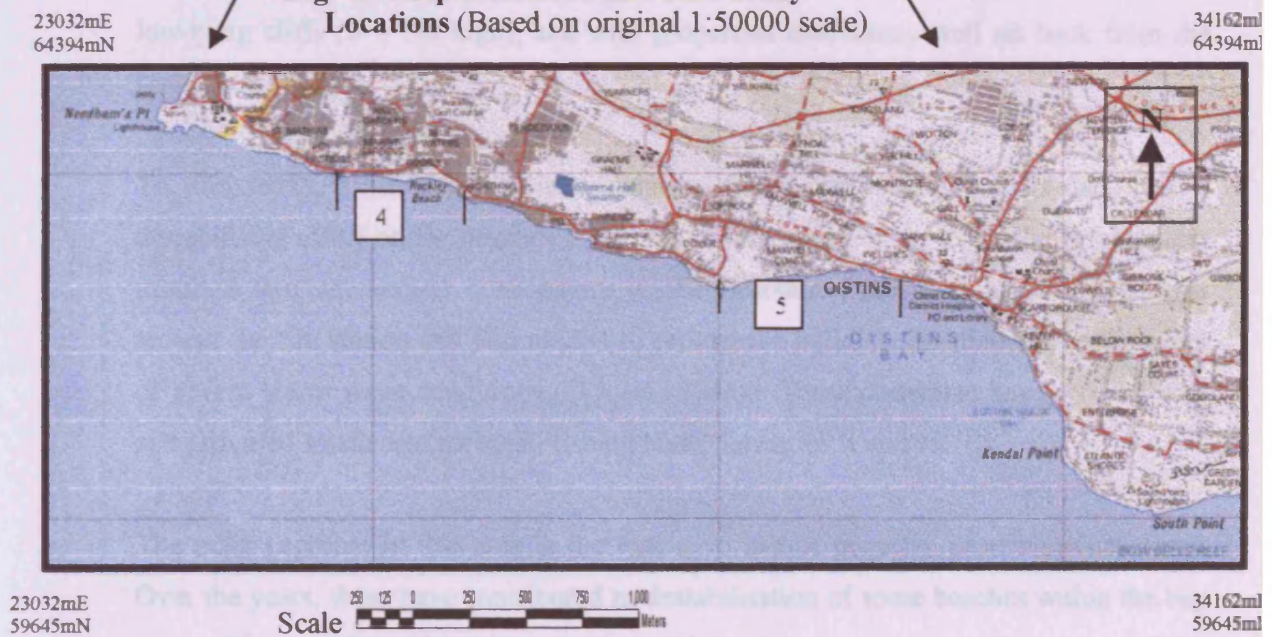


Fig. 4.5 Map of South Coast Case Study Locations (Based on original 1:50000 scale)



4.5.1 West Coast Locations

4.5.1.1 Weston, St. James to Porters, St. James

This coastal segment, comprising headlands and associated bay areas, is about 2305m long (Fig. 4.6) with an undulating appearance. The beach shapes depend on the specific locations with those associated with headland areas being often narrow (occasionally being steep), while bay beaches are of moderate to narrow width. At a few locations (Mount Standfast), low coral rock outcrops (1 – 1.5 m high) are found at the back of these beaches.

The nearshore areas have sand areas and fringe patch reefs dispersed along their entire length. The latter are associated with headland areas. The offshore areas are predominantly sand and bank reefs running almost parallel to the shoreline (Delcan 1994b, Terra Remote Sensing Inc. 2000b).

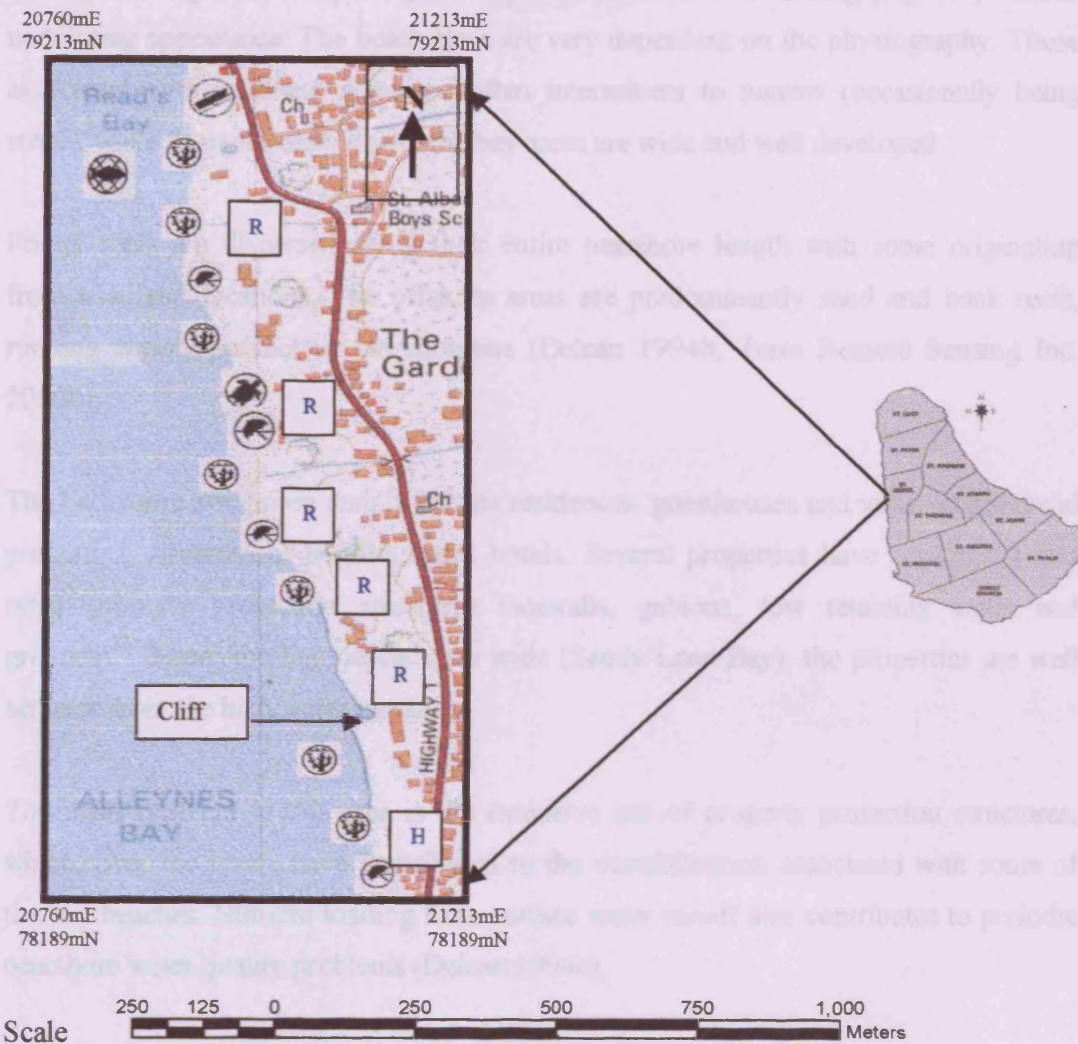
The backshore comprises mainly private residences, guesthouses and villas, commercial properties, government buildings and hotels. Several properties have revetments and other property protection structures (seawalls, revetments, gabions, and low retaining walls). Many southerly locations (The Garden/Mount Standfast) are associated with low-lying cliffs (3 – 5m high), and with properties moderately well set back from the high water mark.

To the north, (Weston), previous damage from storm wave events has had a destabilising effect on the beaches along this coastal segment. In 1993, the Government installed two submerged breakwaters in the nearshore, and two buried revetments around the fire station and fish market to protect the building foundations, in the event of severe storm wave conditions (Delcan 1994a). These structures have worked well and provided a safe area for small fishing boats during such events.

The main problem in this area is the extensive use of property protection structures. Over the years, these have contributed to destabilisation of some beaches within the bay area and have inhibited lateral access at some locations.

Fig. 4.6 Map of Weston, St. James to Porters, St. James

(Based on original 1:10000 scale) (Source: Original)



Symbol Key

Boat ramp	Turtle nesting beach	Recreational beach	Hard coral fringe reefs
Residences	Hotel	Artisanal fishing	

4.5.1.2 Holetown, St James to Sandy Lane Bay, St. James

This coastal segment, comprising two bay areas, is about 2715m long (Fig. 4.7) with an undulating appearance. The beach sizes are very dependent on the physiography. Those associated with headland areas are often intermittent to narrow (occasionally being steep), while those associated with the bay areas are wide and well developed.

Fringe reefs are dispersed along their entire nearshore length with some originating from headland locations. The offshore areas are predominantly sand and bank reefs, running almost parallel to the shoreline (Delcan 1994b, Terra Remote Sensing Inc. 2000b).

The backshore comprises mainly private residences, guesthouses and villas, commercial properties, government buildings and hotels. Several properties have revetments and other property protection structures (seawalls, gabions, low retaining walls and groynes). Where the bay beaches are wide (Sandy Lane Bay), the properties are well set back from the high water mark.

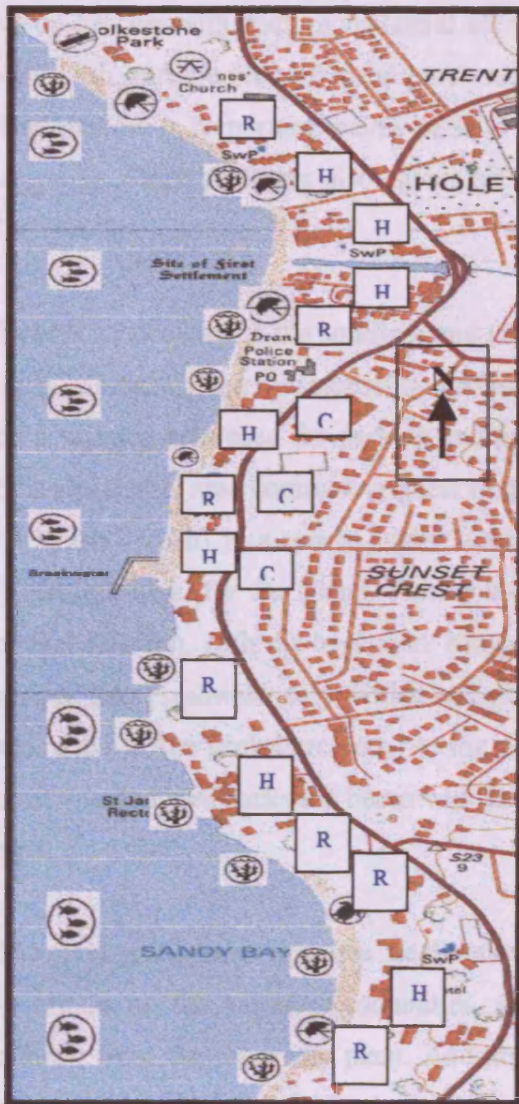
The main problem in this area is the extensive use of property protection structures, which, over the years, have contributed to the destabilisation associated with some of the bay beaches. Nutrient loading from surface water runoff also contributes to periodic nearshore water quality problems (Delcan 1994c).

Fig. 4.7 Map of Hometown, St James to Sandy Lane Bay, St. James

(Based on original 1:10000 scale) (Source: Original)

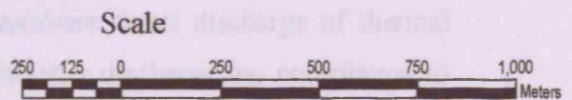
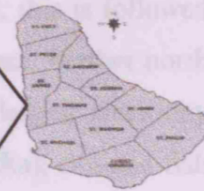
20819mE
76492mN

21687mE
764920mN



20819mE
74129mN

21687mE
74129mN



Symbol Key

Park area	Turtle nesting beach	Recreational beach	Hard coral fringe reefs
Boat access	Vehicular access	Residences	Hotel
		Commercial	Marine Park extent

4.5.1.3 Fresh Water Bay, St. Michael to Brandons, St Michael

This 2605m coastal segment has a straight to convex appearance, including mainly sandy beaches with continuous lateral access (Fig. 4.8). The nearshore is predominantly sand with interspersed soft coral patch reefs. Fringe reefs are found at a few locations. The offshore is comprised mainly of sand and bank reefs, running almost parallel to the shoreline. Patch reefs are also found offshore (Delcan 1994b, Terra Remote Sensing Inc. 2000b).

The backshore area at the southern end (Brandons Beach) is low lying and backed by a main coastal highway. Progressing northwards, the beach becomes wide and is backed by a wooded area used for parking and providing access to the beach; this is followed by a residential area comprising guest houses, apartments and residences. Further north (Brighton Beach) is a tourist visitor centre, a rum refinery and the largest electricity generation plant for the island. Further along (Pile Bay), is a fish landing site and fish market location, with the backshore being mainly of residential use. Finally, the beach widens into Freshwater Bay, which has a large hotel resort and complex of guesthouses and villas in the backshore area. At the northern end of the area (Batts Rock), a large open wooded area backs the beach with extensive beach rock in the nearshore and beach area.

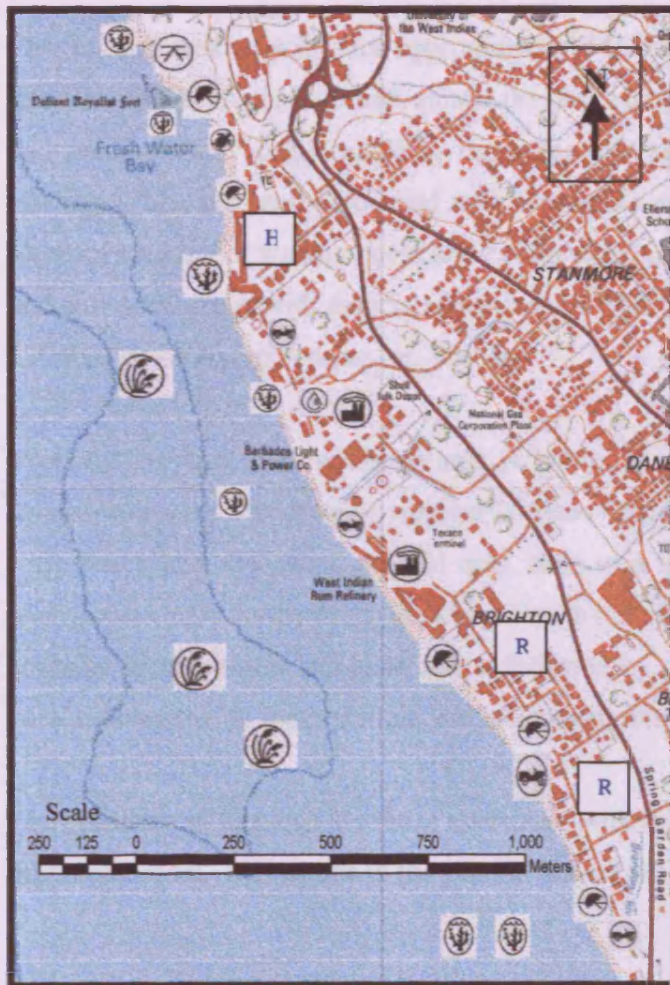
The main problems in this area are the marine discharge of the rum refinery effluent and its effects on the marine communities, and the nearshore direct discharge of thermal effluent from the electricity plant. Additionally, this latter discharge has contributed to some beach instability in its immediate vicinity as a result of the volume of water discharged daily (Leonard Nurse, *pers. comm.* 2000). Terrestrial discharge, resulting from the rum refinery, (e.g. the over flow of holding tanks and the wash down of the refinery facilities) onto the backshore area, has resulted in the compaction and “cementing” of the backshore sands, immediately fronting the refinery. Furthermore, a few properties in that locale have revetments in front of them, acting as hard points along the beach length.

Fig. 4.8 Map of Fresh Water Bay, St. Michael to Brandons, St Michael

(Based on original 1:50000 scale) (Source: Original)

21249mE
69925mN

22590mE
69925mN



21249mE
68060mN

22590mE
68060mN

Symbol Key

Park area	Turtle nesting beach	Recreational beach	Hard coral fringe reefs	Residences
Boat access	Vehicular access	Industry	Soft coral patch reefs	Water intake
				Hotel

4.5.2 South Coast

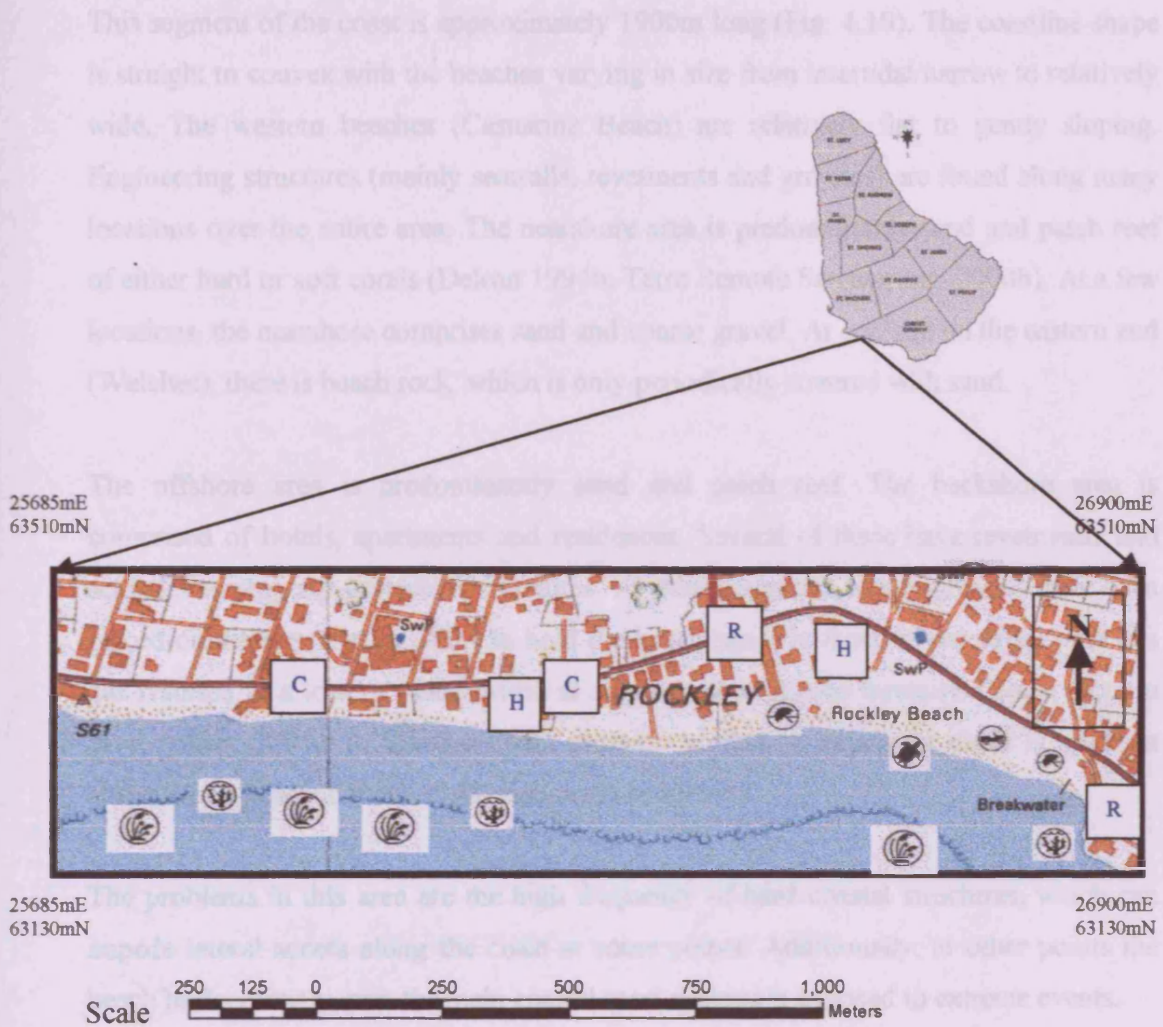
4.5.2.1 Hastings Rocks, Christ Church to Rockley, Christ Church

This coastal area stretches for approximately 1455m (Fig. 4.9). The general coastline shape is straight to concave with almost the entire length being fronted by small beaches and predominantly coral rubble in the immediate nearshore area (Hastings Rocks to Hastings). Limited sand associated with the rubble areas in the nearshore, occurs as a result of clearing of wading pools and “swimming” pools in the rubble area. Patch reefs and soft coral reefs, with associated sand and rubble zones, are found offshore (Delcan 1994b, Terra Remote Sensing Inc. 2000b).

Towards the east, the backshore area is predominantly cliffed (3 – 5 m high) with residences on top. Progressing westwards (from Cacrabank), the backshore changes to a wide beach and associated grassed area, then to a wooded parking area, used as the main access point to the beach (Rockley Beach). Further West (Hastings) the backshore contains several hotels and apartments, followed by commercial businesses, fronted by coral rubble areas in the nearshore and infrequent, intertidal or very narrow beaches.

The problems in this area are those associated with the proximity of the buildings to the high water mark. This results in the general loss of beach area in front of the properties.

Fig. 4.9 Hastings Rocks, Christ Church to Rockley, Christ Church
 (based on original 1:10000 scale) (Source: Original)



Symbols Key

Vehicle access	Turtle nesting beach	Recreational beach	Hard coral fringe reefs
Soft coral patch reefs	Commercial property	Hotel	Residences

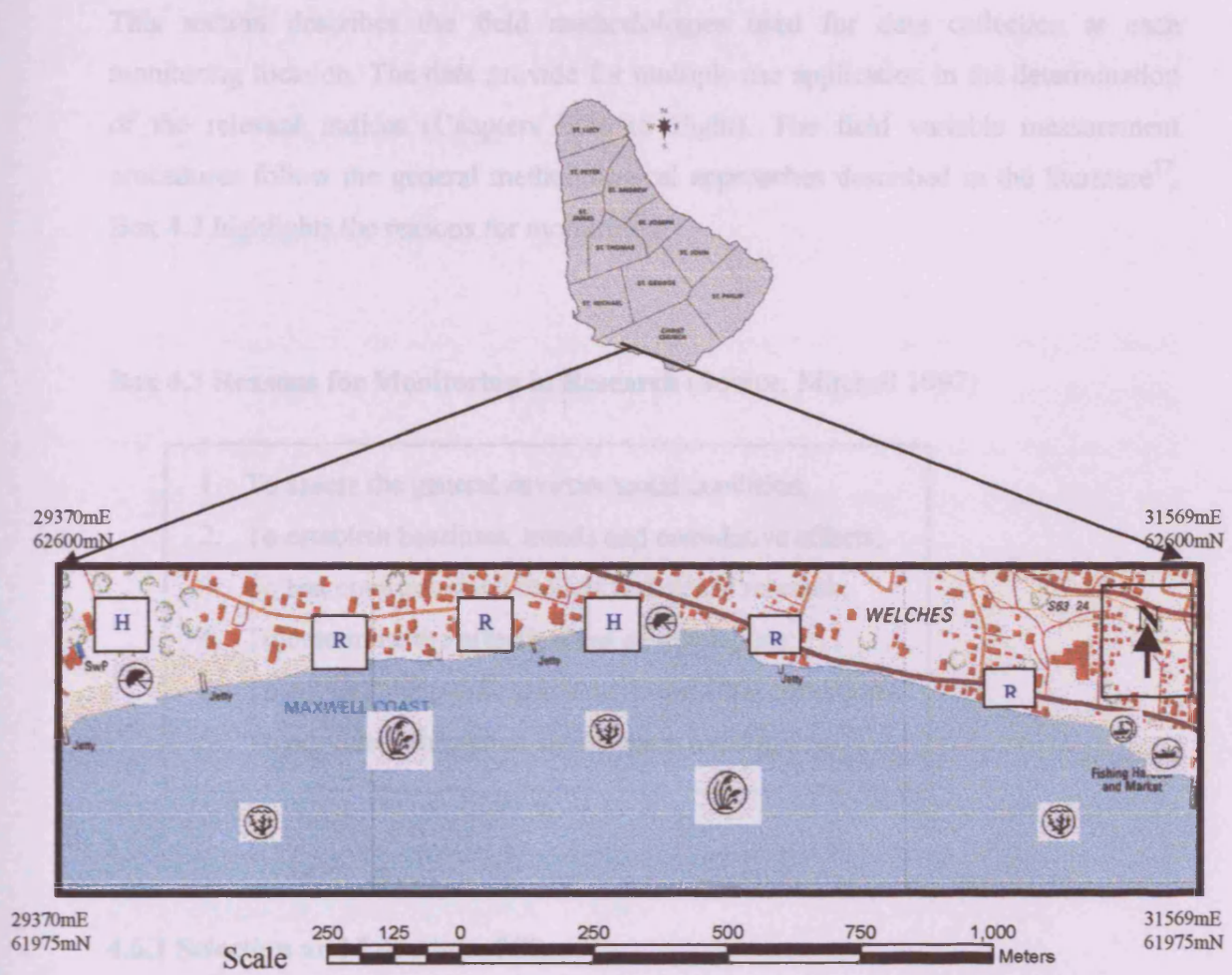
4.5.2.2 Casuarina Beach, Christ Church to Oistins, Christ Church

This segment of the coast is approximately 1900m long (Fig. 4.10). The coastline shape is straight to convex with the beaches varying in size from intertidal/narrow to relatively wide. The western beaches (Casuarina Beach) are relatively flat to gently sloping. Engineering structures (mainly seawalls, revetments and groynes) are found along many locations over the entire area. The nearshore area is predominantly sand and patch reef of either hard or soft corals (Delcan 1994b, Terra Remote Sensing Inc. 2000b). At a few locations, the nearshore comprises sand and coarse gravel. At one site on the eastern end (Welches), there is beach rock, which is only periodically covered with sand.

The offshore area is predominantly sand and patch reef. The backshore area is comprised of hotels, apartments and residences. Several of these have revetments and seawalls as property protection structures. At other locations, single groynes have been placed on the beach in an effort to hold the beach sands in front of properties. Yet this has resulted in a loss of beach width at adjacent downstream locations (Lester Toppin *pers. comm.* 2001). In locations with property protection structures, there is often an absence of a beach in front of the associated properties.

The problems in this area are the high frequency of hard coastal structures, which can impede lateral access along the coast at some points. Additionally, at other points the beach backs directly onto the main coastal road, making it exposed to extreme events.

Fig. 4.10 Map of Casuarina Beach Christ Church to Oistins Christ Church
 (Based on original 1:50000 scale) (Source: Original)



Symbols Key

Vehicle access	Turtle nesting beach	Recreational beach	Hard coral fringe reefs
Soft coral/patch reefs	Residences	Hotels	Boat hoist
			Commercial fishing

4.6 DESIGN OF FIELD SAMPLING PROGRAM

This section describes the field methodologies used for data collection at each monitoring location. The data provide for multiple use application in the determination of the relevant indices (Chapters Five to Eight). The field variable measurement procedures follow the general methodological approaches described in the literature¹⁷. Box 4.3 highlights the reasons for monitoring:

Box 4.3 Reasons for Monitoring in Research (Source: Mitchell 1997)

1. To assess the general environmental condition;
2. To establish baselines, trends and cumulative effects;
3. To test environmental models and verify research;
4. To determine the effectiveness of regulations;
5. To educate the public about environmental conditions.
6. To provide information for decision making.

4.6.1 Selection and Location of Sites

Based on an initial survey of the Barbados coastline in 2001, together with information from available literature on the coastal environment in Barbados (e.g. Proctor and Redfern 1984b, Delcan 1994d and 1995, Halcrow 1998a & b and 1999, Terra Surveys Inc. 2000a and b), a number of sampling sites representing different coastal areas were selected for further study, along the West and South coasts. A total of 60 beaches were chosen, representing the major littoral ecosystems and characteristics within the study areas. The selection of sites was based on easy access and the presence of current beach profile locations used by the CZMU¹⁸. The choice was also designed to ensure a relatively even geographic distribution of sites. Interpretation of aerial photographs

¹⁷ Refer to Proctor and Redfern (1983), Kohsiek *et al.* (1987), de Ruig and Louisse(1991), Jackson and Nordstrom (1992), Natesan and Subramanian (1994), Gorman *et al.* (1997), and Mason *et al.* (2000).

¹⁸ This was done to ensure the replicability and comparability of the results.

(Scale 1:10,000) was also performed in conjunction with the reconnaissance survey to classify the coastline into geomorphic zones.

4.6.2 Data Collection Procedures

4.6.2.1 Physical Oceanographic Indicators

Data were gathered on shoreline characteristics, wind and wave processes and beach change at sites between September 2001 and August 2002. The following methodologies used in this research, conform to other monitoring procedures described in the literature (e.g. Proctor and Redfern 1983, Jackson and Nordstrom 1992, and Natesan and Subramanian 1994), they have been adopted here.

4.6.2.1a Wind, wave, and longshore current data measurements

Visual wind and wave data were gathered at the sites on a minimum of 24 days during the one-year period. Wind direction was measured with a compass by sighting along the fall path of dry sand grains. Wind speed was measured on the crest of the beach berm, using a hand held digital anemometer.

Wave heights were measured visually with reference to a graduated staff held in the breaker zone. Breaker periods were determined by averaging the time taken for 11 waves to pass a given point. Breaker angles were determined by taking the difference between the azimuth of the beach along the waterline and the average azimuth of breaker by sighting along these features, with a compass in the surf zone.

Longshore current velocity was measured in the surf zone using a Swoffer Model 3000 handheld digital current metre.

4.6.2.1b Beach elevations

Beach elevations were measured on a quarterly basis using a total station and stadia rod placed at 3m intervals starting at a bench mark¹⁹ location, landward of the limit of normal wave influence and extending into the sea below the step of the beach. This information was combined with ongoing beach profile data gathered quarterly by the CZMU, for the last 10 years.

4.6.2.1c Identification of erosion accretion regimes

The research used existing profile records established by the CZMU for the island's West and South coasts to identify eroding or accreting sites. Each site was of a different length and the number of reference profile lines for the collection of information on the berm crest for any given area line, varied with the length of the site. Berm crest²⁰ data on each site have been observed quarterly. A ten year time series of data obtained from CZMU (March 1992 to June 2002) was used to determine the average rate of shoreline change (erosion or accretion) at each site.

4.6.2.2 Degree of Urbanisation

The island's coastal aerial photographic series was reviewed for background information. Images cover the periods 1960's, 1980's and 1990's, from which changes in land use classification were identified. The current extent of urbanisation was based on the calculated percentage of land cover that has been used for accommodation, commercial and industrial purposes. These aerial photographs, therefore, provide an acceptable means of identifying major land use changes over the respective years, as well as the identification of major coastal infrastructure over the 40-year period.

¹⁹ A benchmark is a co-ordinate reference point used in surveying, of known height above the known datum level.

²⁰ The berm crest corresponds to the mean high water mark position on the beach. It is the seaward limit of the nearly horizontal portion of the beach or backshore formed by the deposition of sediments by the receding waves.

The current degree of urbanisation, measured from recent aerial photographs (2000) flown at a scale of 1:10,000, was determined by the level of buildings and other infrastructure represented in the first 200m of the coastline²¹, starting from the backshore. The presence of houses, hotels, coastal roads, dunes, and other land use types (e.g. agriculture and woodland) characterise this limit.

4.6.3 Data Recording Procedures

A data-recording sheet has been developed for field use (Table 4.5a and b). As well as being designed to capture the environmental condition at the time of the site visit, the sheet also allows for inclusion of observations on additional data items to help in the general site description and interpretation. The sheet is divided into two sections - one for terrestrial variables and the other for marine ones. For functionality, it was decided that the field sheet would not exceed a page so that all on site data could be easily recorded²² in the field. This provides a clear site representation, at the time of the survey. In both sections, information can be recorded on environmental conditions, if it is found difficult to logistically perform both the terrestrial and marine surveys on the same day. One advantage with this sheet is that it makes provision for the later incorporation of desktop information, if necessary.

²¹ The 200m inland boundary corresponds to the legislated coastal zone management area for the island. See Barbados legislation: Coastal Zone Management Act 1998-39

Table 4.5a: Terrestrial Field Data Sheet for Collecting Site Variable Data
(Source: Original)

Location name:
 Survey date:
 Group:
 Shoreline type:
 Coastal shape:
 Co-ordinates (profile point on beach):
 Weather conditions:

Variable	Investigations (field/desk) site characteristics
<i>Oceanographic /Physical variables of Littoral Processes</i>	
Orientation of Coastline (°N)	
Wind speed (ms-1)	
Wind direction (°N)	
Breaker/wave height (m)	
Breaker/wave period (sec)	
Breaker/wave angle (°N)	
Longshore current speed (cm/s)	
<i>Beach form & shoreline variables²³</i>	
Beach length (m)	
Beach orientation (°N)	
Beach slope (%)	
Beach volume (at profile location)	
Dry beach width (m)	
Minimum back beach width (m)	
Elevation of back shore (m)	
Mean size of beach sediments (mm)	
<i>Morphology of coastline</i>	
Location of cliff in relation to the shoreline (Absent = 0; Active (at the shoreline) = 1; Inactive (present behind a beach) = 2)	
Presence of small scarps with a maximum height of 3m (Absent = 0; Present = 1)	
Cliff height (m)	
Cliff slope (°)	
Cliff texture (Absent = 0; Unconsolidated or soft rock = 1; Hard rock = 2)	
Low rocky shore (Absent = 0; Soft rock = 1; Hard rock = 2)	

²² This was useful to avoid wind-associated problems.

²³ Width of intertidal area (distance from MHW – MLW) (m) can be included where appropriate for locations where there is a noticeable variation between these water marks on the beach. This has not been used in the Barbados context as there is very little variation between these two measurements on the beaches.

Table 4.5b Marine Field Data Sheet for Collecting Site Variable Data
(Source: Original)

Location name:
 Survey date:
 Group:
 Shoreline type:
 Coastal shape:
 Co-ordinates (profile point on beach):
 Weather conditions:

Variable	Investigations
<i>Seafloor morphology and sedimentology variables</i>	
Slope of sea floor between 0 - -3 m (%)	
Mean size of sea floor sediment between 0 - -3 m (mm)	
Distance between shoreline and -3m (m)	
Presence of nearshore coral rubble/ coral reef/ seagrass beds (Absent = 0, Rubble = 1, Seagrass = 2 Coral reef = 3)	
<i>Presence of beach associated landform variables</i>	
Presence of dunes (Absent = 0, Migratory = 1; Single row = 2; Multiple rows = 3)	
Presence of tidal flats (including mud, sand, gravel, and cobble/rubble flats) (Absent = 0; Present = 1)	
Presence of beach rock (Absent = 0; Present = 1)	
Percentage urbanised land on shore first 200m behind the beach	
Presence of low landforms behind the beach (Absent = 0; Soil or sand terrace = 1)	
Presence of sloping land (Absent = 0; Soil over rock covered with vegetation = 1)	
<i>Human intervention variables</i>	
Presence of man made structures/defensive structures (Submerged breakwaters, harbour breakwaters and groynes = 1; Surface piercing breakwaters = 2; Surface piercing breakwaters (with tombolos) = 3; Revetments (including gabions) = 4; Sea walls = 5)	
Length of protected coast covered by structure	
Length of protected coast covered by structure (%)	
<i>Evolutionary trend of shoreline variables</i>	
Mean shoreline accretion rate (m)	
Mean shoreline erosion rate (m)	

Table Notes:

(a) It should be noted that whenever a variable lost significance (i.e. absence of form) a zero value was assigned.

(b) The cliffs were classified and given an assigned value according to:

1. Height (between 3 – 10m = 1; 10 – 20m = 2; >20m = 3).
2. Slope angle (<30° = 1; 30° – 60° = 2; 60° - 90° = 3).
3. The location with reference to the shoreline (absent = 0; on the shore surface = 1; behind beaches = 2).
4. Presence of a small cliff scarp of < 3m found on or slightly behind the shoreline (Absent = 0; Present = 1).

(c) The nearshore ecosystems were identified and given an assigned value according to Absent = 0; Coral rubble = 1; Seagrass = 2; and Coral reef = 3

(d) The dune systems were identified and given an assigned value according to Absent = 0; migratory = 1; Single row = 2; Multiple rows = 3

(e) The presence of tidal flats, beach rock were identified and assigned a value according to Absent = 0; Present = 1.

(f) The presence of low landforms behind the beach were identified and given an assigned value according to Absent = 0; Soil or sand terrace = 1.

The field data was entered and stored in Microsoft Excel for ease of data processing and transfer to other statistical software where applicable to the respective methodologies described in Chapters Five through to Eight. These will be further elaborated therein.

4.7 SUMMARY

This chapter has introduced the methodology and analysis section of the thesis. Section 4.2 has focused on the description of the general methodology. The methodology presents its linkages to the research objectives, and provides a clear procedure for the development of a LVAP for coastal locations. In addition, the chapter builds on the previous one, which examined the various approaches, used in the determination of CV and the development of associated indices. Section 4.3 explained the procedure used in developing the criteria to assess the methodologies and variables proposed for use in the research. Section 4.4 presented the coastal zoning methodology used to define the

coastal boundaries of the study area. Section 4.5 described the selection of the case study areas and provides their descriptions. Finally, Section 4.6 presented the design of the field-sampling programme including the procedures used to (1) establish monitoring locations to measure the field variables and (2) collect, record, and store the field data.

Chapter 5
Development of Environmental Sensitivity Indices for
Littoral Vulnerability Assessment

Chapter 5

Development of Environmental Sensitivity Indices for Littoral Vulnerability Assessment

5.1 INTRODUCTION	118
5.2 DETERMINATION OF THE WAVE EXPOSURE INDEX.....	119
5.2.1 VARIABLE DESCRIPTORS.....	119
5.2.2 PROCEDURE.....	119
5.2.2.1 Pilot Testing of Methodology.....	119
5.2.2.2 Applied Procedure.....	120
5.2.3 WEI RESULTS - INTERPRETATION OF THE BARBADOS FINDINGS.....	121
5.2.3.1 Beach Safety Index	124
5.2.4 DISCUSSION.....	128
5.2.5 EVALUATION OF THE TECHNIQUE USED.....	129
5.2.5.1 Variables Used.....	129
5.2.5.2 Data Availability.....	130
5.2.5.3 Economic Costs	130
5.2.5.4 Logistics and Administration.....	133
5.2.6 RECOMMENDATIONS.....	133
5.2.6.1 Modifications to the Technique	134
5.3 DETERMINATION OF THE COASTAL SENSITIVITY INDEX	134
5.3.1 VARIABLE DESCRIPTORS.....	135
5.3.2 PROCEDURE.....	137
5.3.2.1 Pilot Testing of Methodology.....	137
5.3.2.1 Applied Procedure.....	138
5.3.3 CSI RESULTS - INTERPRETATION OF THE BARBADOS FINDINGS.....	138
5.3.3.1 Results of Ranking of Littoral Habitat Types used to Determine CSI.....	138
5.3.3.2 Environmental Sensitivity Analysis (ESA).....	142
5.3.4 DISCUSSION.....	145
5.3.4.1 Comparison of Proposed Oil Spill Index with Existing Oil Spill Indices.....	145
5.3.5 EVALUATION OF THE TECHNIQUE	151

5.3.5.1 Variables Used in the Barbados Experience and their Application in a Wider Context.....	151
5.3.5.2 Data Availability.....	152
5.3.5.4 Logistics and Administration.....	153
5.3.6 RECOMMENDATIONS.....	155
5.3.6.1 Modification of the Technique	156
5.4 DETERMINATION OF THE BEACH AESTHETIC INDEX.....	156
5.4.1 CHECKLIST ADAPTATIONS TO SUIT THE BARBADOS COAST.....	157
5.4.2 PROCEDURE.....	166
5.4.3 BAI RESULTS - INTERPRETATION OF THE BARBADOS FINDINGS	167
5.4.3.1 Determination of BAI.....	167
5.4.4 DISCUSSION.....	184
5.4.5 EVALUATION OF THE TECHNIQUE	185
5.4.5.1 Variables Used in the Barbados Experience and their Application in a Wider Context.....	185
5.4.5.2 Available Data	187
5.4.5.3 Economic Cost.....	189
5.4.5.4 Logistics and Administration.....	192
5.4.6 RECOMMENDATIONS.....	192
5.4.6.1 Modification of Technique	193
5.5 SUMMARY.....	193

5.1 Introduction

This chapter presents the detailed methodologies and interpreted analyses of the results for the Environmental Sensitivity Indices (ESIs). In discussing these methodologies¹, the research objectives 1 and 3 are achieved. The chapter is structured into three main sections. The first, Section 5.2, describes the determination of the Wave Exposure Index (WEI). The second, Section 5.3, details the determination of the Coastal Sensitivity Index (CSI). The third, Section 5.4, presents the determination of the Beach Aesthetic Index (BAI). Each section includes an evaluation of the methods used and a discussion of their applicability to other small island systems. Within these, the following areas are considered:

- the variables used;
- data availability;
- economic costs; and
- logistics and administration.

Where appropriate, background information on the general trends at some locations has been obtained from existing literature, as well as discussions with the relevant coastal experts and representatives of the island's governmental and non-governmental agencies.

Subsequently, Chapter 9 identifies the way in which such methodologies can be incorporated into the present Barbados CM system.

¹ There has been little previous work carried out in the Caribbean region in this field on which to base the research methodology. As such, techniques from other global locations have been identified as being potentially useful and have been suitably modified to realistically reflect the conditions experienced on Barbados' West and South coasts.

5.2 DETERMINATION OF THE WAVE EXPOSURE INDEX

Wave attack is one of the best-recognised processes affecting shoreline stability. The processes can be described as wave overtopping (including flooding of backshore areas) and wave undercutting (i.e. erosion). The distance travelled inland can affect the coastline's sediment budget and sediment transport rate (Pethick 1997, WCU 2001).

The degree of coastal wave exposure is important for determining: 1) the types of recreational activity that can occur at the location; 2) an indication of the safety of the area; and 3) the contribution to development of an oil spill vulnerability index for the coastline. As presented in Fig. 4.1, when combined with information on bathymetric types and nearshore ecosystem information, it results in the development of a CSI to oil spills (Section 5.2.3) – necessary for oil spill contingency planning (Hanna 1995, RPI 1996, NOAA 1997). The application of this technique to Barbados has not been reported in the literature and, thus, this component of the research makes a contribution to research material on Barbados.

5.2.1 Variable Descriptors

An exposure scale is developed for Barbados' coastline using physical oceanographic variables (wave height, wave period, wind speed and longshore current²) monitored in the nearshore coastal water at each location.

5.2.2 Procedure

5.2.2.1 Pilot Testing of Methodology

Initially, the procedure was piloted over a one-week period at eight beaches in the study area to determine potential ranges for the measured variables. The data collected was

² Based on the work of Nansingh and Jurawan (1999) who carried out similar work on the coastline of Trinidad, West Indies. Refer to glossary for definitions of oceanographic variables.

intended to capture normal recreational wave climate conditions³. This approach resulted in little differentiation in the measured variables, demonstrating the method's low sensitivity. The procedure was, therefore, modified in order to represent the wider potential range of measurements that could be achieved at various beaches outside the study area. This approach has, therefore, potential application to the entire island.

5.2.2.2 Applied Procedure

After the pilot survey, a one-month intensive island-wide survey of littoral variables (Section 5.2.1) was performed to determine the range for the coastal exposure scale. Thereafter, the variables were monitored twice monthly at the respective sites (as established in Sections 4.6.1 & 4.6.2) during dry and wet season for a year. The mean value of each variable was recorded for each season. Each variable was assigned to a score range. Each score range was then assigned a value of one, two, or three, corresponding to a scale value of 'high', 'moderate' or 'low' according to the total score received. From these, the exposure scale was developed.

The exposure scale categories divides the coastal areas into one of four possible options – 'highly exposed', 'exposed', 'fairly sheltered' or 'sheltered'. When the total score for each location is calculated, a value range is assigned to the relevant exposure scale, and an index value assigned to each scale value (i.e. highly exposed – index value I, exposed – index value II, fairly sheltered – index value III, sheltered – index value IV). A shore is considered exposed if the value of the total combined score⁴ is less than or equal to seven, and sheltered if the value is greater than or equal to eight.

The scores are ranked in descending order and then the quartile calculation in the Microsoft Excel software package is used to separate the ranked scores into the four

³ The normal recreational wave conditions represent the sea state that allows for best use of the nearshore for recreation. During the winter swell period and at times when the coast is being affected by tropical storm waves, there is very little active recreational use made of the nearshore, as the sea is too rough and therefore potentially more dangerous to be in. The measured waves presented in this research do not reflect the abnormally high waves associated with such conditions.

⁴The total combined score is calculated from the scores recorded during the wet and dry seasons (see Appendix 5)

exposure ratings. These ratings represent highly exposed (0 – 25%), exposed (25 – 50%), fairly sheltered (50 – 75%), and sheltered (75 – 100%) (I to IV respectively). These index values have then been represented on the relevant 1:10,000 map sheet for each coastal location.

5.2.3 WEI Results - Interpretation of the Barbados Findings

Following the wave exposure methodology, the scale for each variable has been established (Tables 5.1a and 5.1b). The overall average annual variable per beach location have been calculated and summarised in Appendix 5.

Based on the calculated values from the exposure scale, classification tables for the coastal locations have been developed (Tables 5.2 and 5.3). The higher the total score, the more sheltered the location. Within the study areas, such conditions are predominantly found at all sites, with only six locations on the South coast (Cotton House Bay North, Cacrabank, Rockley in Christ Church, and Hilton Beach, Needham’s Point, Bridgetown Harbour in St. Michael), being exposed.

Table 5.1a Value Ranges Developed for Exposure Scale Determination

Littoral Processes Scores and Exposure Scale Data					Value	Scale Value
Wave height (m)	Wave period (s)	Wind speed (m/s)	Longshore current (cm/s)			
> 0.6	< 4.5	> 3	> 20	1	High	
0.4 - 0.6	4.5 to 7	1.75 to 3	12 to 20	2	Moderate	
< 0.4	> 7	< 1.75	< 12	3	Low	

Table 5.1b Value Ranges Used in Exposure Scale and WEI Determination

Exposure Scale	Total Combined Score	WEI
Highly exposed	1 to 4	I
Exposed	5 to 7	II
Fairly Sheltered	8 to 9	III
Sheltered	> 10	IV

On the South coast, there is a more varied exposure range than on the West coast, with 46.9% of the coast being sheltered, 34.4% being fairly sheltered and 18.8% being considered exposed (Tables 5.2). Sheltered locations (Table 5.3) dominate the West coast (92.9%).

Table 5.2 Summary Exposure Scale for South Coast Locations

South Coast Beach Name	Total Score	Exposure Scale	WEI
South Point	10.00	Sheltered	IV
Atlantic Shores	10.00	Sheltered	IV
Cotton House Bay South	10.00	Sheltered	IV
Cotton House Bay North	7.00	Exposed	II
Enterprise	9.00	Fairly sheltered	III
Oistins	11.00	Sheltered	IV
Oistins Fishing Complex	10.00	Sheltered	IV
Welches	10.00	Sheltered	IV
Cachel	10.00	Sheltered	IV
Club Mistral	9.00	Fairly sheltered	III
Bougainvillaea	10.00	Sheltered	IV
Casuarina	8.00	Fairly sheltered	III
Turtle Beach	9.00	Fairly sheltered	III
Dover	10.00	Sheltered	IV
Rostrevor	9.00	Fairly sheltered	III
Pisces	10.00	Sheltered	IV
Little Bay	11.00	Sheltered	IV
Graeme Hall	10.00	Sheltered	IV
Rendezvous	8.00	Fairly sheltered	III
Cacrabank	7.00	Exposed	II
Rockley	7.00	Exposed	II
Kentucky	8.00	Fairly sheltered	III
Hastings Rocks	10.00	Sheltered	IV
Sierra	10.00	Sheltered	IV
Coconut Court	9.00	Fairly sheltered	III
Asta	8.00	Fairly sheltered	III
Drill Hall	10.00	Sheltered	IV
Hilton	7.00	Exposed	II
Needham's Point	7.00	Exposed	II
Pebbles	9.00	Fairly sheltered	III
Carlisle Bay	9.00	Fairly sheltered	III
Bridgetown Harbour	6.00	Exposed	II

Table 5.3 Summary Exposure Scale for West Coast Locations

West Coast Beach Name	Total Score	Exposure Scale	WEI
Brandons	11.00	Sheltered	IV
Brighton	10.00	Sheltered	IV
Spring Garden	10.00	Sheltered	IV
Paradise	11.00	Sheltered	IV
Batts Rock	10.00	Sheltered	IV
Batts Rock Bay	12.00	Sheltered	IV
Prospect	12.00	Sheltered	IV
Fitts Village	10.00	Sheltered	IV
Cyrus	12.00	Sheltered	IV
Crystal Cove	12.00	Sheltered	IV
Paynes Bay Revetment	12.00	Sheltered	IV
Paynes Bay Market	10.00	Sheltered	IV
Buccaneer Bay	11.00	Sheltered	IV
Tamarind Cove	10.00	Sheltered	IV
Coach House	11.00	Sheltered	IV
Sandy Lane	11.00	Sheltered	IV
Almond Beach Club	12.00	Sheltered	IV
Regent	12.00	Sheltered	IV
Holetown South	12.00	Sheltered	IV
Holetown North	12.00	Sheltered	IV
Folkstone	12.00	Sheltered	IV
Heron Bay	12.00	Sheltered	IV
Royal Pavilion	12.00	Sheltered	IV
Lone Star Garage	12.00	Sheltered	IV
Weston	11.00	Sheltered	IV
Lower Carlton	10.00	Sheltered	IV
Greensleeves	12.00	Sheltered	IV
Gibbs Bay	12.00	Sheltered	IV
Mullins Bay	11.00	Sheltered	IV
Road View	9.00	Fairly sheltered	III
Cholera Bay	12.00	Sheltered	IV
Goddings Bay	12.00	Sheltered	IV
Fort Denmark	11.00	Sheltered	IV
Fisherman's Pub	11.00	Sheltered	IV
Sand Street	11.00	Sheltered	IV
Almond Beach Village	11.00	Sheltered	IV
Port St Charles	11.00	Sheltered	IV
Six Men's	11.00	Sheltered	IV
Shermans	9.00	Fairly sheltered	III
Smittons Bay	9.00	Fairly sheltered	III
Half Moon Fort	11.00	Sheltered	IV
Fryers Well Bay	11.00	Sheltered	IV

5.2.3.1 Beach Safety Index

The concept of beach safety as part of shoreline description is of importance from a recreational perspective. Such an approach has been devised and documented by the Australian Coastal Studies Unit (Short 1993, Short and Hogan 1994). This international system (Table 5.4a) has application in locations with tidal ranges less than 2m making it useful for Barbados. Short (1993) has identified 3 descriptive beach types (reflective, intermediate, dissipative⁵) that can be used to establish a beach safety index.

The beach safety rating system has been applied to the research area, within a recreational context where wave heights normally range between 0.5 – 1.5 meters (Tables 5.2 and 5.3). Barbados' beaches may be characterized as dissipative, however much of the recreational nearshore zone (the first 30m) is shallow to gently sloping. The measured wave height is often 0.5 meters or less allowing for the application of the lower value of four to be assigned to most beaches. As a result, there are seldom large breakers as described by Short and Hogan (1994) restricting recreation to the swash zone. This research has demonstrated that sheltered beaches are considered good locations for swimming and other nearshore recreation activities. These are identified by the NCC by signage as good location for swimming and are therefore safe by interpretation (Keith Neblett *pers. comm.*). It is concluded that using this approach it is possible to identify safe beaches and factor these into management initiatives. When wave heights in excess of 2m are experienced on the coast (normally during the winter swell⁶ season and periodically associated with a tropical depression or storm), the safety

⁵ Short (1994) provides complete descriptions of the six beach types found along the coast of New South Wales. Reflective beaches are characterised by low energy waves, steep, narrow, coarse sand beaches; Intermediate beaches are generally between low energy reflective beaches and high energy dissipative beaches. Intermediate beaches have four classifications but are characterised by the presence of a surf zone with bars and rips and have moderate wave heights affecting the shoreline. The sand of these beach types are described as fine to medium sands. Dissipative beaches are described as locations having wave heights greater than 2.5 m with wide surf zones. These beaches are characterised by being wide, low, and comprised of fine sand.

The beach safety index ratings refer to hazards associated with the normal beach state together with any local hazards. Beach safety is influenced by headlands, oblique waves, high tide, rising seas, strong onshore and alongshore winds, mega ripples, low tide and changing wave conditions (Short 1994).





⁶ Winter swells occur annually between December and March, normally lasting up to four days, however prolonged swell episodes of eight to ten consecutive days have been known to occur, depending of the severity of the meteorological conditions generating the swells. While rare events, such occurrences remove large volumes of beach sediment from affected areas resulting in the narrowing of the recreational beaches.

score ratings of seven to ten developed by Short are applicable as it becomes dangerous to use the nearshore. Tables 5.4b and c present the developed beach safety scores for Barbados under normal wave conditions, using the score ranges as developed by Short (1994).

While this Australian beach safety rating system may not be fully applicable for Barbados, it is accepted that within the general SIDS context this rating system provides a useful technique for determining the beach safety level at locations that may have a similar wave climate to that experienced in Australia.

Table 5.4a Beach Safety Rating Table (Source: Short and Hogan 1994)

BEACH STATE	WAVE HEIGHT							
	<0.5 (m)	0.5 (m)	1.0 (m)	1.5 (m)	2.0 (m)	2.5 (m)	3.0 (m)	>3.0 (m)
Dissipative	4	5	6	7	8	9	10	10
Long Shore Bar Trough	4	5	6	7	7	8	9	10
Rhythmic Bar Beach	4	5	6	6	7	8	9	10
Transverse Bar Rip	4	4	5	6	7	8	9	10
Low Tide Terrace	3	3	4	5	6	7	8	10
Reflective	2	3	4	5	6	7	8	10

SAFETY RATING	KEY TO HAZARDS
Safest: 1- 3	 Water depth and/or weak currents
Moderately Safe: 4 – 6	 Shore break
Low Safety: 7 – 8	 Rips and surf zone currents
Least safe: 9 – 10	 Rips, currents and large breakers

NOTE: All safety level ratings are based on a bather being in the surf zone and will increase with increasing wave height or with the presence of feature such as inlet, headland or reef induced rips and currents. Rips also become stronger with falling tide. **Bold** grading indicates safety level under modal wave conditions.

**Table 5.4b Summary Beach Safety Rating Scale for South Coast Locations
(Source: Original)**

South Coast Beach Name	WEI	Beach Safety Rating
South Point	IV	5
Atlantic Shores	IV	4
Cotton House Bay South	IV	4
Cotton House Bay North	II	8
Enterprise	III	3
Oistins	IV	2
Oistins Fishing Complex	IV	3
Welches	IV	3
Cachel	IV	3
Club Mistral	III	4
Bougainvillaea	IV	4
Casuarina	III	4
Turtle Beach	III	4
Dover	IV	4
Rostrevor	III	6
Pisces	IV	4
Little Bay	IV	3
Graeme Hall	IV	2
Rendezvous	III	4
Cacrabank	II	8
Rockley	II	5
Kentucky	III	5
Hastings Rocks	IV	6
Sierra	IV	3
Coconut Court	III	4
Asta	III	4
Drill Hall	IV	3
Hilton	II	6
Needham's Point	II	8
Pebbles	III	2
Carlisle Bay	III	2
Bridgetown Harbour	II	10

The results demonstrate that more than 75% of the beaches on the south coast are safe to moderately safe⁷ and that the majority of these correspond to sheltered beach locations. Unsafe locations correspond to those areas that have cliff lines or exposed engineering structures.

⁷ Safe is considered here as having a score of 5 or lower

**Table 5.4c Summary Beach Safety Rating Scale for West Coast Locations
(Source: Original)**

West Coast Beach Name	WEI	Beach Safety Rating
Brandons	IV	3
Brighton	IV	5
Spring Garden	IV	7
Paradise	IV	5
Batts Rock	IV	4
Batts Rock Bay	IV	4
Prospect	IV	5
Fitts Village	IV	5
Cyrus	IV	3
Crystal Cove	IV	3
Paynes Bay Revetment	IV	8
Paynes Bay Market	IV	5
Buccaneer Bay	IV	3
Tamarind Cove	IV	3
Coach House	IV	4
Sandy Lane	IV	3
Almond Beach Club	IV	4
Regent	IV	5
Holetown South	IV	6
Holetown North	IV	6
Folkstone	IV	5
Heron Bay	IV	6
Royal Pavilion	IV	5
Lone Star Garage	IV	4
Weston	IV	6
Lower Carlton	IV	3
Greensleeves	IV	4
Gibbs Bay	IV	3
Mullins Bay	IV	4
Road View	III	5
Cholera Bay	IV	4
Goddings Bay	IV	4
Fort Denmark	IV	5
Fisherman's Pub	IV	4
Sand Street	IV	4
Almond Beach Village	IV	4
Port St Charles	IV	4
Six Men's	IV	4
Shermans	III	5
Smittons Bay	III	5
Half Moon Fort	IV	6
Fryers Well Bay	IV	4

The results demonstrate that more than 83% of the beaches on the west coast are safe to moderately safe and that the majority of these correspond to sheltered beach locations.

5.2.4 Discussion

This WEI, the first of its kind for Barbados, has provided an effective means of quantifying data on nearshore variables for designation purposes. The exposure scale will assist in the co-ordinated management of multiple use recreational zones along the coastline where watersports activities (e.g. windsurfing) may be in direct conflict with passive nearshore recreation (e.g. swimming and snorkelling which occurs for instance in the Holetown area on the West coast⁸). It will also assist in the establishment of lifeguard stations⁹, as currently, there are only twelve such stations along the West and South coast. The current policy of the National Conservation Commission (NCC) is “to only establish lifeguard facilities on beaches that are known to be popular recreation locations and considered safe” (Steve Devonish, *pers. comm.* 2001).

It is expected that, within the exposed locations, wave action and dissipation of wave energy, continuously rework the sediments. The results demonstrate that, along the South coast, exposed locations coincide with headland areas; the most prominent of these being Hilton Beach and Needham's Point, in St. Michael, and the cliff line at Cacrabank, Christ Church. The sheltered locations along the West coast demonstrate very little wave action under normal conditions. As such, it is expected that there will be limited sediment reworking, and little overall sediment movement.

The Beach Safety Rating is also the first of its kind for Barbados. The results demonstrate that generally safe beaches correspond with sheltered areas. This is useful within a CM and public education contexts, as it presents recreational safety information in a format that is easily understood. This can be posted on notice boards at specific beaches, or, documented in recreational brochures to assist persons who are unfamiliar with the coast.

⁸ Competition between watersports operators associated with hotels in the area results in these conflicts and although zoning for water sport activities exists there are still some infringements of the law in the actual use of the areas.

⁹Lifeguard stations are controlled and administered by the National Conservation Commission (NCC).

5.2.5 Evaluation of the Technique Used

5.2.5.1 Variables Used

It is concluded that the four variables are appropriate for the determination of the WEI. They are easily measured on-site, provided that the appropriate equipment is available. The CZMU purchased the following equipment items for use in the determination of the exposure index¹⁰ (Table 5.5).

Table 5.5 Main Equipment Items Used in the Determination of WEI

Equipment Item	Accuracy ¹¹
A hand held digital current meter (for determining longshore current speed) <ul style="list-style-type: none"> • Swoffer 3000 Series open stream current velocity meter*¹² • Speed tech Flow meter/Anemometer 	Current velocity accuracy +/- 1% (minimum reading 0.1 ft/s, 0.03 m/s) Current velocity accuracy +/- 3% (minimum reading 0.6 mph, 1km/h, 0.3 m/s)
8ft fibreglass telescoping pole	0.5 cm
Silva compass	0 – 360 ⁰
Dual display digital stopwatch*	1/100sec
A pocket weather station (digital anemometer and temperature readings)*	Anemometer accuracy +/- 3% (minimum reading 0.7 mph, 1km/h or 0.3m/s) Temperature accuracy +/- 1 ⁰ C (Temperature range –20C to + 60C)

¹⁰ A complete listing of items purchased for use in this thesis is presented in Appendix 5. These purchases arose out of the Unit's interest in the potential use of the collected information for the long-term use of the department.

¹¹ Equipment accuracy information obtained from Forestry Catalogue 2001-2002.

¹² Where * = Purchased by CZMU for longshore current measurements and generic weather condition assessment.

5.2.5.2 Data Availability

The CZMU historic data records¹³ provide a good reference record for the trends in variable ranges. This has been verified by on-site investigation, using the equipment purchased as part of the thesis. The results have shown that, in the absence of available data, *in situ* data can be used to determine WEIs, and suggests that this application fulfills research objective 1, 3 and 5 (Section 1.3.1.2). In situations where there are accurate data sets, their use would make the overall interpretation of wave variable data and the determination of the WEI more robust.

5.2.5.3 Economic Costs

The economic cost associated with the application of this technique includes the actual cost of equipment, transportation to site and man-hours for collecting the data (Table 5.6). The focus on equipment falls into the issues of reliability and accuracy at minimum cost. The equipment purchased for this aspect of the research cost approximately GB £ 1619 (US \$ 2667)¹⁴, although this could have been reduced if a less costly flow meter had been purchased. The CZMU purchased the Swoffer Current Velocity Meter costing GB £1513 (US \$2495) based on its level of accuracy and ability to retain a large series of data points that could be downloaded into a computer for future data processing. The alternate meter Speedtech Flow meter/Anemometer costing GB £187 (US \$309) could have been purchased; however, it would have necessitated the manual recording of field data at each location, and hence only having one record of the field data collected. The first meter allowed for the ability to recheck data obtained from the field in case of transcription or transposition errors in the recording of the field sheet information. The purchase of the field equipment plus the alternate meter is GB £292 (US \$481). An estimated savings of GB £1327 (US \$2186) however, could have been made if the alternate meter had been purchased.

¹³ This data has been collected from the inception of the Barbados beach monitoring programme in 1982 (Lester Toppin, *pers. comm.* 2001).

¹⁴Based on equipment prices (excluding shipping and handling) quoted in Forestry Suppliers Inc catalogue 2001/2002. Currency converter used <http://www.xe.com/ucc/convert.cgi> on 26/5/03.

Transportation costs depend on the current prices of petrol and costs of rental of a vehicle. In Barbados, as with any other country, these figures are highly dependent on rates set by the government for petrol cost and by private hire firms for vehicles. As the CZMU provided transportation, this cost was incorporated into the routine departmental functioning. However, cost estimates using existing car rental rates range from GB £183 to GB £245 per week (Sun Isle Car Rentals *pers. comm.* 2002). It takes GB £15 to fill the CZMU diesel field vehicle, which lasts a minimum of 1 - 2 weeks, depending on the field work to be performed (Anne-Marie Burke, *pers. comm.* 2002).

Man-hour costs reported here are based on the rates characteristically paid to the CZMU field staff with qualifications ranging between 'O Level' and 'A Level' Cambridge General Certificate of Education academic standards. Such personnel are fully familiar with the Unit's routine beach monitoring protocols, and are, therefore, aware of the need for accuracy in the collection and recording of field data. The collection of the littoral variable data (with the exception of the longshore current speed) was already an ongoing routine of the Unit's beach profile monitoring regime, although the information had never been used in the determination of WEI.

A one-week training course has been included in the costings to train staff in the proficient use of field equipment, standardised field procedures, data collection and processing.

Table 5.6 Cost Associated with the Determination of the WEI (Indicated as Man Week Costs)

Activity	Number of staff (weekly rate) and staff time (days) required to determine Wave Exposure Index	Cost (GB £) (US \$)
Field equipment cost*		160 (263)
(1) Swoffer Current Meter		1513 (2495)
(2) Speedtech Current Meter		187 (309)
Transportation cost		15 (23)
Man week cost (data acquisition)**	2 staff (week rate £121 (US \$199) per man); 5 days	1210 (1990)
Man week cost (data processing)	1 staff (week rate £168 (US \$277)); 10 days	336 (554)
Training cost	1 staff (week rate £455 (US \$750)); 5 days	455 (750)
Sub Total***		2182 (3580)
Grand total with:		
(1) Swoffer Current Meter		3695 (6075)
(2) Speedtech Current Meter		2369 (3889)

Table Notes:

*Refer to Appendix 6 Table III for equipment listing. However, the cost with the Swoffer current meter (1) and the cost with Speedtech current meter (2) are reflected separately to show their effect on the total costs.

** Man week costs are salary rates based on current Government monthly salary scales, for the positions of Chainman (for field data collection) and Clerical Officer (for data processing) (Paula Holder, *pers. comm.* 2002) as these are the level of staffing required to perform these works.

*** Costs not included here would be for the purchase of direct capital costs (e.g. computer hardware (including colour printer and incidentals for computer usage) and associated software (Microsoft Office Suite and SPSS).

5.2.5.4 Logistics and Administration

The greatest difficulty associated with this technique is the determination of appropriate locations from which to take the measurements. Within the Barbados experience, the use of current beach profile locations contributed to the selection of monitoring sites. This is because they are co-ordinate-referenced locations that have been repeatedly used for beach profile data collection. This ensures the scientific validity of the data for each sampling episode. Additionally, the ability to co-ordinate the work by using several personnel simultaneously ensures a time effective method for the multiple variable data collection.

In island situations, where such sites do not exist, there would be a need to either establish benchmark locations for the long-term monitoring of the wave information or use GPS systems for accurate positioning. The use of handheld Differential GPS would be suitably accurate to ensure a return to the same exact location (within centimetre accuracy) for the sampling of the wave information. The cost of such equipment would have to be identified as part of the non-recurrent capital purchases, as it has multiple application purposes for many of the variables monitored and cannot be repeated each time for each variable monitored. The cost of this equipment item is identified as a non-recurrent item in the equipment listing (Appendix 5).

5.2.6 Recommendations

Given the success of this approach, it is recommended that the WEI exposure scale be applied to the rest of the island. As identified in Section 5.2, this is of significance for application in oil spill contingency planning as several East coast locations are frequently subjected to continuous low level exposure to oil pollution (in the form of tar balls and light oil slicks).

The designation of coastal stretches based on their exposure scale ranking (Section 5.2), can also help identify beach locations that can support different recreational activities

(e.g. surfing, wind surfing, kite surfing and parasailing). However, it is necessary to consider how and when these activities can be managed safely¹⁵.

5.2.6.1 Modifications to the Technique

There is little modification required to this technique. However, some modifications to the data collection process may be needed for different coastal environments, (e.g. safety factors - how far to venture into the nearshore to measure the longshore current in high energy environments, or considering the use of a boat to measure the longshore currents). Improved accuracy could be achieved with the use of improved statistical data analysis to fine-tune the scale ranges. It should be pointed out that, as referred to earlier (Section 5.2.2.2), this research is only based on a single year's data. Its usefulness will be improved as more data are collected.

5.3 DETERMINATION OF THE COASTAL SENSITIVITY INDEX

Figure 4.1 demonstrates the link between bathymetric types (including habitats) and wave exposure along a coastline. The development of a CSI provides a procedure on which to assess the habitats and bathymetric characteristics of a coastline, in order that they receive prioritised attention, in the event of an oil spill. This approach addresses research objectives 1, 3 and 5 (Section 1.3.1.2) defining the general sensitivity of coastline using a minimum of easily identifiable variables.

The prediction of the behaviour and persistence of oil on coastal habitats has been well documented¹⁶. The applicability of this technique is reliant on the relationship between a coast's physical and biological characteristics. The relationship is governed by the relative exposure to wave and tidal energy, sediment type, shoreline slope and

¹⁵ Caution has to be exhibited in the planning of multiple use zones to avoid recreational conflicts and hazards resulting from active motion recreation and passive recreation and possible resulting dangerous collisions between the two, which in some instances can result in death.

¹⁶ See Gundlach and Hayes (1978), Hayes *et al.* (1992), IMO (1993), RPI (1993 & 1996), Hayes (1996), Fisher *et al.* (1997), and NOAA (1997).

biological productivity (Hayes 1996). Shoreline sensitivities vary due to local environmental conditions (Owens and Robilliard 1981). Oil spill sensitivities have been developed for various coastal types (Gregory 1980, Tsouk *et al.* 1986, Tortell 1990, Hanna 1995, NOAA 1997 and Fischer *et al.* 1997).

This section describes the methodology used in determining the CSI for the study area. Five criteria were selected for the development of the index. While they may be indirectly related to each other in their definition, they are used and weighted differently to satisfy the requirements of each definition¹⁷.

The procedure involved performing an initial island-wide visual inspection survey of the various shoreline types and their associated littoral habitats. These have been assigned scores, based on their sensitivity to oil pollution, which conform to the available literature.

5.3.1 Variable Descriptors

Five sensitivity criteria were used to describe the coastal habitats: a) sensitivity to oil pollution; b) cultural and social value; c) economic/recreation value; d) scientific value; and e) other environmental considerations. The descriptors, derived from Kenchington and Hudson (1984) and Brody (1998) have been modified, based on local knowledge and consultation¹⁸.

¹⁷ The definitions are theoretical constructs that are difficult to measure precisely or even determine with scientific certainty but provided some level of rationality for choosing the score values assigned for each variable type.

¹⁸ Local knowledge of the use of and appreciation of the importance of the resources along the coastline were obtained from personal communication with Angela Watson (2001), Gordon Murphy (2001) and Janice Cumberbatch (2002).

(a) Sensitivity to Oil Pollution

The sensitivity of the habitat type to oil pollution is based on the NOAA guidelines (1997) and other authors' coastal sensitivity criteria¹⁹. The following modifications have been made for the current study:

- **Habitat identification**

Submerged habitats identified to a depth of 3m (the immediate nearshore recreational zone) are considered to be most at threat in an oil spill event, as the island has few other natural coastal habitats.

- **Coastal structures**

Shoreline protection and engineering structures have been identified as either exposed or sheltered based on their exposure to incipient wave energy.

(b) Cultural and Social Value

The socio-cultural activity of a coast describes its use. Along the coast, there are several features of special historic, cultural or archaeological significance; therefore, consideration has to be given to their importance, access and availability for human use. This is important, since the greater the access, the greater the public importance of the location and, hence, its higher value. The habitats could also be in areas that are, for example, of traditional importance to fishermen or other cultural uses.

(c) Economic and Recreational value

The economic value of beaches has been well described in the literature (Houston 2002 1996 and 1995, Strong 2000, Clean Beaches Council 2001, and Marlowe 1999). This economic benefit can capture the direct contribution beach tourism makes to national economies, together with indirect tourist related revenues associated with beaches (King 1999, Morgan 2000, Clean Beach Council 2001, Houston 2002). Additionally, such

¹⁹ These are exemplified by Gundlach and Hayes (1979), RPI (1993 & 1996), Hayes (1996) and Abdel Kader *et al.* (1998).

benefits can capture the importance of fisheries; the locations may be used by artisanal fishermen or may be protected to encourage fish recruitment and, thus, contribute to the artisanal fishery resource. The recreational use captures the appreciation by tourists and others (e.g. scenic potential and associated economic benefits resulting from beach enhancement through beach nourishment programmes, multi-use aspects and the issues related to user conflict). Included here is attention to the diversity of activity within the given location and the potential effect the activities can have on the ecosystem.

(d) Scientific Value

The scientific value defines the scientific importance of the habitat or location under consideration. It represents the significance of the coastline for long-term scientific research and education and includes long-term opportunities for establishing monitoring programmes²⁰. Educational aspects recognise the opportunity for the habitat to demonstrate the importance of the ecosystem or coastal area in understanding and appreciating the sustainable use of the area.

(e) Other Environmental Considerations

This category reflects the sensitivity of the system to the effects of litter, pollution from sewage or land runoff and other environmental concerns. It also acknowledges the present and potential threats to the ecosystem from development projects and the issues related to the protection and maintenance of the coastline.

5.3.2 Procedure

5.3.2.1 Pilot Testing of Methodology

The methodology was piloted for each of the coastal habitats (natural and anthropogenic) in the study area, based on aerial photographs, field investigation and available documents.

²⁰ With sustained monitoring it will then be possible to detect changes in environmental conditions and identify possible trends.

5.3.2.1 Applied Procedure

Each sensitivity criteria was assigned a value ranging from one to ten (representing least sensitive to most sensitive, respectively) for their respective habitat type. All criteria scores were based on the importance of the habitat in relation to each criterion, the use of the area and the environmental concerns experienced there.

To develop a protection priority classification against oil spills²¹, each criterion score was assigned a weighting value of one, two, or three. A total score representing the level of protection to be applied to each littoral habitat was then determined for each shoreline type. The larger the total scores, the more sensitive the habitat type.

The scores are ranked in descending order and then the quartile calculation is performed to separate the ranked scores into four sensitivity ratings. These sensitivity ratings representing low (0% –25%), moderate (25% – 50%), high (50% – 75%) or very high (75% –100%) and are assigned a corresponding index value of I to IV, respectively. These index values were then represented on the relevant 1:10,000 map sheet for the coastal locations.

5.3.3 CSI Results - Interpretation of the Barbados Findings

Following the coastal sensitivity methodology, the littoral habitats have been ranked to determine their sensitivity indices (Section 5.3.3.1) and to provide an environmental sensitivity analysis for the coastline (Section 5.3.3.2).

5.3.3.1 Results of Ranking of Littoral Habitat Types used to Determine CSI

The review of bathymetric and topographic maps as well as field investigations identified 10 main coastal types for the study areas intertidal and nearshore locations

²¹ Based on the work of Kenchington & Hudson (1984), these weightings are suitable for the Barbados context.

(extending to the -3m contour). Each habitat has been scored to reflect the level of importance (value) within each criterion (Table 5.7a), and to determine the total protection rating for each habitat and shoreline type (Table 5.7b). Based on the values from the protection rating table, a sensitivity classification scale has been developed (Table 5.8a). The higher the total score, the more the location is in need of protection. The CSI habitat rankings are presented in Table 5.8b.

Table 5.7a Sensitivity Criteria for the Coastal Habitats of the West and South Coasts

Shoreline Types	Sensitivity for Oil Pollution	Cultural and Social Value	Economic/ Recreation Value	Scientific Value	Other Environmental Consideration
Exposed man-made coastal protection structures	1	1	1	1	1
Sheltered man-made coastal protection structures	8	1	2	2	1
Exposed sea cliff	1	2	1	3	2
Sheltered sea cliff	6	3	2	4	2
Sandy beach (fine - medium grain)	4	10	10	7	7
Sheltered sandy beach	5	10	10	7	7
Sheltered tidal flat (coral rubble)	8	6	2	4	5
Sheltered seagrass beds	9	5	7	8	9
Submerged nearshore coral reef (fringe and patch reefs)	7	9	10	10	10
Shallow coral reef community (fringe and patch reefs)	10	8	10	10	10

Table Notes: 1 = least sensitive; 10 = most sensitive

Table 5.7b Weighting Factors (1, 2, 3) of Sensitivity and Total Relative Response for Protection Priority²²

Shoreline Types	Sensitivity for Oil Pollution (3)	Cultural and Social Value (1)	Economic/ Recreation Value (1)	Scientific Value (2)	Other Environmental Considerations (3)	Total Score for Protection Priority
Exposed man-made coastal protection structures	3	1	1	2	3	10
Sheltered man-made coastal protection structures	24	1	2	4	3	34
Exposed sea cliff	3	2	1	6	6	18
Sheltered sea cliff	18	3	2	8	6	37
Sandy beach (fine - medium grain)	12	10	10	14	21	67
Sheltered sandy beach	15	10	10	14	21	70
Sheltered tidal flat (coral rubble)	24	6	2	8	15	55
Sheltered sea grass beds	27	5	7	16	27	82
Submerged nearshore coral reef (fringe and patch reefs)	21	9	10	20	30	90
Shallow coral reef community (fringe and patch reefs)	30	8	10	20	30	98

²² Weightings used are based on similar weightings used by Kenchington and Hudson (1984), as they were considered generic enough for use within the Barbados context.

Table 5.8a Sensitivity Classification Developed for Coastal Habitats of the West and South Coast.

CSI	Sensitivity Rating	Total Score	Habitat Ranked:
I	Low (0 - 25%)	< 34.8	1 to 3
II	Moderate (25 - 50%)	34.8 - 61	4 to 5
III	High (50 - 75%)	61 - 79	6 to 7
IV	Very high (75 - 100%)	>79	8 to 10

Table 5.8b Determination of Environmental Protection Priority and Coastal Sensitivity Index (CSI) Rankings for the West and South Coasts

Shoreline Types	Environmental Protection Priority Score	Habitat Rank	CSI
Shallow coral reef community (fringe and patch reefs)	98	10	IV
Submerged nearshore coral reef (fringe and patch reefs)	90	9	IV
Sheltered seagrass beds	82	8	IV
Sheltered sandy beach	70	7	III
Sandy beach (fine - medium grain)	67	6	III
Sheltered tidal flat (coral rubble)	55	5	II
Sheltered sea cliff	37	4	II
Sheltered man-made coastal protection structures	34	3	I
Exposed sea cliff	18	2	I
Exposed man-made coastal protection structures	10	1	I

Table Notes: Where CSI ranked 10, this requires the most protection, CSI ranked 1 this requires the least protection from oil spills.

Currently, Barbados does not have an oil spill contingency plan and does not identify coastal segments as “sacrificial”. This new approach, prioritising habitat types needing protection, suggests that much of the west coast will require protection; especially as there are fringe reef systems associated with most west coast sheltered sandy beaches. Along the relatively straight south coast, patch reefs predominate - being more submerged than the fringe reefs of the west coast. In this case, emphasis needs to be placed on the protection of the beaches themselves.

The results also demonstrate that the nearshore seagrass and coral reef systems generally require the highest protection, followed by the beaches. In addition, these ecosystems each receive the highest scores in the criteria allocations for sensitivity to oil, scientific value, and other environmental considerations (Table 5.7b), further supporting their protection priority requirements.

As part of any CSI for oil spills, consideration should be given to the inclusion of biological resources and relevant biological information. NOAA (1997), Abdel-Kader *et al.* (1998), Nansingh & Jurawan (1999) and Price *et al.* (2000) describe such procedures. However, the analysis and inclusion of such information was not attempted here due to time constraints.

5.3.3.2 Environmental Sensitivity Analysis (ESA)

The Environmental Sensitivity Analysis (ESA) system, mapping oil spill sensitive coastal environments and information on wildlife resources, has been developed to guide oil spill response co-ordinators in evaluating the probable hazards associated with oil spills and to plan spill control operations effectively (Gundlach *et al.* 1981, cited Abdel-Kader *et al.* 1998). The shoreline sensitivity criteria for oil pollution have been well established in the literature²³, and have been used as part of this research to provide the applied values presented in Table 5.7a. As identified in the literature (RPI 1993, Ritchie 1995, NOAA 1997, Nansingh and Jurawan 1999, Price *et al.* 2000), the shoreline sensitivity criteria are highly dependent on:

- (a) nature of the shoreline and sediment grain sizes;
- (b) intertidal slope;
- (c) wave exposure nature of the shoreline; and
- (d) biological productivity.

The first three criteria have been used within this research. The interpretation of the results and their general implications are considered below.

²³ Refer to NOAA (1997) Environmental Sensitivity index Guidelines Ver. 2.0

(a) Nature of the shoreline and sediment grain sizes

The field observations were consistent with what was reported in the literature²⁴ for the coastal habitats and their associated shoreline description. In some locations, there had been noticeable shoreline changes associated with recent shoreline protection structures, which had not been observed in the aerial photographs of the 1990's. The sand samples collected from each beach location for most of the west and south coast beaches, were classified as fine (0.300 mm) to medium (0.375 mm) sized with very few locations of coarse grain sizes (0.400 – 0.500 mm). The coastal characteristics per shoreline segment in summary include:

1. Coral sand beaches with coastal protection structures in the beach backshore areas; or
2. Structures of property protection in the areas immediately fronting the coastal property (or in some instances in the nearshore area).

The use of these criteria has future application, as the shoreline sediment classifications (solid, rocky, coarse and fine sediments) can be effectively applied to the other coastal types around the island. As indicated by NOAA (1997) and Abdel-Kader *et al.* (1998), the characteristics of the coastal substrate can affect the degree of oil impact²⁵. These effects will also make clean up efforts difficult and expensive since the grain size of the substrate and the sorting range of the grain sizes primarily control the depth of oil penetration.

(b) Intertidal slope

The beach slope measurements of the locations surveyed varied across the three slope types (steep – being greater than 30 degrees, moderate – between 30 – 5 degrees, and gentle or flat - less than 5 degrees). These slopes also indicated whether the beaches had

²⁴ Refer to Cambers (1979), Procter and Redfern (1983), Delcan (1995), Halcrow (1999).

²⁵ While solid substrates/sediments prevent oil penetration, the unconsolidated nature of the sand and/or granule sediments, identified above, provide the potential for the penetration, burial and general retention of oil in the sediment, resulting in the prolonged exposure of susceptible biological organisms

experienced any major storm events within the monitoring periods²⁶. Thus, the shoreline slope provides an important measurement, and its oil retentive capacity in the event of a spill, since it determines the effect on wave reflection and breaking experienced on the shoreline²⁷.

(c) Wave exposure nature of the shoreline

From the developed WEIs, the west coast locations appear predominantly more sheltered, than south coast locations. It would be expected that the sheltered coastlines are more sensitive to oil spills with long retention times causing possible devastating effects on the natural biota.

(d) Biological productivity and sensitivity

This criterion, intended to capture the sensitivity of shoreline biological resources, plays a significant role in the determination of those resources that would be threatened in the event of an oil spill. Due to time constraints, however, this aspect was not pursued, as it was logistically difficult to collect the necessary samples to perform the abundance, diversity, and biomass measurements for the littoral habitats. It should be noted however, that the potential contribution of this could significantly alter the ultimate ranking developed for the coastal habitat types (Table 5.8b).

The following criterion, although not listed in the NOAA (1997) guidelines, has been included because of its significance in a small island context:

(e) Cleaning and reclamation considerations

Abdel-Kader *et al.* (1998) identified this criterion as important. The rationale presented for this was that, by increasing the available opportunities for cleaning and reclamation

²⁶ In such situations, a steep scarp or storm wave berm line would be found on the beach, generated from the high energy scouring that would have occurred on the beach, during the storm episode.

²⁷ The steeper the slope, the more the likelihood of high-energy conditions and abrupt wave run up and wave breaking, the less chance of oil retention. Conversely, the more gentle the slope, the lower the wave energy, and the greater the probability for oil retention.

of the shoreline, its overall sensitivity is reduced (i.e. the type of clean up procedure to be used on an affected area contributes to the determination of its level of sensitivity). This criterion has provided useful information to Barbados. As all of the island's beaches are tourism-revenue earners, their economic importance has to factor significantly into any beach treatment post oil spill. Their status, therefore, has been recognised to be moderately to highly sensitive. Such considerations should be linked to a BAI, whereby the identification of "potential sacrificial" beaches can be considered, for the preservation of the other beaches.

5.3.4 Discussion

This methodology and the associated results have permitted an effective coastal assessment. This has been achieved through shoreline evaluation of potential oil pollution impact, the potential persistence of the pollution, the uniqueness and importance of the ecosystem, and the accessibility and ease of clean up of the selected locations. Additionally, the index can be used to delineate oil sensitive environments, as part of an overall contingency plan, like those successfully applied elsewhere (Table 5.9).

Further applications include the use of the CSI in oil spill simulations using GIS applications. Such approaches can assist in the identification of sensitive habitats at greatest risk; however, they require the wind and current data, in order that trajectory predictions of any simulated oil spill flow can be made (Price *et al.* 2000). This requires the establishment of permanent monitoring stations for wind, wave and current data collection.

5.3.4.1 Comparison of Proposed Oil Spill Index with Existing Oil Spill Indices

This approach to CSI classification to oil pollution has developed a modified version of the Gundlach and Hayes' (1978) and NOAA (1997) 1 – 10 scale (low to high

vulnerability) classification. Table 5.9 compares the index generated in this study with those presented by various authors in the literature.

Table 5.9 Coastal Sensitivity Index Comparison for Coastal Habitat Types used in this and Other Similar Studies²⁸

(Source: Original)

CSI	Gundlach and Hayes (1978) ⁱ	Agard (1983) (cited Nansingh & Jurawan (1999) ⁱⁱ	RPI (1993) ⁱⁱⁱ & NOAA (1997) ^{iv}	Dames and Moore (1997) (cited Price <i>et al.</i> 2000) ^v	Abdel-Kader <i>et al.</i> (1998) ^{vi}	Nansingh & Jurawan (1999) ^{vii}	Price <i>et al.</i> (2000) ^{viii}	This Research Study (Barbados coastline - Original)
1	Exposed rocky headlands and shores	Exposed rocky cliffs	Exposed rocky shores/cliffs and exposed man-made structures	Rocky headlands	Sea cliffs	Eroding wave cut platforms	Man-made structures	<i>Exposed man-made structures</i>

²⁸ Table notes on coastal locations where ESI were applied by authors:

- i. Gundlach and Hayes (1978) application to eastern seaboard of North America and some locations in Spain.
- ii. Agard (1983) (cited Nansingh & Jurawan 1999) application to Trinidad West Indies
- iii. RPI (1993) application to Southern California USA (source: <http://www.epa.gov/glnpo/lakemich/esi>)
- iv. NOAA (1997) application to coastal states of USA
- v. Dames and Moore (1997 cited Price *et al.* 2000) application to Cameroon, Africa
- vi. Abdel-Kader *et al.* (1998) application to Egypt (Ras-Mohammed area), Africa
- vii. Nansingh & Jurawan (1999) application to Trinidad West Indies
- viii. Price *et al.* (2000) application to Cameroon, Africa

Table 5.9 CSI Comparison for Coastal Habitat Types used in this and Other Similar Studies (cont'd)

CSI	Gundlach and Hayes (1978) ⁱ	Agard (1983) (cited Nansingh & Jurawan (1999) ⁱⁱ	RPI (1993) ⁱⁱⁱ & NOAA (1997) ^{iv}	Dames and Moore (1997) (cited Price <i>et al.</i> 2000) ^v	Abdel-Kader <i>et al.</i> (1998) ^{vi}	Nansingh & Jurawan (1999) ^{vii}	Price <i>et al.</i> (2000) ^{viii}	This Study (Barbados coastline - Original)
2	Eroding wave cut platforms	Eroding wave cut platforms	Exposed wave cut platforms ⁱⁱⁱ Man-made structures	Man-made structures	Sheltered sea cliffs	Exposed medium to coarse grained sand beaches	Sandy beaches	<i>Exposed sea cliffs</i>
3	Fine sand beaches	Exposed tidal flats	Fine to medium grained sand beaches ⁱⁱⁱ Eroding scarps in unconsolidated sediments	Sandy beaches	Sheltered rocky beaches	Exposed tidal flats	Mixed sand and gravel beaches	<i>Sheltered manmade structures</i>
4	Coarse grained sand beaches	Sheltered medium to coarse sand beaches	Coarse grain sand to granule beaches ⁱⁱⁱ Sandy beaches	Mixed sand and gravel beaches	Sabkha	Exposed rocky shores	Gravel beaches	<i>Sheltered sea cliffs</i>
5	Exposed compacted tidal flats	Exposed fine grained sand beaches	Mixed sand and gravel beaches	Gravel beaches	Sand beaches	Sheltered fine to medium grained sand beaches	Rocky headlands	<i>Sheltered tidal flats (coral rubble)</i>
6	Mixed sand and gravel beaches	Mixed sand and gravel beaches	Riprap ⁱⁱⁱ Gravel beaches	Stabilised sand dunes	Sheltered sand beaches	Mixed sand and gravel beaches	Stabilised sand dunes	<i>Sandy beach (fine to medium grain)</i>

Table 5.9 CSI Comparison for Coastal Habitat Types used in this and Other Similar Studies (cont'd)

CSI	Gundlach and Hayes (1978) ⁱ	Agard (1983) (cited Nansingh & Jurawan (1999) ⁱⁱ	RPI (1993) ⁱⁱⁱ & NOAA (1997) ^{iv}	Dames and Moore (1997) (cited Price <i>et al.</i> 2000) ^v	Abdel-Kader <i>et al.</i> (1998) ^{vi}	Nansingh & Jurawan (1999) ^{vii}	Price <i>et al.</i> (2000) ^{viii}	This Study (Barbados coastline - Original)
7	Gravel beaches	Sheltered rocky coasts	Exposed tidal flats	Vegetation shrubs and trees	Sheltered sand beaches	Sheltered tidal flats	Vegetation shrubs and trees	<i>Sheltered sandy beaches</i>
8	Sheltered rocky coasts	Sheltered tidal flats	Sheltered rocky shores ⁱⁱⁱ Sheltered riprap and man-made structures	Tourism recreation beaches	Intertidal beach flats	Sheltered rocky shores	Tourism recreation beaches	<i>Sheltered seagrass beds</i>
9	Sheltered tidal flats	Coral – algal reefs	Sheltered tidal flats ⁱⁱⁱ Sheltered sand mud flats	Sheltered tidal flats/mud flats	Sheltered mangrove swamps	Coral reefs	Sheltered tidal flats mud flats	<i>Submerged nearshore coral reefs (fringe & patch)</i>
10	Salt marshes and mangrove swamps	Mangrove coasts and wetlands	Marsh, mangrove swamps, Wetlands	Estuary wetland Wildlife conservation areas	Shallow coral reefs	Mangrove swamps	Estuary mangrove wetland wildlife conservation areas	<i>Shallow coral reefs (fringe & patch)</i>

In the oil spill indices, proposed by RPI (1993) and NOAA (1997), exposed rocky shores and exposed man-made structures are given an index value of one. In this research, exposed man-made structures are also assigned this value as, from field observations, they are generally of low biological diversity. In providing a protective role to shoreline property or infrastructure, these are frequently exposed to high-energy wave environments and seldom have sediment accumulation associated with them. An index value of two is given to exposed sea cliffs here, as they have value in both social/cultural and scientific applications (Table 5.7b).

In this study, sheltered man-made structures, sheltered sea cliffs and sheltered tidal flats have CSI values of three, four and five, respectively. These values do not directly relate to the other indices. However, their low scores, despite being sheltered, arise from the low scores assigned to their social and economic values. In the case of the sheltered man-made structures, while the economic value associated with the sheltered shore protection structure is high (in terms of the value of the property being protected), the economic value and associated recreational potential is low. This is not to say that in other small island contexts, the economic and recreational value of such structures could not be very high. One reason for the low value is that the structures are often installed by private property owners and, therefore, are inaccessible to the public.

CSI rankings six and seven correspond to sandy and sheltered sandy beaches respectively. This classification corresponds favourably with CSI values developed by Price *et al.* (2000), and Abdel-Kader *et al.* (1998). It also reflects the level of importance that can be placed on the beaches in terms of their need for protection, after fringe reefs and seagrass bed ecosystems (CSI values eight to ten respectively).

Coral reefs and other nearshore systems are not given an index value on the ESI²⁹, developed by NOAA, because they are “considered subtidal complex systems and should be ranked separately” (NOAA 1997). However, notwithstanding this, it is generally acknowledged that coral reefs are highly sensitive ecosystems - especially to oil spills and other environmental stresses. The contribution of these ecosystems to

²⁹ ESI term used by NOAA (1997) describes the coastal habitats and is equivalent in terminology here to CSI.

beach stability, and their other related recreational, socio-cultural and scientific values, result in their high protection priority status.

5.3.5 Evaluation of the Technique

5.3.5.1 Variables used in the Barbados experience and their application in a wider context

The variables used in this study are appropriate for the determination of the coastal sensitivity scale for Barbados. Making use of current background literature on the determination of CSI values has been an effective means of ensuring standardised evaluation. The shoreline descriptors (nature of the shoreline, sediment grain size at the location, intertidal shoreline slope, and the shoreline wave exposure) are easily measured on-site. The items in Table 5.10 have been identified in order to perform the CSI analysis.

The results which achieve research objectives 1, 3, and 4 (Fig. 5.4a - d and Fig.5.5a – f), demonstrate that the variables selected can suitably define the CSI for coastal segments and suggest that the application of these within a wider generic small island context can be easily achieved. The predominant factor in the establishment of such scales relies on the ability to acquire the inexpensive scientifically accurate equipment. The methodology requires not only objective interpretation of the physical characteristics, found on the coastline, and determining their relationship to existing environmental guidelines relating to shoreline oil spill sensitivity, but also a knowledge of the socio-economic considerations of the “actual use value/ importance”. While this may be considered subjective, it can be verified by consultation with the appropriate agencies (both governmental and non-governmental), familiar with the areas. In so doing, a “realistic level of value/importance” can be applied. Despite the author’s knowledge of the coastline, such consultation was performed here³⁰.

³⁰ Agencies consulted included: (1) Government - Fisheries Division (Ministry of Agriculture), National Conservation Commission and Environmental Engineering Division (Ministry of Environment), Ministry of Tourism; (2) Private sector - Barbados Hotel and Tourism Association, Alys Consultants, SEMS consultants, Bellairs Research Institute (McGill University), University of the West Indies, Weston

Table 5.10 Main Equipment Items Used in the Determination of the Coastal Sensitivity Index

Equipment Item	Accuracy
100m open reel fibreglass tape	+/- 2mm
*Automatic level	+/-1.5mm
*Total station	+/- 0.2mm
Fibreglass tripod	
6 sand sieve set	According to the mesh size required
Sand sieve shaker	
Ohaus Scout 2 portable electronic balance	200g x 0.01g
Brunton ClinoMaster	+/- 90 ⁰
Scale master Classic	+/- 25 % (resolution 1mm)
Stereoscope (small mirror)	

Table notes: The items used in the determination of the beach slope (e.g. telescoping rod) and wave exposure indexes has already been identified in Section 5.2.5.1, and are therefore, not repeated here.

5.3.5.2 Data Availability

The data used in this component of the research have demonstrated their applicability and ease of availability. Past work focused primarily on the generic description of the shoreline and related this to the shoreline oil spill sensitivity characterisation, as identified by NOAA (1997) (Anthony Headley, *pers. comm.* 2001). The results have fulfilled research objectives 1 and 3 (Section 1.3.2).

5.3.5.3 Economic Costs

The economic cost of this technique includes the actual cost of equipment, transportation to site and man-hours for collecting the data (Table 5.11). Although the equipment costs approximately GB £7,374 (US \$12,036)³¹ this cost could have been reduced with a less costly levelling instrument. The recommended purchase of a Pulse Total Station costing GB £6,162 (US \$9,990) is based on its level of accuracy and ability to retain large series of data points for future data processing. An alternate instrument, a SAL 24 automatic level costing GB £263 (US \$429), would have meant the manual recording of data on field sheets, only allowing one record of the field data. The first instrument allowed for the ability to recheck data obtained from the field in case of transcription or transposition errors in field recording. The purchase of the field equipment plus the alternate meter is GB £1516 (US \$2475). The saving to be made if the alternate meter was purchased is GB£ 5860 (US \$9561).

Transportation costs have been previously considered in Section 5.2.5.3. Man-hour costs and the training cost reported here are based on the rates characteristically paid to the CZMU field staff, previously quoted at Section 5.2.5.3.

5.3.5.4 Logistics and Administration

The greatest difficulty associated with this technique is the determination of appropriate measurement locations. For Barbados, the beach profile locations predetermined the selection of monitoring sites for this index. The rationale for the location selection is previously described in Section 5.2.5.4. However, the sites chosen allow for returning in the future, to perform the biological assessments to describe the full environmental sensitivity of these locations.

In island situations where these sites do not exist, it is necessary to either establish bench-mark locations for the long-term monitoring or use GPS systems to allow for a

³¹Based on equipment prices (excluding shipping and handling) quoted in Forestry Suppliers Inc catalogue 2003/2003. Currency converter used <http://www.xe.com/ucc/convert.cgi> on 29/5/03.

return to the same position. The associated requirements for consideration in such situations are discussed in Section 5.2.5.4.

Table 5.11 Cost Associated with the Determination of CSI (indicated as Man Week Costs)

Activity Determination of Coastal Sensitivity Index	Number of staff (weekly rate) & staff time (days) required to determine Coastal Sensitivity Index	Cost GB£ (US\$)
Field equipment cost*		1254 (2046)
(1) Automatic level		263 (429)
(2) Total station		6121 (9990)
Transportation cost **		15 (23)
Man week cost (data acquisition)**	2 staff (week rate £121 (US\$ 199) per man); 5 days	1210 (1990)
Man week cost (data processing)**	1 staff (week rate £ 168 (US\$ 277)); 10 days	336 (554)
Training cost **	1 staff (week rate £455 (US\$ 750)); 5 days	455 (750)
Subtotal***		1254 (2046)
(1) Automatic level		1516 (2475)
(2) Total station		7374 (12,036)

Table Notes:

*Refer to Appendix 5 Table III for equipment listing. However, the cost with (1) the automatic level, and (2) the Total Station instrument are reflected separately to show their effect on total costs.

** Man week costs are salary rates based on current Government monthly salary scales for the positions of Chainman (for field data collection) and Clerical Officer (for data processing), as these are the level of staffing required to perform these works. These costs are not included since they have been quoted previously and are weekly rates.

*** Costs not included here would be the purchase of direct capital costs (e.g. computer hardware (including colour printer and incidentals for computer usage) and associated software (Microsoft Office Suit and SPSS).

5.3.6 Recommendations

In addition to the foregoing, it would be instructive to include relevant biological information associated with each coastal habitat. This might be achieved through the determination of foreshore sensitivity criteria as identified by Abdel-Kader *et al.* (1998) or Nansingh and Jurawan (1999). Emphasis would have to focus on flora and fauna as the NOAA Guidelines (1997) suggest. However, the broad classifications, while applicable to Barbados, do not hold true everywhere³². This recommendation provides for future work in identifying other habitats in need of protection, as only the immediate nearshore habitats are considered here.

Human use features encountered along the coastline can also be mapped and included. In this thesis the human use component was captured as part of the five criteria in the sensitivity criteria table, described previously (Table 5.7a). However, the main human use features of the study area include those that can be impacted by an oil spill or could provide access for clean up operations³³. Although these have not been separately accounted for, these features could be incorporated into the CZMU GIS³⁴.

If this approach were extended to encompass the entire island, new categories would need to be developed to address the contrasting shoreline geomorphology and nearshore habitats along the east and southeast coasts (Figure 2.3). Such modifications could result in a new ranking for the island's habitats.

³² Barbados has no relevant coastal bird population so emphasis in this area would have to focus on the migratory bird species, known to frequent the island annually, as part of their migration route. There are no mammals that use the nearshore habitats. Additional consideration should be given to including information, where appropriate on shellfish and marine reptiles. Regarding the fish species associated with the coastal habitats it can be envisaged that the reef fish found at each location would constitute the major fish species to be found.

³³ Refer to NOAA (1997) for a listing of the types of features to be considered for inclusion.

³⁴ For each respective human use feature (where appropriate) the name of a contact person, and contact number should be provided.

5.3.6.1 Modification of the Technique

The CSI technique has successfully demonstrated its usefulness as a rapid approach to determining the environmental sensitivity of the shoreline to oil spill pollution. Modifications should include the ability to identify total lengths of coastal types susceptible to oil pollution. This could be calculated from the percentage of the shoreline affected and its vulnerability score. These could then be presented as an applied oil spill vulnerability index for the shoreline type. Additionally, it could be used to determine the percentage of the shoreline, classified according to the relative vulnerability index levels and, hence, their classification according to their susceptibility to oil spills.

5.4. DETERMINATION OF THE BEACH AESTHETIC INDEX

As tourism attractions, beaches are prone to degradation by waste disposal, over engineering, urbanisation and over development (IRF 1996, Zann 1997, James 2000). Beach evaluation and rating systems have been widely used to indicate beach quality to beach users. Such evaluations have focused mainly on beach litter and marine debris (Somerville *et al.* 2003, Derraik 2002, Marine Conservation Society 2002, Balance *et al.* 2000, Nelson *et al.* 2000, Ribic 1998, Jones 1995, and CMC 1990). In such surveys, site selection is subjective, although a representative sample of the coastline can be surveyed supporting general conclusions (Rees and Pond 1995, Tudor and Williams 2001).

As part of this research, an assessment is made of the beach aesthetic quality within the study areas. The foundation for the beach-rating checklist was derived from the ideas set out by Leopold (1969) in the assessment of river scenery (Williams *et al.* 2000). The beach checklist is based on the work of Williams *et al.* (1993 and 2000), in which 50 factors were divided into three subgroups – physical, biological and human use. This checklist has been extensively applied to the coast of the United Kingdom, USA and several European coastlines (Williams *et al.* 1993, Williams & Morgan 1995,

Leatherman 1997, Williams *et al.* 2000) and the classification categories associated with it are suitable for generic use in this research. The application of this technique to Barbados has not been reported in the literature and, thus, makes a research contribution. The aesthetics rating also contributes to the ESI process (Fig 4.1), providing an interdisciplinary approach using semi-quantitative techniques to maintain and improve the beach as a recreational resource. This section describes the methodology used in determining the Beach Aesthetic Index (BAI).

5.4.1 Checklist Adaptations to Suit the Barbados Coast

The variables used in the checklist have been modified from other beach evaluation systems to reflect the Barbados beach and nearshore conditions. The main modifications are presented in Table 5.12a, while Table 5.12b provides the BAI checklist for Barbados. New inclusions to the checklist are presented in italics.

Table 5.12a Modified Variables in BAI Checklist (Source: Original)

Variable Modification/Inclusion	Rationale for Modification
Beach material	This has been modified to present a description of beach material types experienced on the island's coastline. It is suited for island wide application and also has wider application for other small island characteristics.
Beach width	This is modified to provide specific size ranges, applicable to Barbados. This is necessary given the island's beach characteristics. Similar ranges may be applicable to other islands of the Caribbean, but suitable modification of this to reflect the location, where the checklist is applied, would have to be developed.
Sand softness based on the compaction level	Different beach sediment grain sizes provide a different aesthetic feel underfoot due to its compaction characteristics. This has implications for the aesthetic quality of the area. Modification achieved by actual measurement of compaction levels for different beach types and applying these values to the variable ranking. A three-scale system has been applied as these represent the compaction characteristics of the island's coast. In other SIDS applications such characteristics would need to be modified to reflect the sediment types experienced.
Use of specific temperature ranges for air and nearshore waters	This modification provides specific temperature ranges allowing for a better determination of one of the aesthetic features of the beach. Such features are measured <i>in situ</i> and help to build a reliable database on the environmental variables of the beach area, not considered previously for the island.
Beach condition of variation based on the work of Gornitz <i>et al.</i> (1994)	Erosion or accretion rates can be rapid or gradual depending on the natural and anthropogenic factors' action on the coastline. The use of these ranges provides an approximation of the level of beach stability, based on historical beach profile records. In the absence of such records, the ranges provide a guide in the provisional determination of beach trends.
Shoreline slope using the characteristics proposed by RPI (1993) in the determination of the steepness of the intertidal zone between maximum high and low tides.	Provision of an actual value of slope allows for accurate determination of the variable. Such slope information is obtained as part of the beach monitoring work, that occurs during field investigation. With routine monitoring, this allows for an average slope range to be developed for the beach.

Table 5.12a Modified Variables in BAI Checklist (cont'd)

Variable Modification/Inclusion	Rationale for Modification
Size of breaking waves based on the work of Gornitz <i>et al.</i> (1994) and Thieler and Hammar-Klose (1999).	The ranges applied are based on <i>in situ</i> measurements used in the development of the WEI. The ranges in the literature set a variable range that capture the wave regimes, experienced under natural and storm events on the island.
Colour of sand description	Sand colour provides an indication of its source material. This modification provides descriptions, specific for the island. These descriptions are capable of modification to represent the environment where the checklist is being applied.
Bathing area bottom conditions	This is modified to provide specific category types for each allocated score, as it can influence the choice of selected areas for recreational use.
Intensity of beach use.	This is modified to provide specific category types for each allocated score, as it can influence the choice of selected areas for recreational use.
Building/urbanisation.	This is modified to provide specific category types for each allocated score. From an aesthetic view, over-developed beaches are of lower aesthetic value than natural or coastlines with limited development.
Presence of shoreline protection structures	This is modified to provide specific category types for each allocated score, as it can influence the available recreational beach area and the aesthetic quality of the beaches.
Commercial/random extraction	Although not applicable to the current study area it does have implications for other sections of coast, and in SIDS, where dredged sediment material or beach sand is used for the construction industry.

Table 5.12a Modified Variables in BAI Checklist (cont'd)

Variable Modification/Inclusion	Rationale for Modification
<i>Visitor/tourist pressure</i>	<i>This is a new inclusion, as it can influence the choice of selected areas for recreational use by local residents.</i>
<i>Beach size</i>	<i>This is a new inclusion and reflects the characteristic beach sizes, measured along the island's coastline. The scores applied are based on the importance of size in relation to carrying capacity of the beaches where the larger the beach, the greater the carrying capacity.</i>
<i>Presence of watercourse discharge points across the beach</i>	<i>This is a new inclusion to the checklist, reflecting the number of natural egress points on the beach and potential contributory nearshore effects, experienced at the location.</i>
<i>Type of watercourse discharge point</i>	<i>This is a new inclusion to the checklist and reflects their potential effects on beach stability.</i>
<i>Discharge of drains and culverts across the beach</i>	<i>This is a new inclusion to checklist to reflect the effect of such man-made egress points on the beach and its potential stability.</i>

Table 5.12b Beach Rating Checklist for Barbados³⁵ (Source: Original)

Variables	Categories				
	1	2	3	4	5
Physical Factors					
1. Beach width at low tide	<input type="checkbox"/> narrow, <10 m	<input type="checkbox"/> 10 - 20 m	<input type="checkbox"/> 20 - 25 m	<input type="checkbox"/> 25 - 30 m	<input type="checkbox"/> > 30 m, wide
2. Beach material	<input type="checkbox"/> beachrock/ cobble	<input type="checkbox"/> sand/ cobble	<input type="checkbox"/> coarse sand	<input type="checkbox"/> medium sand	<input type="checkbox"/> fine sand
3. Beach condition of variation (after Gornitz <i>et al.</i> 1994)	<input type="checkbox"/> erosional (< -2.0 m)	<input type="checkbox"/> (-1.1 - -2.0)	<input type="checkbox"/> stable (- 1.0 - +1.0)	<input type="checkbox"/> (1.0 - 2.0)	<input type="checkbox"/> depositional (> 2.1)
4. Beach slope (after RPI 1993)	<input type="checkbox"/> steep (slope > 30°)		<input type="checkbox"/> moderate (slope < 30° - >5°)		<input type="checkbox"/> gentle (slope <5°)
5. Sand softness	<input type="checkbox"/> >300 psi, hard		<input type="checkbox"/> 200 - 300 psi, medium		<input type="checkbox"/> <200 psi, soft
6. Water temperature	<input type="checkbox"/> cold/hot (<60° F) /(>90° F)	<input type="checkbox"/> 60 - 65° F	<input type="checkbox"/> 65 - 70° F	<input type="checkbox"/> 70 - 75° F	<input type="checkbox"/> warm (75° - 80° F)
7. Air temperature (midday)	<input type="checkbox"/> (<60° F) & (>100° F)	<input type="checkbox"/> 60 - 70° F	<input type="checkbox"/> 70 - 75° F	<input type="checkbox"/> 75 - 80° F	<input type="checkbox"/> 80° - 90° F
8. Number of sunny days	<input type="checkbox"/> few		<input type="checkbox"/> some		<input type="checkbox"/> many
9. Amount of rain	<input type="checkbox"/> large		<input type="checkbox"/> moderate		<input type="checkbox"/> little
10. Wind speeds	<input type="checkbox"/> high		<input type="checkbox"/> medium		<input type="checkbox"/> low
11. Size of breaking waves (adapted Gornitz <i>et al.</i> 1994)	<input type="checkbox"/> high/ dangerous (>6.0 m)	<input type="checkbox"/> (5 - 5.9m)	<input type="checkbox"/> moderate (3 - 4.9m)	<input type="checkbox"/> (1 - 2.9m)	<input type="checkbox"/> low/safe (<0.9m)

³⁵ The checklist adapted from Williams *et al.* (2000) with appropriate modifications applicable to the Barbados coast.

Table 5.12b Beach Rating Checklist for Barbados (cont'd)

Variables	Categories				
	1	2	3	4	5
12. Number of waves/width of breaker zone	<input type="checkbox"/> 5+	<input type="checkbox"/> 5 - 4	<input type="checkbox"/> 4 - 3	<input type="checkbox"/> 3- 1	<input type="checkbox"/> none
13. Nearshore slope (beach slope underwater)	<input type="checkbox"/> steeply sloping bottom		<input type="checkbox"/> moderately sloping bottom		<input type="checkbox"/> gently sloping bottom
14. Longshore current	<input type="checkbox"/> strong		<input type="checkbox"/> moderate		<input type="checkbox"/> weak
15. Rip currents present	<input type="checkbox"/> often		<input type="checkbox"/> occasional		<input type="checkbox"/> never
16. Colour of Sand	<input type="checkbox"/> black/grey	<input type="checkbox"/> brown	<input type="checkbox"/> light tan	<input type="checkbox"/> white	<input type="checkbox"/> white/pink
17. Tidal range	<input type="checkbox"/> large (> 4 metres)	<input type="checkbox"/> 3 - 4 m	<input type="checkbox"/> 2 - 3 m	<input type="checkbox"/> 1-2 m	<input type="checkbox"/> small (< 1 metre)
18. Beach shape	<input type="checkbox"/> straight/headland		<input type="checkbox"/> pocket		<input type="checkbox"/> curved/bay
19. Beach size	<input type="checkbox"/> very small <100m	<input type="checkbox"/> small 100 - 150m	<input type="checkbox"/> medium 150 -300m	<input type="checkbox"/> large 300 -500	<input type="checkbox"/> giant >500m
20. Bathing area bottom conditions	<input type="checkbox"/> rocky, cobbles, limited sand	<input type="checkbox"/> coral rubble & sand	<input type="checkbox"/> sand & coral rubble	<input type="checkbox"/> coarse sand	<input type="checkbox"/> fine sand
Total					

Table 5.12b Beach Rating Checklist for Barbados (cont'd)

Variables	Categories				
	1	2	3	4	5
Biological factors					
21. Turbidity	<input type="checkbox"/> turbid 0 – 30cm		<input type="checkbox"/> cloudy 45 – 60cm		<input type="checkbox"/> clear/ aquablue 75 - 90cm
22. Water colour	<input type="checkbox"/> grey/brown / green		<input type="checkbox"/> pale green/pale blue		<input type="checkbox"/> clear/ aquablue
23. Floating/ suspended human material (sewerage, scum)	<input type="checkbox"/> plentiful		<input type="checkbox"/> some		<input type="checkbox"/> none
24. Algae in water- amount (filamentous blue green algae)	<input type="checkbox"/> present				<input type="checkbox"/> absent
25. Red tide	<input type="checkbox"/> common		<input type="checkbox"/> occasional		<input type="checkbox"/> none
26. Smell (e.g. seaweed, rotting fish)	<input type="checkbox"/> bad odour		<input type="checkbox"/> occasional bad odour		<input type="checkbox"/> fresh salty air
27. Wildlife(e.g., shore birds)	<input type="checkbox"/> none		<input type="checkbox"/> some		<input type="checkbox"/> plentiful
28. Pests (flies, biting flies, mosquitoes)	<input type="checkbox"/> common		<input type="checkbox"/> occasional		<input type="checkbox"/> no problem/ seldom
29. Presence of runoff culvert & drains on/across the beach/	<input type="checkbox"/> >5 several		<input type="checkbox"/> 1-5 some		<input type="checkbox"/> none
30. Presence of seaweed/jellyfish on the beach	<input type="checkbox"/> many/ much		<input type="checkbox"/> some		<input type="checkbox"/> none

Table 5.12b Beach Rating Checklist for Barbados (cont'd)

Variables	Categories				
	1	2	3	4	5
31. Presence of watercourse discharge points across the beach	<input type="checkbox"/> >5 several		<input type="checkbox"/> 1-5 some		<input type="checkbox"/> none
32. Type of watercourse discharge points across the beach	<input type="checkbox"/> not applicable		<input type="checkbox"/> continuous		<input type="checkbox"/> seasonal/ periodic
Total					
Human Use and Impacts					
33. Trash and litter (paper, plastics, nets, ropes, planks, glass, rubble)	<input type="checkbox"/> common		<input type="checkbox"/> occasional		<input type="checkbox"/> rare
34. Oil and tar balls	<input type="checkbox"/> common		<input type="checkbox"/> occasional		<input type="checkbox"/> none
35. Views and vistas – beach view to sea	<input type="checkbox"/> obstructed				<input type="checkbox"/> un- obstructed
36. Views and vistas – along shoreline	<input type="checkbox"/> confined				<input type="checkbox"/> unconfined
37. Buildings/urbanism	<input type="checkbox"/> over developed	<input type="checkbox"/> expanding development	<input type="checkbox"/> developed	<input type="checkbox"/> limited development	<input type="checkbox"/> pristine/ wild
38. Public access	<input type="checkbox"/> no access		<input type="checkbox"/> limited/ pedestrian		<input type="checkbox"/> good/ vehicular
39. Misfits (e.g. refinery, cement plant, power station; offshore dumping)	<input type="checkbox"/> present		<input type="checkbox"/>		<input type="checkbox"/> none/ absent
40. Vegetation (nearby) – trees, shrubs, pioneer plants	<input type="checkbox"/> none		<input type="checkbox"/> some		<input type="checkbox"/> many

Table 5.12b Beach Rating Checklist for Barbados (cont'd)

Variables	Categories				
	1	2	3	4	5
41. Well-kept grounds/promenades or natural environment	<input type="checkbox"/> no		<input type="checkbox"/> occasional		<input type="checkbox"/> yes
42. Amenities (showers, chairs, bars, etc.)	<input type="checkbox"/> absent				<input type="checkbox"/> present
43. Lifeguards	<input type="checkbox"/> none				<input type="checkbox"/> present
44. Domestic animals (e.g., dogs, horses)	<input type="checkbox"/> many		<input type="checkbox"/> few		<input type="checkbox"/> none
45. Vehicular Noise (cars, nearby highways, trains)	<input type="checkbox"/> much	<input type="checkbox"/> some	<input type="checkbox"/> occasional	<input type="checkbox"/> little	<input type="checkbox"/> none
46. Recreational Noise (e.g., crowds, radios)	<input type="checkbox"/> much	<input type="checkbox"/> some	<input type="checkbox"/> occasional	<input type="checkbox"/> little	<input type="checkbox"/> none
47. Presence of shoreline protection structures along beach length - seawalls, riprap, revetments, gabions, groynes, breakwaters concrete/rubble	<input type="checkbox"/> entire length (90% -100%)	<input type="checkbox"/> majority of length (70% - 90%)	<input type="checkbox"/> frequently along length (30% - 70%)	<input type="checkbox"/> Some of length (0% - 30 %)	<input type="checkbox"/> none
48. Intensity of beach use	<input type="checkbox"/> over crowded	<input type="checkbox"/> crowded	<input type="checkbox"/> clustered crowding	<input type="checkbox"/> ample open space	<input type="checkbox"/> unoccupied
49. Off-road vehicles	<input type="checkbox"/> common		<input type="checkbox"/> occasional		<input type="checkbox"/> none
50. Public safety (e.g. pickpockets, harassment, crime)	<input type="checkbox"/> common		<input type="checkbox"/> occasional		<input type="checkbox"/> rare

Table 5.12b Beach Rating Checklist for Barbados (cont'd)

Variables	Categories				
	1	2	3	4	5
51. Competition for free use of beach (e.g. fishermen, boaters, water skiers)	<input type="checkbox"/> many		<input type="checkbox"/> some		<input type="checkbox"/> few
52. Visitor/Tourist Pressure	<input type="checkbox"/> high		<input type="checkbox"/> moderate		<input type="checkbox"/> low
53. Commercial/random extraction on beach or in back beach/ dune area	<input type="checkbox"/> much		<input type="checkbox"/> some		<input type="checkbox"/> none
Total					

5.4.2 Procedure

The principle objective of this rating survey was to provide an objective appraisal of the recreational beaches. The beach rating assessments were performed twice per month, between the hours of 11:00 and 14:30, during expected maximum beach occupancy. Emphasis focused on the peak winter tourist season (December 2001 – April 2002) when the beaches are typically at their narrowest and tourism is at its highest.

The checklist (Table 5.12b) is separated into three categories – physical (20 variables), biological (12 variables) and human use factors (21 variables). The variables have been assessed to allow for a qualitative, and where appropriate quantitative comparison of beaches. On each visit, all variables were attributed a score from 1 (poor) to 5 (excellent), based on examination of the beach. A five-scale range was used for most variables. However, for some, a three-scale scoring system had to be used (1 - poor, 3 - moderate/average, 5 - good/excellent) and for others, a 2-scale range (1 – absent, 5 – present or vice versa depending on the variable being considered).

The totals for each sub-grouping were calculated and a grand total obtained³⁶. The subtotals were then converted into percentages and recorded. Histograms of factor contributions were developed for each beach. The percentages were then totalled, and an average taken to derive the overall beach rating score.

These scores were ranked in descending order and quartile calculations were performed providing BAI values of I to IV (poor to very good) respectively. These values were then represented on relevant 1:10,000 map sheets.

5.4.3 BAI Results - Interpretation of the Barbados Findings

The checklist has been used to evaluate 60 beaches (20 - South coast and 40 - West coast) using *in situ* field equipment and subjective assessments. In addition, current literature and discussions with relevant coastal experts has provided background information on the general coastal trends.

5.4.3.1 Determination of BAI

Given the contrasting nature of the two coastlines (Appendix 4), individual beach ratings were performed to both, allowing for ranking of the beaches and identification of best beaches. Overall percentage scores for the West coast beaches range from 89.4% (Sandy Lane) to 70.7% (Fort Denmark). For the South coast beaches the overall percentage scores range from 87.7% (Enterprise) to 72.9 % (Kentucky). The results show that the beaches fall within a very narrow percentage range (70% to 90%). The need to delineate beach quality types efficiently is considered an important determinant for assigning the BAI.

³⁶ The maximum total scores for each sub-grouping are: physical factors – 100, biological factors – 60, human use factors – 105; the grand total score for the checklist is 265 which was equated to a total of 100 percent.

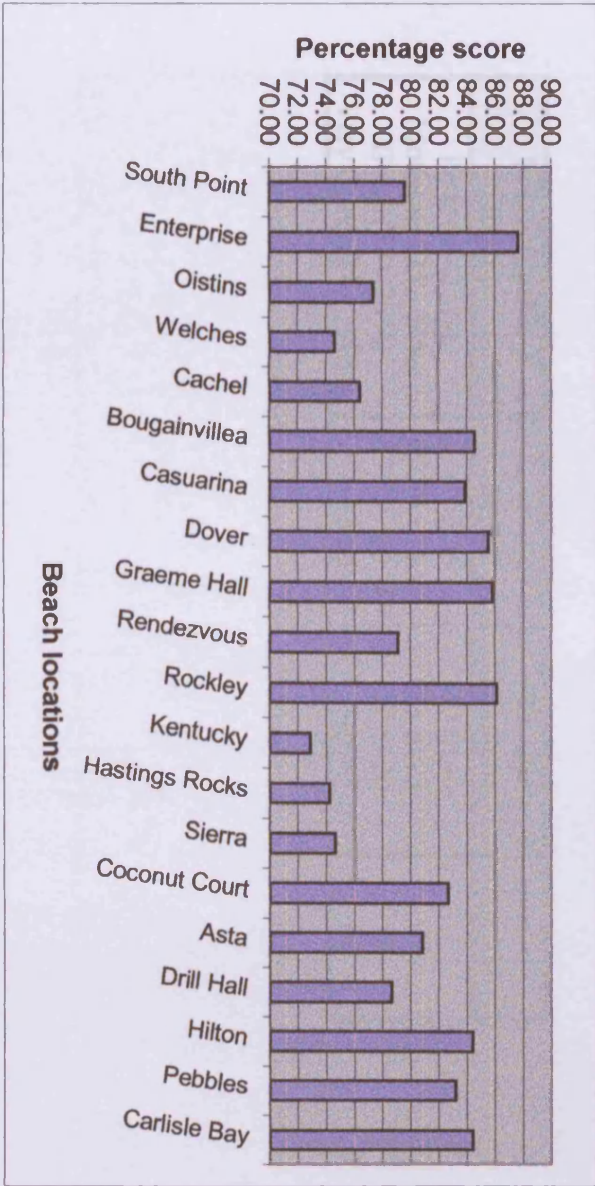


Fig 5.1b South Coast Beaches: Overall Beach Aesthetics Percentage Scores

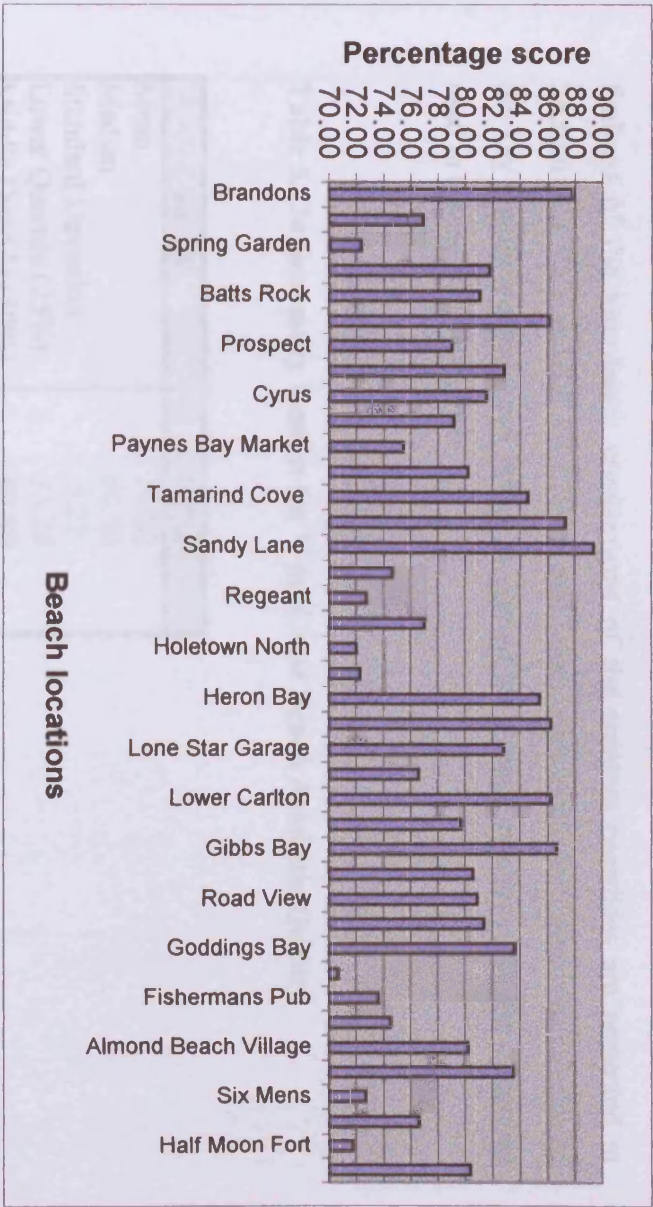


Fig 5.1a West Coast Beaches: Overall Beach Aesthetics Percentage Scores

The beach rating values are presented in Tables 5.13a – c for West coast, and Tables 5.14a – c for the South coast. Given the overall scope of the checklist, only the main findings of the inter-beach comparisons of the separate coastlines are presented in Sections 5.4.3.1.1 and 5.4.3.1.2 (West and South coast locations respectively). A few of the key results are discussed below as part of the general evaluation of the categories used in the index development.

Table 5.13a Summary Results for West Coast Beach Aesthetic Quality

Result	Value
Mean	78.82
Median	80.30
Standard Deviation	5.22
Lower Quartile (25%)	75.26
Middle Quartile (50%)	80.30
Upper Quartile (75%)	83.55

Table 5.13b: Beach Aesthetic Quality Ratings

Beach Quality Rating	Score	Beaches Ranked:	BAI
Poor (0 - 25%)	< 75.26	30 to 40	I
Moderate (25 - 50%)	80.30 - 75.26	21 to 29	II
Good (50 - 75%)	83.55 - 80.30	11 to 20	III
Very Good (75 - 100%)	> 83.55	1 to 10	IV

Table 5.13c: West Coast BAI and Rankings

West Coast Beach Name	Overall Score	Rank	BAI
Sandy Lane	89.37	1	IV
Brandons	87.86	2	IV
Coach House	87.30	3	IV
Gibbs Bay	86.70	4	IV
Royal Pavilion	86.25	5	IV
Lower Carlton	86.24	6	IV
Batts Rock Bay	86.08	7	IV
Heron Bay	85.43	8	IV
Tamarind Cove	84.59	9	IV
Goddings Bay	83.63	10	IV
Port St Charles	83.52	11	III
Lone Star Garage	82.84	12	III
Fitts Village	82.81	13	III
Paradise	81.76	14	III
Cyrus	81.51	15	III
Cholera Bay	81.38	16	III
Batts Rock	81.08	17	III
Road View	80.87	18	III
Mullins Bay	80.59	19	III
Fryers Well Bay	80.35	20	III
Buccaneer Bay	80.24	21	II
Almond Beach Village	80.22	22	II
Greensleeves	79.71	23	II
Crystal Cove	79.16	24	II
Prospect	79.00	25	II
Holetown South	77.02	26	II
Brighton	76.90	27	II
Shermans	76.63	28	II
Weston	76.60	29	II
Paynes Bay Market	75.44	30	I
Almond Beach Club	74.71	31	I
Sand Street	74.52	32	I
Fisherman's Pub	73.65	33	I
Regent	72.76	34	I
Six Men's	72.75	35	I
Spring Garden	72.35	36	I
Folkstone	72.32	37	I
Holetown North	72.05	38	I
Half Moon Fort	71.75	39	I
Fort Denmark	70.68	40	I

Table 5.14a: Summary Results for South Coast Beach Aesthetic Quality

Result	Value
Mean	80.83
Median	81.75
Standard Deviation	4.61
Lower Quartile (25%)	77.12
Middle Quartile (50%)	81.75
Upper Quartile (75%)	84.48

Table 5.14b: South Coast Beach Aesthetic Quality Ratings

Beach Quality Rating	Score	Beaches Ranked:	BAI
Poor (0 - 25%)	< 77.12	16 to 20	I
Moderate (25 - 50%)	77.12 - 81.75	11 to 15	II
Good (50 - 75%)	81.75 - 84.48	6 to 10	III
Very Good (75 - 100%)	> 84.48	1 to 5	IV

Table 5.14c: South Coast BAI and Rankings

South Coast Beach Name	Overall Score	Rank	BAI
Enterprise	87.68	1	IV
Rockley	86.10	2	IV
Graeme Hall	85.81	3	IV
Dover	85.54	4	IV
Bougainvilla	84.59	5	IV
Hilton	84.44	6	III
Carlisle Bay	84.41	7	III
Casuarina	83.87	8	III
Pebbles	83.19	9	III
Coconut Court	82.65	10	III
Asta	80.84	11	II
South Point	79.59	12	II
Rendezvous	79.11	13	II
Drill Hall	78.63	14	II
Oistins	77.35	15	II
Cachel	76.41	16	I
Sierra	74.65	17	I
Welches	74.60	18	I
Hastings Rocks	74.25	19	I
Kentucky	72.87	20	I

5.4.3.1.1 West Coast Beaches

5.4.3.1.1a Comparison of the Physical Factors.

The physical factor variables describe the general physical characteristics of the beach, nearshore and the general ambient conditions, at each location. The results identify 10 beaches having the best physical features (Table 5.15a, Fig.5.2a, and Appendix 5, Table 5) with the percentage scores for the physical factors ranging from 90% (Sandy Lane) to 66% (Folkestone) (Appendix 5, Table 5).

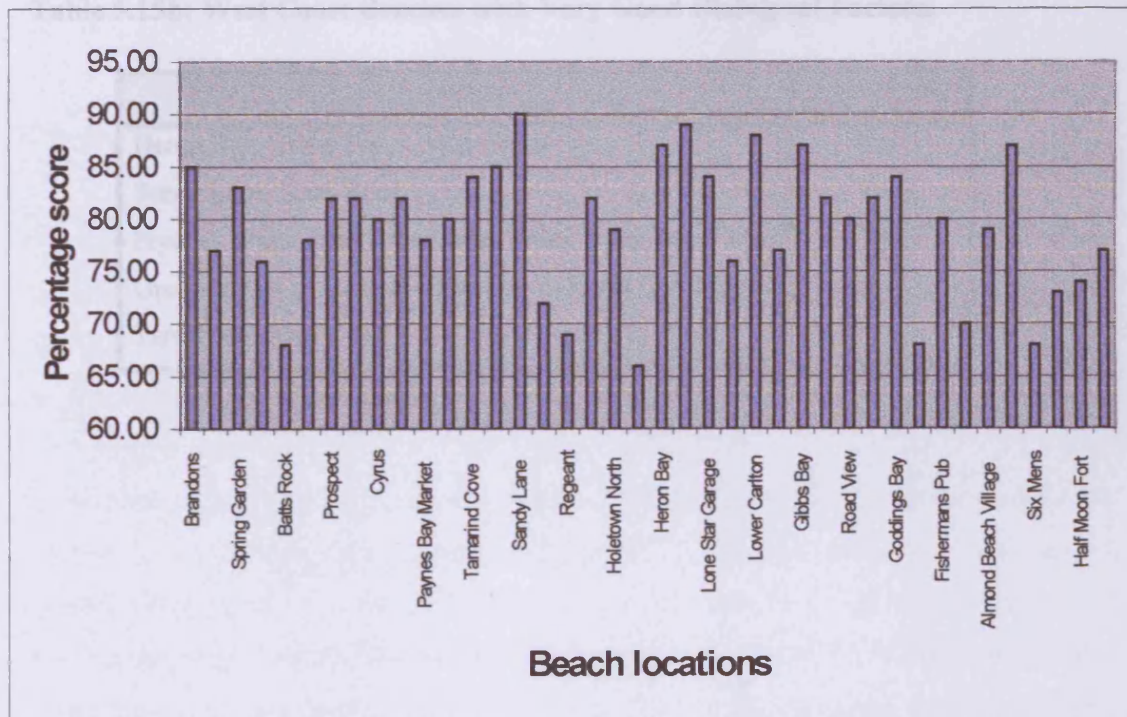
The majority of beaches (65%) have an average beach width of 10 - 20m. The remaining beaches (32.5%) have an average width of less than 10 m while only one beach has a width ranging between 20 - 25 m. Generally, beach material of medium grain size (60%). Most beach conditions are stable (60%), (i.e. neither eroding nor accreting), while 12.5% are slightly accreting and 10% are slightly eroding.

All West coast beaches are coral sand beaches, with sand colour varying between light tan to white/pink (light tan 45%, white 35% and white/pink 20%). One of the main field observations is that light tan sandy beaches are found predominantly at beach locations that have natural watercourse discharge points associated with them. This colour could be a result of the combined effects of the sand generated from reef bio-erosion as well as the input of sediments from the watercourses. White sand occurs in bayed locations where sediment is derived from the bio-erosion of nearshore and offshore reefs. Bathing bottom conditions for the west coast beaches are mainly coarse to medium sand (55%) or fine sand (25%). Only 20% possess rubble bottom conditions. These locations correspond to areas with very narrow beaches, or in some cases, shorelines that possess only shoreline protection structures.

Table 5.15a: West Coast Beaches with Very Good Physical Factors.

Location	Percentage
Sandy Lane	90
Royal Pavilion	89
Lower Carlton	88
Gibbs Bay, Heron Bay	87
Coach House, Brandons	85
Tamarind Cove, Lone Star, Goddings Bay	84

Fig 5.2a Percentage Scores for Physical Factors on the West Coast Beaches



5.4.3.1.1b Comparison of Biological Factors.

The biological factor variables describe the perceived biological quality of the beach and nearshore environments, focusing on issues related to perceived nearshore water quality, the abundance of fauna, and the presence of discharge points (natural and manmade). These effluents can contribute to the degradation of the nearshore environment³⁷. These results identify 12 beaches having the best biological features (Table 5.14b, Fig. 5.2b, and Appendix 5, Table 5) with percentage scores for the biological factors ranging between 88% (Coach House, Heron Bay, and Gibbs Bay) and 73.3% (Holetown North and Fisherman's Pub). For most West coast beaches (87.5%), the nearshore water is clear to aqua blue while the remainder (12.5%) is cloudy³⁸.

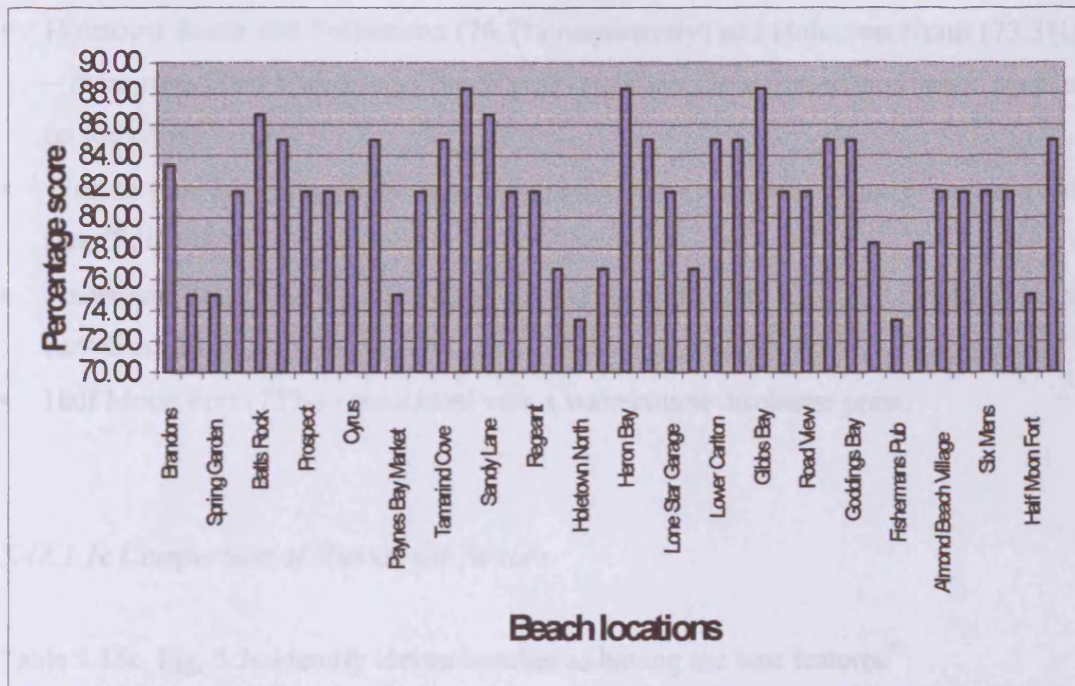
Table 5.15b: West Coast Beaches with Very Good Biological Factors.

Location	Percentage
Heron Bay, Gibbs Bay, Coach House	88.3
Sandy Lane, Batts Rock	86.7
Fryers Well Bay, Goddings Bay, Cholera Bay, Greensleeves, Lower Carlton, Royal Pavillion, Tamarind Cove	85

³⁷ See Pendleton (2001), and Freeman (1995).

³⁸ The description of cloudy refers to the level of visibility through the water column. It was measured using a secchi disk to a depth of 90cm measured at 15cm intervals, to determine when the disk became occluded.

Fig 5.2b Percentage Scores For Biological Factors on the West Coast Beaches



Of note also for each West coast location is the absence of wildlife (e.g. shore birds). The assessment of the wildlife variable resulted in an overall lowering of the total scores for each beach. This occurred since it was only a two-scale measurement that could be applied – either absent or present.

Indicators of pollution (e.g. red tides, algae in the water and floating suspended human material) in the water column were consistently absent, indicating good recreational coastal water quality from an aesthetic view. This observation would have to be verified by bacteriological examination of the nearshore water. It should be noted, however, that despite these general trends, the beaches with the poorest biological factors are those associated with major runoff points as exemplified by the following locations:

- Brighton and Spring Garden (75%) - an industrialised coast with a thermal effluent discharge point in the area;

- Paynes Bay Market (75%) – a water course discharge and road runoff discharge point;
- Holetown South and Folkestone (76.7% respectively) and Holetown North (73.3%) – areas associated with two of the largest catchment areas and natural water courses on the island;
- Weston (76.7%) - associated with a natural water course discharge point and road runoff discharge;
- Fisherman Pub (73.3%) - associated with a water course discharge point and road runoff discharge;
- Half Moon Fort (75%) - associated with a watercourse discharge point.

5.43.1.1c Comparison of Human use factors.

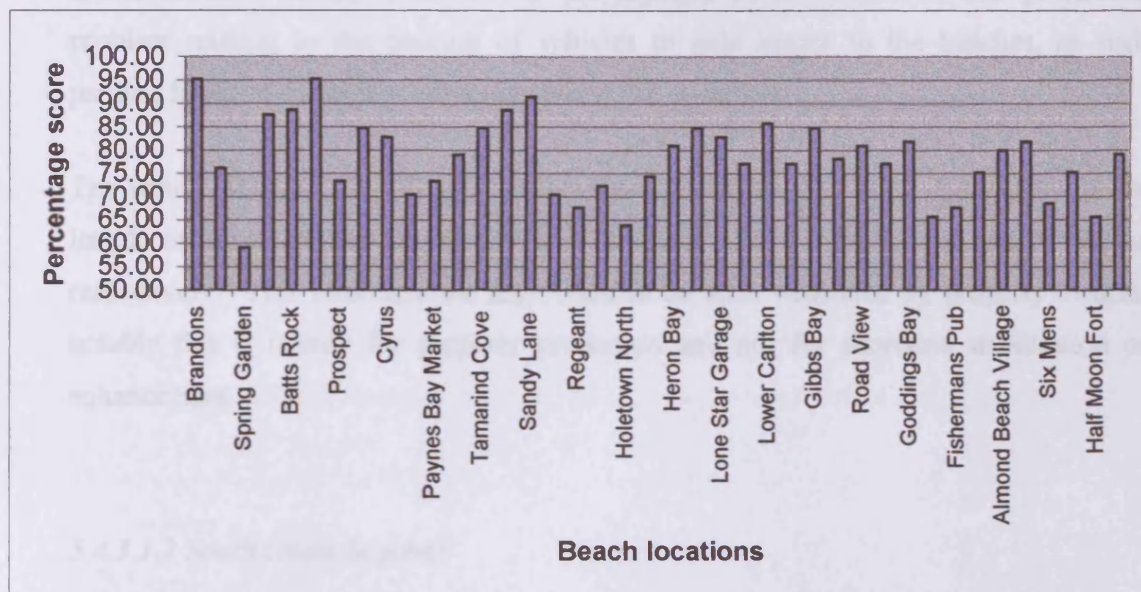
Table 5.15c, Fig. 5.2c identify eleven beaches as having the best features³⁹:

Table 5.15c: West Coast Beaches with Very Good Human Use Factors

Location	Percentage
Brandons, Batts Rock Bay	95.24
Sandy Lane	91.43
Batts Rock, Coach House	88.57
Paradise	87.62
Lower Carlton	85.71
Fitts Village, Tamarind Cove, Royal Pavilion, Gibbs Bay	84.76

³⁹ Refer to Appendix 5 Table 5

Fig.5.2c Percentage Scores for Human Use Factors on the West Coast Beaches



The human use variables⁴⁰ describe the various man-made impacts experienced on the beach and in the nearshore. The percentage scores for human use factors range between 95.24% (Brandons Beach and Batts Rock Bay) and 59.05% (Spring Garden Beach).

At most West coast beaches (77.5%) litter is rare. Given the high tourism use, there is high beach maintenance, ensuring that beaches are kept clean (Keith Neblett, Deputy General Manager NCC *pers. comm.* 2001).

The majority of the beaches (60%) are developed, with the remainder divided into: - limited development (25%) and expanding in development (15%). Most coastal access is either limited pedestrian (72.5%) or good vehicular access (25%). Only one location has no formal or informal access (Greensleeves). While it is important to note that all the beaches have some measure of access, not all the access points are formal (i.e. sign posted or access points, provided by the government). Many informal accesses are tracks either between properties or across currently vacant lots. In the latter, these are

⁴⁰ These include pollution, shoreline developments and urbanisation, access, beach amenities for beach users, noise, public safety and commercial extraction of the beach material.

under high risk of loss when the property owners develop land parcels. While this is the case, many of the island's West coast beaches are continuous and can be reached by lateral access (walking from one to the adjacent other). However, this presents a problem relating to the parking of vehicles to gain access to the beaches, as such parking facilities are highly infrequent along this coastline.

The results show 32.5% of the beaches have shoreline structures, along their entire length or some of the length (30% - 70% and 0% - 30% of the beach lengths respectively). This illustrates the high reliance on such structures by property owners, notably this is mainly for property protection and not for shoreline stabilisation or enhancement.

5.4.3.1.2 South Coast Beaches

5.4.3.1.2a Comparison of Physical Factors.

The results of this comparison identify five beaches with the best physical features. (Table 5.16a, Fig.5.3a, Appendix 5 Table5)

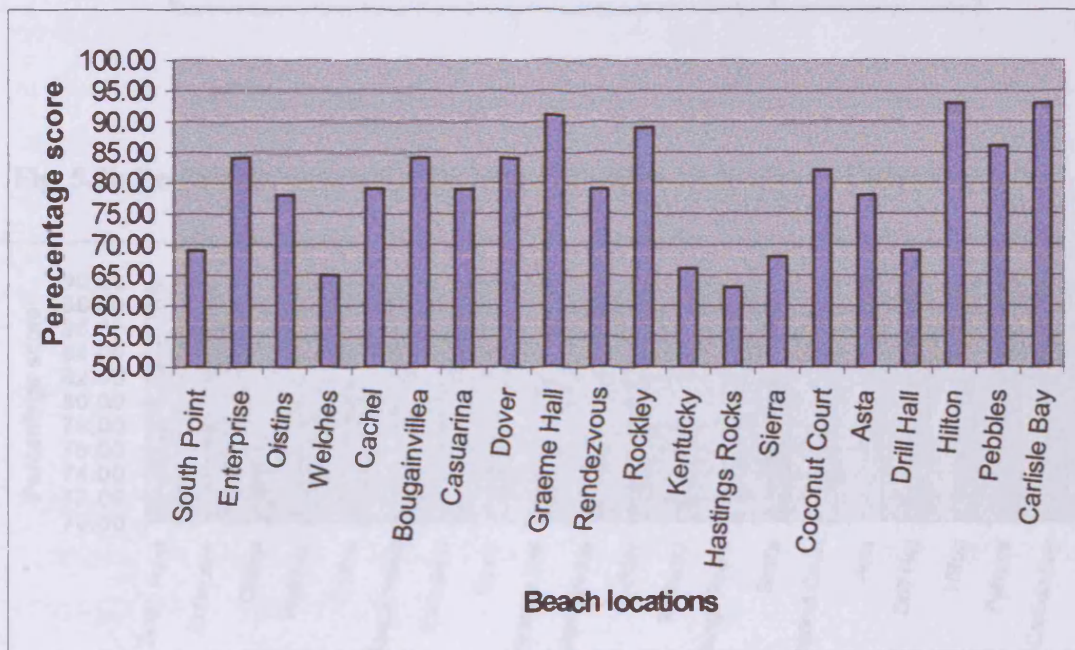
The percentage scores range from 93% (Hilton Beach) to 63% (Hastings Rocks). In general, the majority of the South coast beaches (50%) have average beach widths of 10 - 20m, followed by beach widths of less than 10m (30%). Most beaches (70%) comprise medium to fine sand, while 20% comprise beach rock or cobble material.

In assessing general beach stability, 40% of the beaches are stable, 45% are stable to accretionary and 15% are stable to erosional. This coastline can, therefore, be considered to be largely accretional.

Table 5.16a: South Coast Beaches with the Very Good Physical Features.

Location	Percentage
Hilton, Carlisle Bay	93
Graeme Hall	91
Rockley	89
Pebbles	86

Fig. 5.3a Percentage Scores for Physical Factors on the South Coast Beaches



Most south coast beach sands are white to pink in colour (55%), with the remainder being light tan. The majority of the nearshore areas (45%) consist of coarse to medium sand, while 20% comprise rocky or cobble substrate. From review of current (2000) aerial photographs, the coral rubble locations constitute a continuous coastline. This makes for limited recreational use of the coastal area and a poor aesthetic quality for many associated beach areas.

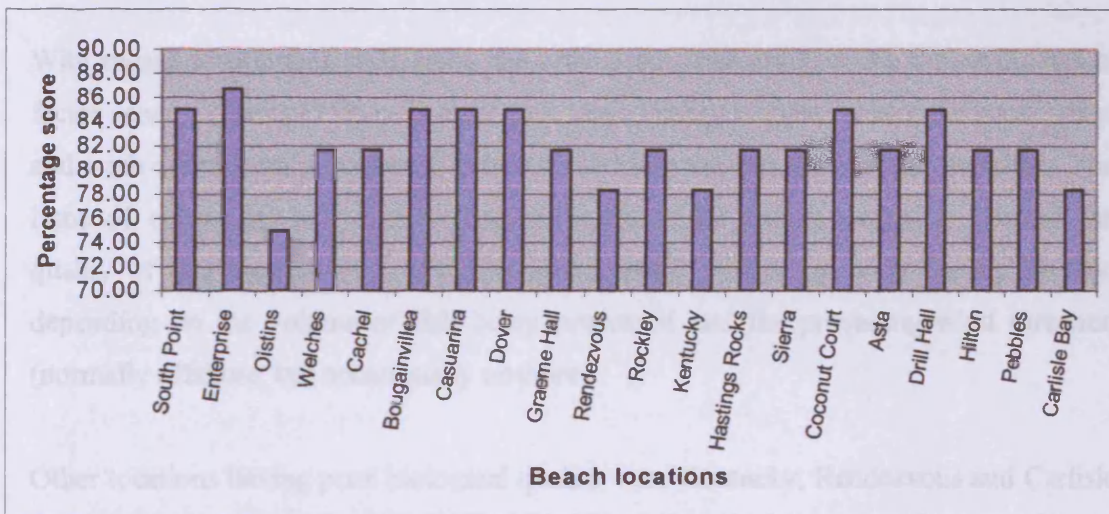
5.4.3.1.2b Comparison of biological factors.

Under this analysis, seven beaches have been identified as having the best features. (Table 5.16b, Fig. 5.3b and Appendix 5 Table 5).

Table 5.16b: South Coast Beaches with Very Good Biological Features

Location	Percentage
Enterprise	86.67
South Point, Bougainvillea, Drill Hall, Casuarina, Dover, Coconut Court	85

Fig. 5.3b Percentage Scores for Biological Factors on the South Coast Beaches



The percentage scores for the biological features range from 86.67% (Enterprise Beach) to 75% (Oistins Beach). The results also show that for all of the South coast beaches, the nearshore water is clear to aqua blue.

There was a similar absence of wildlife at these beaches, as observed on West coast. With the absence of a value for this variable, this led to a lowering of the overall biological scores for the beaches. It might be considered more appropriate in the future to provide an absence value with a zero; this would have no effect on the overall beach score.

Generally, not more than five runoff culverts and drains are found per beach length. Most beaches (60%) have one to five culverts along their shores with only one beach (representing 5% of the beaches) had more than five culverts along its length. The remaining beaches did not have any runoff culverts.

In contrast to the West coast, there are no natural watercourse discharge locations at any of the South coast beaches, except for the Graeme Hall Swamp Outlet at Sandy Beach in Worthing. This is a canalised outlet controlled by a sluice gate and, is routinely breached mechanically, primarily to control floodwater levels in the Graeme Hall Swamp and associated low-lying areas, in proximity to the swamp.

With regard to pollution indicators, the only beach location with the lowest biological factor score - Oistins (75%) - is close to a large fishing complex where the waste water and wash down from processed fish is disposed into the sea, close to the shoreline. The issue of occasional bad odours, originating from the fishing complex, affected the quality of this location (e.g. raw fish blood smell), which can vary during the day, depending on the volume of fish being processed and the prevailing wind direction (normally offshore, but occasionally onshore).

Other locations having poor biological quality were Kentucky, Rendezvous and Carlisle Bay (78.33% each). Each of these locations had low scores, arising from the presence of culverts and drains along their coastal lengths. This issue is even more apparent when looking at Carlisle Bay, one of the better South coast beaches. However, the presence of more than five culverts and drains, along its length, makes the site value fall markedly. This demonstrates the influence of such features on beach aesthetic quality.

5.4.3.1.2c Comparison of Human Use factors

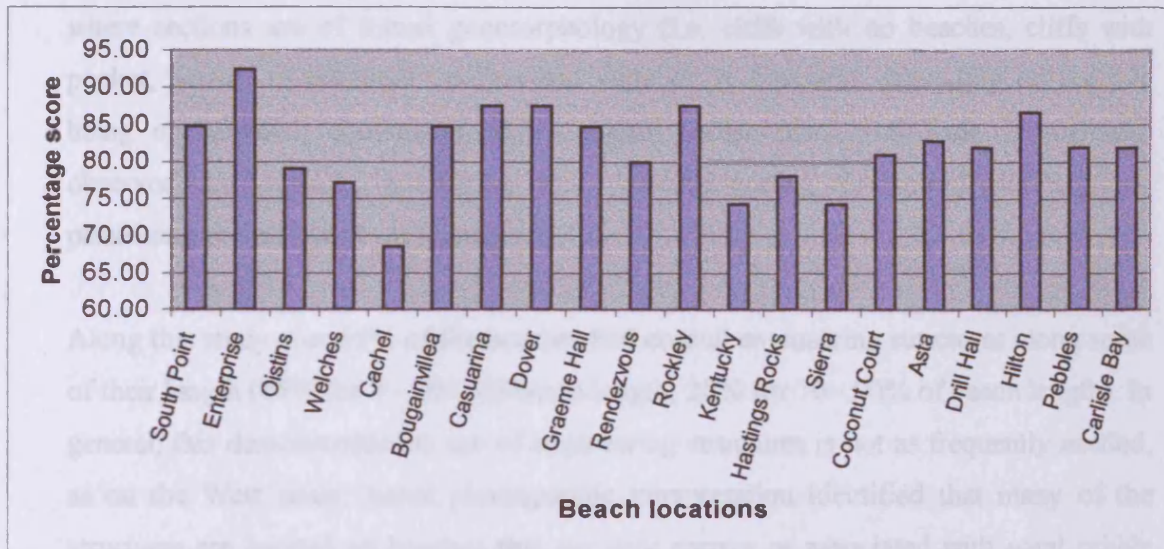
These comparative results identified eight beaches as having the best human use features. (Table 5.16c, Fig. 5.3c and Appendix 5 Table II). The percentage scores for the human use factors ranged from 92.38% (Enterprise Beach) to 68.57% (Cachel Beach).

Most South coast beaches (85%) had no litter. The remainder (Oistins, Kentucky and Drill Hall) had occasional litter. Oistins has a high degree of recreational traffic at night, as there is a “fish fry” each evening, where the fish market vendors prepare traditional fish dinners for the public. This activity is highly patronised, with much litter and garbage generated nightly. The Kentucky site is associated with a KFC franchise and has waterfront-dining facilities. In some instances patrons do not tidy away garbage, thus contributing to the litter. The employees of KFC do, however, clean the dining area frequently to alleviate this problem. The last site, Drill Hall, is also a highly used recreational area especially for picnics. While public garbage bins are provided, inconsiderate users frequently leave their garbage on picnic benches where such waste is often carried away by birds and dogs.

Table 5.16c: South Coast Beaches with Very Good Human Use Features

Location	Percentage
Enterprise	92.38
Rockley, Casuarina, Dover	87.62
Hilton	86.67
South Point, Bougainvillea, Graeme Hall	84.74

Fig. 5.3c Percentage Scores for Human Use Factors on the South Coast Beaches



All other sites mainly coincide with tourism premises or residential accommodation. As with the West coast beaches these are kept clean by a regular beach maintenance programme undertaken by the NCC, and in some instances by individual tourism establishments (Keith Neblett, *pers. comm.* 2001). This approach helps safeguard general beach quality.

The results also indicate that most of the coastline (75%) is developed, 20% has limited development and only 5% is pristine/wild. At most beaches, sea views are unobstructed, although, views along the shoreline are confined at Oistins, Cachel and Sierra (15% of the locations). This human use factor is highly subjective in its determination⁴¹.

Most beach access (60%) along the South coast is pedestrian. Of the remainder, 35% has good vehicular accesses and 5% no access at all. Like the West coast beaches, the access to South coast beaches is informal. The formal pedestrian accesses have the same

⁴¹ On-site, this factor is interpreted by taking lateral views along the beach. Where such views are prevented by engineering structures or properties projecting further forward than their adjacent neighbours, the view along the shore is considered obstructed. Such a situation results in the view therefore being confined to only the immediate beach sector, where the survey as being performed.

problems as the West coast beaches, with no available parking for each access point. Most South coast beaches can be accessed laterally from adjacent beaches. However, where sections are of mixed geomorphology (i.e. cliffs with no beaches, cliffs with pocket, narrow to intertidal beaches and wide sandy beaches), depending on the tide being experienced, continuous lateral coastal access can be difficult. It was also observed that locations, possessing good vehicular access, correspond with locations possessing recreational beach amenities.

Along this study area 65% of the beaches had coastal engineering structures along some of their length (45% for 0 - 30% of beach length; 20% for 70 - 90% of beach length). In general, this demonstrates the use of engineering structures is not as frequently needed, as on the West coast. Aerial photographic interpretation identified that many of the structures are located on beaches that are very narrow or associated with coral rubble locations.

Generally, there was very little competition for free beach use. Most beaches surveyed (85%) had ample open space or were unoccupied at the time of the surveys. The only locations with clustered crowding were found at Cachel, Rockley and Pebbles, popular sites for the public and tourists alike.

5.4.4 Discussion

The individual beach results are presented for each location in Appendix 5. Due to time constraints it was not possible to provide an individual critique of each beach surveyed; however, it does provide for future research.

Some of the original variables were retained to investigate their effect on the rating index, allowing the variable list to be general enough to be applied to other potential islands. This is exemplified by the inclusion of the wildlife variable, which is limited, when considered against other Caribbean islands. The main reason for this is the high level of coastal development experienced and the commensurate loss of natural wildlife habitat. However, at some remote locations, wildlife (e.g. some migratory bird species)

does seasonally frequent coastal areas. This includes marine turtles, which return annually to nest on beaches around the island (Horrocks 1992). As the variable is to reflect application for the whole island, it was, therefore, retained.

The use of this simple rapid beach appraisal method has never been applied to Barbados and provides an innovative approach for the identification of the best beaches on the island for potential use within the tourism industry. The procedure has demonstrated that it is practical to measure general beach variables (describing the physical, biological, and human use impacts), to develop a BAI for a particular beach environment. Despite being general and prone to subjective assessment, the results demonstrate the ease with which the beaches surveyed can be ranked and rated. The data could have undergone further statistical analyses through inter-beach comparisons that allow for more beach specific informed discussion of the results. Such approaches, demonstrated in the literature (e.g. Williams *et al.* 1992 and 2000, Leatherman 1997), should be considered in future beach-rating assessments, as these would provide valuable information for the State of the Coast Report, as identified by Halcrow (1999)⁴².

5.4.5 Evaluation of the Technique

5.4.5.1 Variables Used in the Barbados Experience and their Application in a Wider Context

The results suggest that the BAI is highly sensitive to the structure of the checklist, scaling system and data processing procedure. The checklist used by Leatherman (1997) to classify American beaches applied all parameters with equal weightings. This implies that some physical beach parameters (e.g. beach slope and longshore current) are of equal importance as human use parameters (e.g. buildings/development and amenities). This is clearly not the case as has been demonstrated by Williams *et al.* (2003) along

⁴² Refer to the Barbados Coastal Zone Management Plan (1999). This is an annually report that provides an analysis of the current issues affecting the coast, beach change trends and potential policy issues that should be considered for enhanced beach and coastal management.

Mediterranean coasts. As indicated with an initial piloting of a weighted checklist in this research, it demonstrated no significant effects on the results, as several of the beaches were highly similar in their characteristics. This is similar to the findings on Maltese beaches where the weighted checklist was applied (Micallef *pers. comm.* 2003). In some of these beach locations, the weightings resulted in large differences, and in others there were minor differences (Micallef *pers. comm.* 2003). As a result it was, therefore, decided that no weightings would be used in the developed checklist.

As the index has been prepared for Barbados, it may be suitably transferred to other SIDS. The important component of the procedure is the identification of the suitable variables for BAI determination. For this research, suitable modifications to some variables have to be made (Table 5.12a). For application to other islands, a key list of cues is needed to see which variables should/can be modified, and what would be the best approach to do this. This would have to be determined on a site-specific basis.

The other checklist modification was the removal of the safety record variable, which indicated the number of drowning deaths at a particular beach. This was removed since drownings are very infrequent. However, it was difficult to determine an appropriate time scale i.e. annually, bi-annually, or over a five-year period. Originally a three scale score of frequent (1), occasional (3), and none (5) was considered; however when it came to applying this, such as difficult to determine. It has to be accepted that all the beaches have an inherent danger associated with them, hence, there is need for due care and vigilance when visiting them. This consideration has a strong association therefore, with the developed wave exposure and beach safety indices (Section 5.2).

Another variable removed was “floatables in water” as this was considered not applicable to the general coastline. Furthermore, the descriptions associated with this variable included garbage and toilet paper, indicating some level of sewerage disposal and storm water discharge. While there is storm water discharge from natural watercourses, there is seldom discharge of floatable garbage into the nearshore⁴³.

⁴³ Occasional floatables are normally in the vicinity of reef areas offshore where, the coastal cruisers and catamaran patrons have thrown garbage overboard. At the time of surveying, such floatables were not observed in the nearshore.

However, given the varying levels of development in other small islands there will be a need to retain this variable. Within a broader context this variable may also have application on coastal sectors that have high levels of marine debris, which can make its way onshore.

Another factor removed was the “presence of oil and tar balls”. This was removed, as there is no visual observation of such impacts on any beaches in the study area. However, it does have application for other beaches on the East coast, where low level oil pollution is a persistent problem (Cambers 1979, Brewster 1990). When applied to the rest of the island, this parameter will need to be included, with modification to reduce its negative impact on the BAI rankings.

The results have focused on the key variables of significance in trend determination found along the coastal segments, and their contribution to the overall beach ranking. At some locations, where variables received a score that indicated little or no activity, they were not discussed as it was felt to be self evident for the variable being considered. This is exemplified with the variable relating to off road vehicles. The narrowness of the beaches and the high recreational use of the beach areas prevent this activity from occurring. However, there are few places along the South coast where off road vehicles are used for recreational driving (John Nicholls, Manager, Folkstone Marine Park, NCC *pers. comm.* 2001) a practice, which is currently prohibited. It is known⁴⁴ that there are other locations on the East coast where off road driving regularly occurs on the beaches and sand dune areas, having a significantly destructive impact on their beach habitats. In an expanded shoreline BAI ranking, this variable would have to be retained.

5.4.5.2 Available Data

In most instances, the field data are primary in source, and easily collected. In only a few instances was there a need to refer to secondary data sources (e.g. beach erosion/

⁴⁴ Information provided by the NCC, CZMU, Bellairs Research Institute of McGill University and University of the West Indies.

accretion trends, rip current presence). As this technique relies primarily on observation and quantitative measurements, it is more appropriate to focus future data collection on improving the level of accuracy in determining the acceptable range of levels on some variables.

Table 5.17 provides a list of equipment items that can be purchased to improve the sensitivity and scientific validity of the variables measured. Increased equipment accuracy will result in improved assessment ranges for some variables.

Table 5.17 Equipment Items used to Increase the Accuracy of the Variables Measured

Equipment Item	Accuracy
OptiLogic Laser Hypsometer 100LH (to measure height of objects)	+/- 1ft resolution; +/- 2ft accuracy
OptiLogic range finder 300XL (to measure distance to objects)	+/- 3ft accuracy
Hondex Hand held Digital depth sounder with built in transducer (to measure depth offshore for sediment sampling)	Maximum depth 260' (79m); +/- 1% accuracy
Salinity, conductivity, temperature and dissolved oxygen meter (to measure multiple variables simultaneously)	+/- 2% of full scale for each variable
Soil Compaction meter (to measure sand softness)	Range 0 – 18 ‘‘ (0 – 45 cm) depth; accuracy +/- 0.5’’ depth; +/- 15 PSI (1.25 cm; +/- 103kPa)
Portable turbidity meter	+/- 2% of Nephelometric Turbidity Units (NTU) or 0.2 NTU (whichever is greater); Range 0 – 1000 NTU
Digital sound level meter (to measure recreational beach and other related noises)	Range 40 dB to 130 dB; accuracy +/- 2 dB at 94dB
Green Programme Estuary Monitoring Kit (to test 3 water samples for Coliform bacteria and 7 other variables)	No information on accuracy available

5.4.5.3 Economic Cost

The economic cost associated with this is presented in Tables 5.18a and b. The focus on equipment relates to reliability and accuracy at minimal cost. The equipment purchased for this aspect of the research cost an approximate total of GB £2152 (US \$3574)⁴⁵.

This cost could have been reduced if a manual soil compaction tester had been identified. The recommended purchase of a digital compaction tester GB £1054 (US \$1675) is based on its level of accuracy and ability to retain large series of data points to be downloaded into a computer for future data processing. The alternate manual instrument (cost of GB £129 (US \$215)) could have been recommended, however, it would have meant the manual recording of data with the same implications as discussed in Section 5.3.5.3. The purchase of the field equipment plus the alternate meter is GB £1273 (US \$2114). The saving to be made if the alternate meter was purchased is GB £879 (US \$1460). Hence, the equipment cost, required for the determination of the beach amenity index ranges from GB £215 to £1675.

Transportation, man-hour and the training costs have been previously considered in Sections 5.3.5.3 and are therefore not repeated here.

⁴⁵Based on equipment prices (excluding shipping and handling) quoted in Forestry Suppliers Inc. catalogue 2003/2003. Currency converter used <http://www.xe.com/ucc/convert.cgi>.

Table 5.18a Main Equipment Cost Associated with BAI Determination (indicated as man week costs)

<p align="center"><u>Activity</u> Determination of BAI</p>	<p align="center">Cost GB£ (US\$)</p>
<p>Field equipment cost*</p>	<p align="right">1254 (2046)</p>
<ul style="list-style-type: none"> • OptiLogic Laser Hypsometer (to measure height of objects) 	<p align="right">428 (679)</p>
<ul style="list-style-type: none"> • OptiLogic range finder ^{&}(to measure distance to objects) 	<p align="right">173 (275)</p>
<ul style="list-style-type: none"> • Hand held Digital depth sounder^{&} (to measure depth offshore for sediment sampling 	<p align="right">106 (169)</p>
<ul style="list-style-type: none"> • Salinity, conductivity, temperature and dissolved oxygen meter^{&} (to measure multiple variables simultaneously) 	<p align="right">918 (1455)</p>
<ul style="list-style-type: none"> • Soil Compaction meter^{&1} (to measure sand softness) 	<p align="right">1054 (1675)</p>
<ul style="list-style-type: none"> • Soil Compaction meter² (to measure sand softness) 	<p align="right">129 (215)</p>
<ul style="list-style-type: none"> • Portable turbidity meter 	<p align="right">674 (1069)</p>
<ul style="list-style-type: none"> • Digital sound level meter (to measure recreational beach and other related noises 	<p align="right">50 (79)</p>
<ul style="list-style-type: none"> • Green Programme Estuary Monitoring Kit[#] (to test 3 water samples for Coliform bacteria and 7 other variables) 	<p align="right">22 (35) – reoccurring cost given small sample number</p>

Table Notes on optional equipment considered:

Soil Compaction meter¹ – The Investigator (digital soil compaction meter with built in data logger); Soil Compaction meter² – manual soil compaction tester; OptiLogic range finder; Digital depth sounder, Salinity multi meter, and Portable turbidity meter.

Table 5.18b Table of Cost Associated with the Determination of the Beach Rating Index

Activity BAI Determination	Number of staff (weekly rate) and staff time (days) required to determine BAI	Cost GB £ (US \$)
Transportation cost **		15 (23)
Man week cost (data acquisition)**	2 staff (week rate £121 (US \$199) per man); 5 days	1210 (1990)
Man week cost (data processing)**	1 staff (week rate £ 168 (US \$277)); 10 days	336 (554)
Training cost **	1 staff (week rate £455 (US\$ 750)); 5 days	455 (750)
Subtotal***		1254 (2046)
1. Subtotal optional equipment ¹		2152 (3574)
2. Subtotal optional equipment ²		1273 (2114)

Table Notes:

Optional costs for performing the bacteriological analyses. This could end up being a high recurring cost, as the kit only has provision for three bacteriological analyses. It may therefore, not be considered to be an effective low cost option, unless these analyses are only performed at site specific locations considered to be bacteriologically contaminated.

& This identifies the optional equipment items purchased by the CZMU as part of this research and for long-term use.

* Refer to Appendix 5 Table I for equipment listing.

** Man week costs are salary rates based on current Government monthly salary scales for the positions of Chainman (for field data collection) and Clerical Officer (for data processing), as these are the level of staffing required to perform these works. These costs are not included since they have been quoted previously and are weekly rates.

*** Costs not included here would be the purchase of direct capital costs (e.g. computer hardware (including colour printer and incidentals for computer usage) and associated software (Microsoft Office Suit and SPSS).

Currency converter used: <http://www.xe.com/ucc/convert.cgi> on 26/5/03.

5.4.5.4 Logistics and Administration

As with the prior indices, the determination of appropriate locations from which to take the measurements was of concern. As previously explained (Sections 5.2.5.4 and 5.3.5.4), the locations chosen corresponded to the existing CZMU profile locations. The associated requirements for consideration in such situations were previously discussed in Section 5.2.5.4. The requirements for island situations have also been presented in Section 5.3.5.4.

Difficulty was also experienced in the standardisation of the method of assessment for some variables of a highly subjective nature (e.g. noise variables). As part of this research the use of repeat visits to locations allowed for increased familiarity with the conditions experienced *in situ*. This allowed for better interpretation of the qualitative ranges applied to the checklist.

5.4.6 Recommendations

The general approach for beach aesthetic rating and index determination could be extended for the whole island, as most variables are suitable for such use. Given the highly contrasting nature of the other beaches, it would be highly instructive in the determination of the overall range of beach quality for the island. The aesthetic rating approach fits well with similar approaches found in the literature (Williams et al. 2002. and Leatherman 1997 and 1998). The checklist, when standardized for SIDS, can provide useful information for recreational beach areas, which then can be further modified to focus on specific activities (e.g. walking, scenery and sports).

It is important to have the survey performed every quarter or at least twice a year to get a true representation of the beach conditions. It can be expected that many permanent features at each beach location will not change. Therefore, the beach assessment process can be expedited by pre-completing the unchanging variables (e.g. beach material, sand colour, presence of runoff culverts and draining, presence of watercourse discharge points and misfits).

5.4.6.1 Modification of Technique

There is a need for greater consistency in the determination of some variables (e.g. the turbidity variable where a portable turbidity meter is recommended to establish a measurable range of NTU units). This would improve the accuracy applied to the applicable variables.

The assessment of nearshore water quality pollution can be improved using portable bacteriological assessment kits to provide rapid and a “greater range of accuracy”, for bacteriological contamination. The use of these kits, while not providing a specific number of bacteria per 100ml, presents an effective range for bacteriological contamination, which can be used to provide range values for each category score (1 – 5). This would improve the level of interpretation of the results. The use of the test kits in locations of suspect contamination also allows the problem sites to be brought to the attention of the relevant government agencies (e.g. Environmental Engineering Division, Ministry of Environment) for further detailed investigations and if necessary, appropriate enforcement action.

The use of a sound meter to measure the decibel levels on recreational beaches would provide a more accurate range for scoring. This is important in locations where there are high multiple usages and indirect user conflicts (e.g. motorised water sports, coastal property owners, and nearshore recreationists), especially during peak recreation use. This is a significant concern as some coastal home owners have complained, over the past few years, of the level of noise generated at some beaches, when coastal cruiser vessels, jet skis and catamarans simultaneously use the same coastal area (Carl Ince, *pers. comm.* 2001).

5.5 SUMMARY

This chapter has been concerned with the first component of the research findings – the development of ESIs to represent the WEI, CSI and BAI for Barbados’ coastal areas.

Sixty locations were assessed and several clear trends have been subsequently identified. Section 5.2 examined the development of the WEI. The analyses (Table 5.19, Figures 5.4a – d and 5.5a – f) demonstrated that the South coast is more exposed than the West coast. The results have substantiated that the variables used can define the wave exposure indices for the coastal segments.













Section 5.3 presented a CSI classification scheme for Barbados' coastal habitats. This has been developed to determine the sensitivity of the coastline to potential oil spills. The habitat rankings identified fringe coral reefs and seagrass beds as being most sensitive. Despite this, importance is also placed on sheltered sandy beaches because of their importance to the tourism industry.

Section 5.4 presented the BAI findings for the study areas. The results have shown that with checklist modification to the variables, it is practical to measure general beach variables to determine a BAI. Despite this, it has also been shown that the index is sensitive to the checklist scaling system and data processing procedure.

The ESIs have used a four-category classification scheme based on the quartile ranges of the calculated index scores to apply sensitivity ranges to coastal segments within a CVA context. It was chosen for application in this research as it provides a more sensitive representation than a three-category classification scheme (since the latter may generalise those locations that could be considered to be within the middle range (average or moderate) in their index value).

The following summary maps are useful for interpreting the ESIs as part of coastal resource maps. Such information has future potential when reporting on the state of the coast and other aspects relating to public education and information dissemination.

Table 5.19 Key for Representation of Indices on Study Area Maps

Index Value	Index Scale	Symbol
WEI		
I	Highly Exposed (HE)	
II	Exposed (E)	
III	Fairly Sheltered (FS)	
IV	Sheltered (S)	
CSI		
I	Low (L)	
II	Moderate (M)	
III	High (H)	
IV	Very High (VH)	
BAI		
I	Poor (P)	
II	Moderate (M)	
III	Good (G)	
IV	Very Good (VG)	

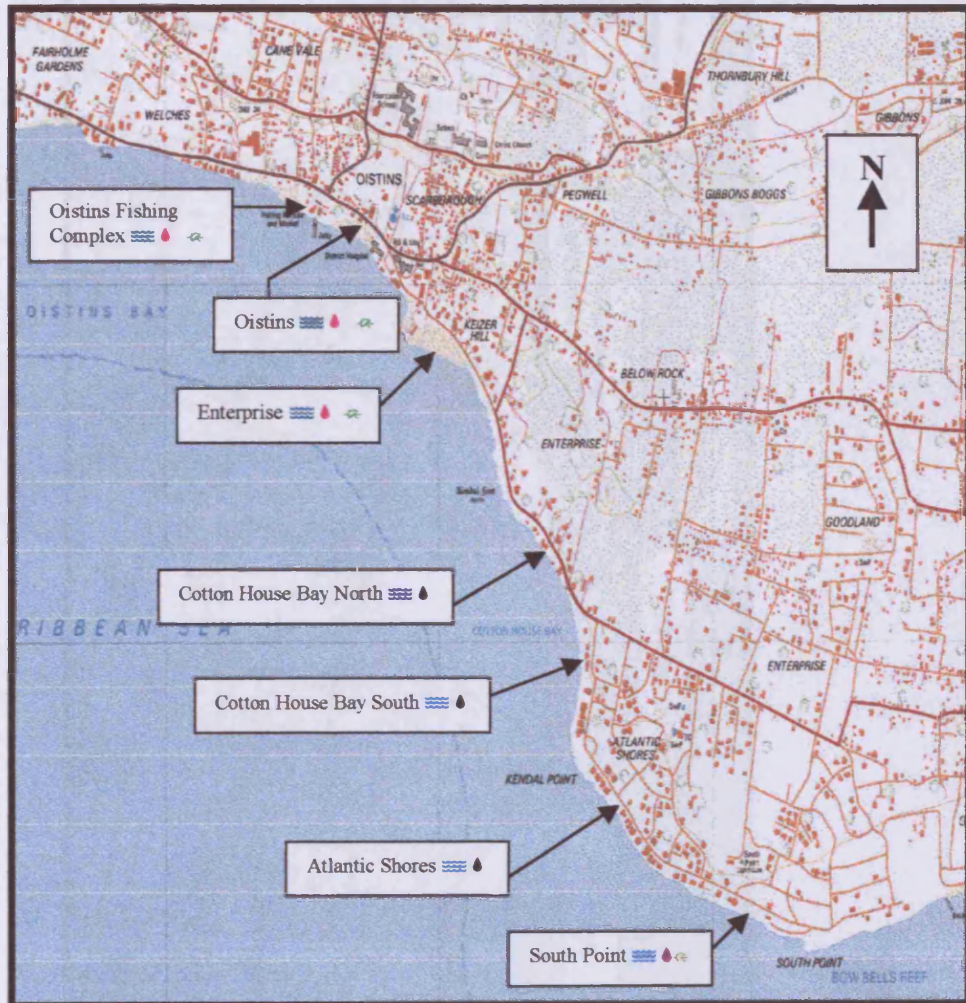
Where:

WEI = Wave Exposure Index; CSI = Coastal Sensitivity Index; BAI – Beach Aesthetics Index

Fig. 5.4a Map of South Coast - South Point to Oistins (based on original Scale 1:10,000) (Source: Original)

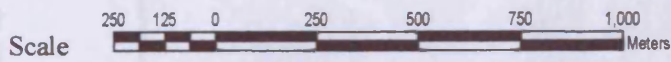
30423mE
63787mN

33958mE
63787mN



30423mE
61000mN

33958mE
61000mN



Symbol Key

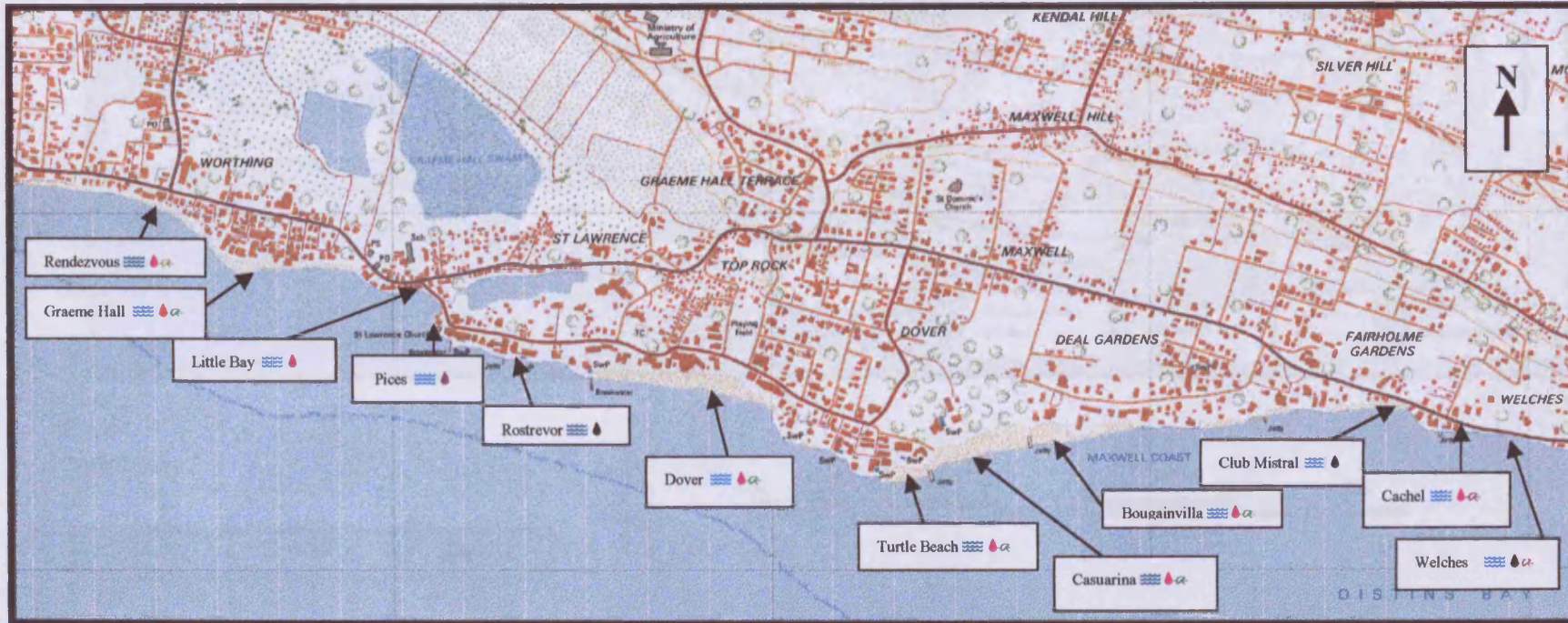
WEI		CSI		BAI	
HE	≡≡≡	L	●	P	↗
E	≡≡≡	M	●	M	↗
FS	≡≡≡	H	●	G	↗
S	≡≡≡	VH	●	VG	↗

Fig. 5.4b Map of South Coast - Welches to Worthing (based on original Scale 1:10,000)

(Source: Original)

27000mE
63536mN

31125mE
63536mN



27000mE
61875mN

31125mE
61875mN

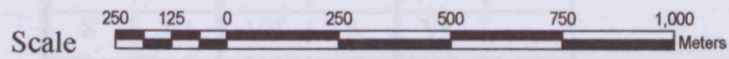
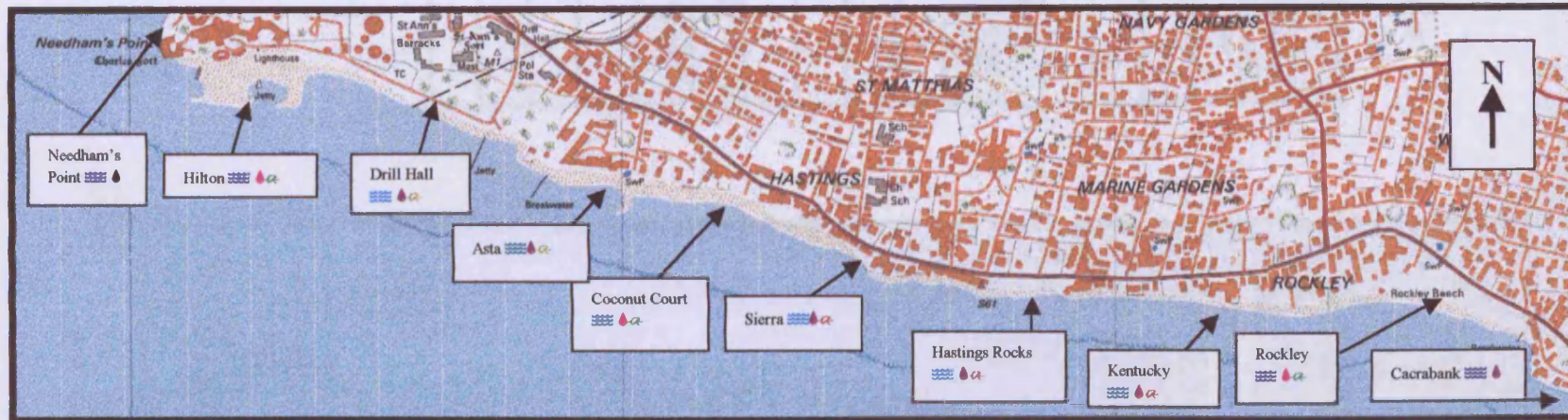


Fig. 5.4c Map of South Coast - Cacrabank to Needham's Point (based on original Scale 1:10,000) (Source: Original)

23750mE
63939mN

26943mE
63939mN



23750mE
63104mN

26943mE
63104mN

Symbol Key

WEI		CSI		BAI	
HE	☰	L	⬇️	P	α
E	☰	M	⬇️	M	α
FS	☰	H	⬇️	G	α
S	☰	VH	⬇️	VG	α

Scale



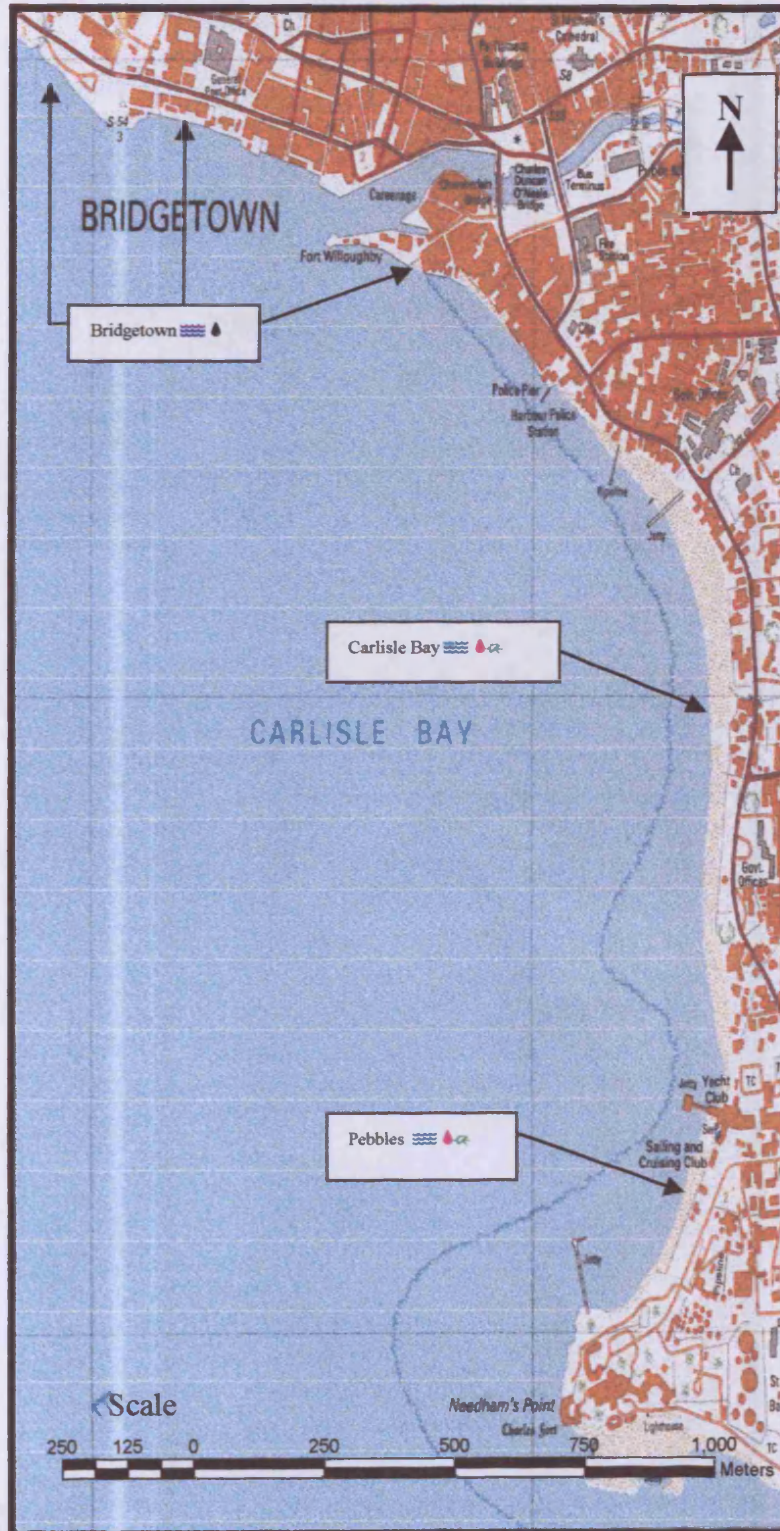
Fig. 5.4d Map of South Coast - Needham's Point to Bridgetown (based on original Scale 1:10,000) (Source: Original)

22800mE
66127mN

24600mE
66127mN

Symbol Key

WEI	
Value	Symbol
HE	
E	
FS	
S	
CSI	
Value	Symbol
L	
M	
H	
VH	
BAI	
Value	Symbol
P	
M	
G	
VG	



22800mE
63501mN

24600mE
63501mN

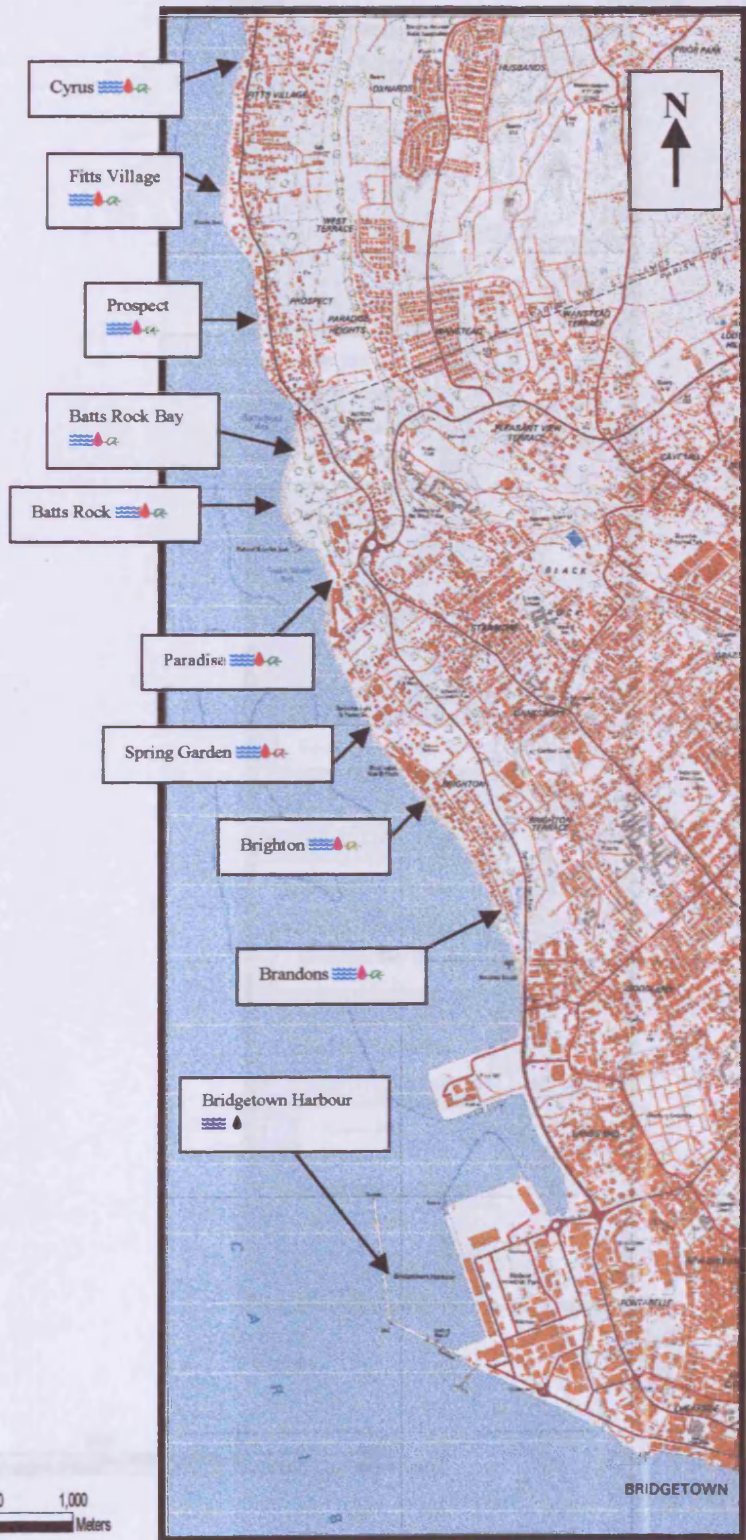
Fig. 5.5a Map of West Coast – Bridgetown to Fitts Village (based on original Scale 1:10,000) (Source: Original)

20966mE
72034mN

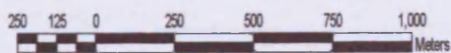
23509mE
72034mN

Symbol Key

WEI	
Value	Symbol
HE	
E	
FS	
S	
CSI	
Value	Symbol
L	
M	
H	
VH	
BAI	
Value	Symbol
P	
M	
G	
VG	



Scale



20966mE
65525mN

23509mE
65525mN

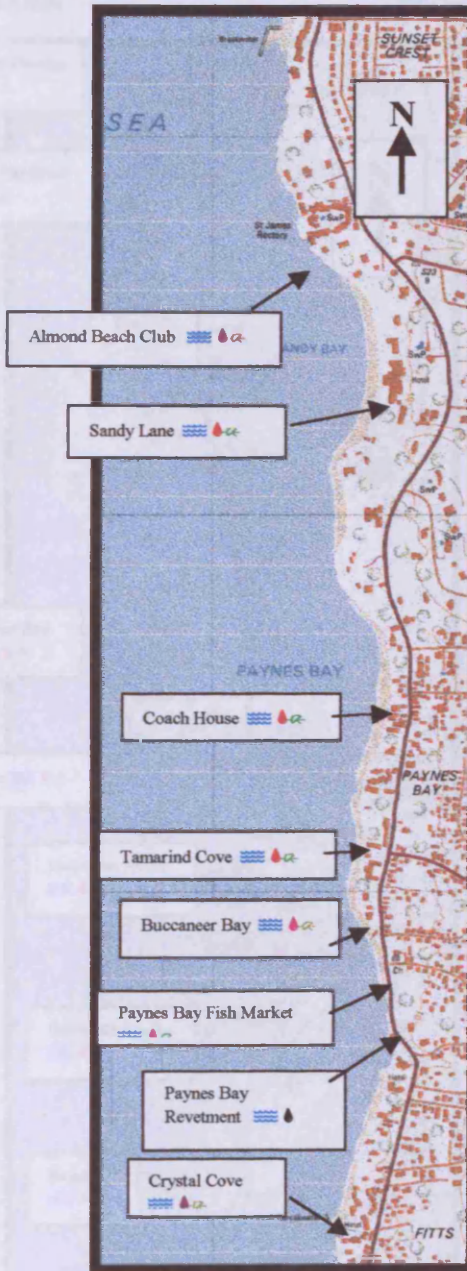
Fig. 5.5b Map of West Coast – Fitts Village to Almond Beach Club (based on original Scale 1:10,000) (Source: Original)

20696mE
75348mN

21717mE
75348mN

Symbol Key

WEI	
Value	Symbol
HE	
E	
FS	
S	
CSI	
Value	Symbol
L	
M	
H	
VH	
BAI	
Value	Symbol
P	
M	
G	
VG	



20696mE
71983mN

21717mE
71983mN

Scale



Fig. 5.5c Map of West Coast – Regent to Mount Standfast (based on original Scale 1:10,000) (Source: Original)

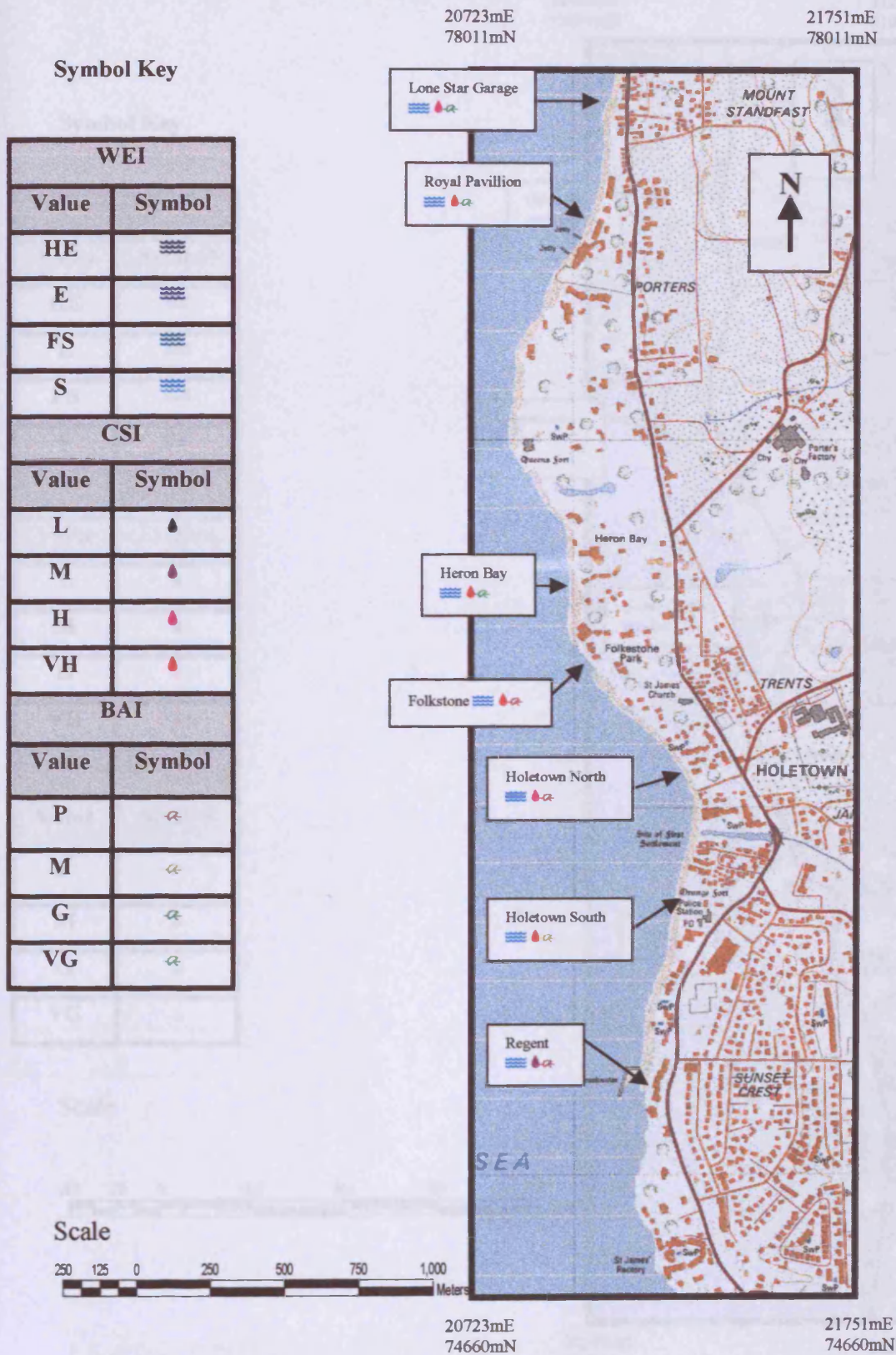


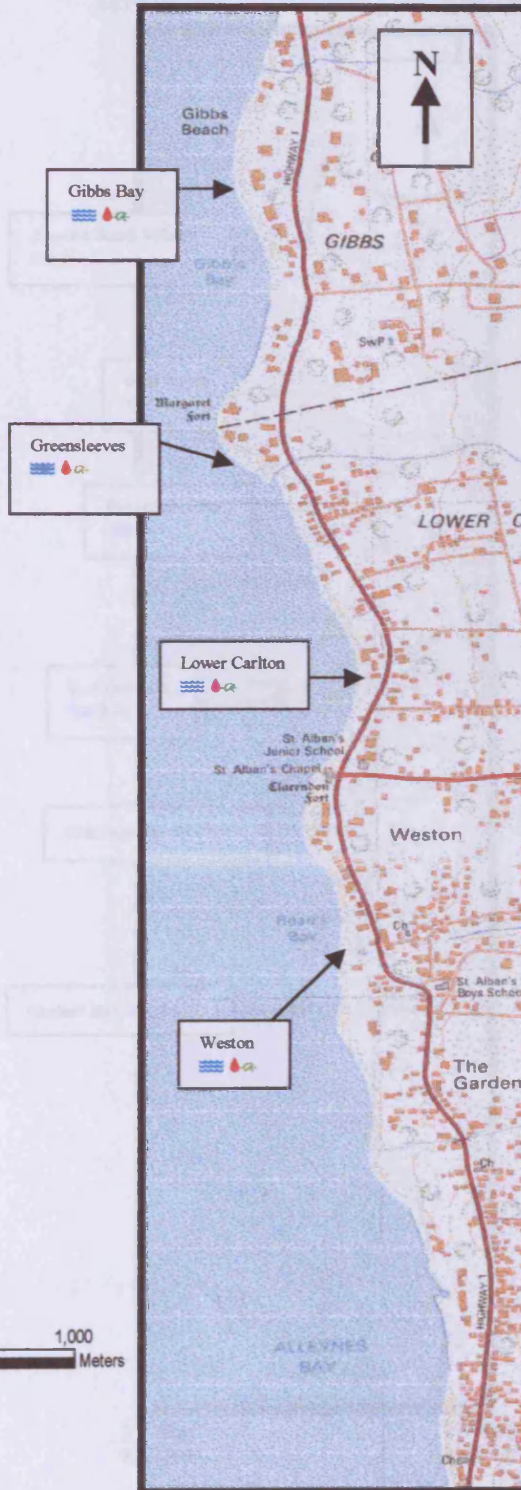
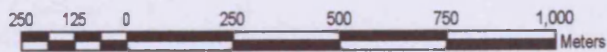
Fig. 5.5d Map of West Coast – Mount Standfast to Gibbs (based on original Scale 1:10,000) (Source: Original)

20549mE 21289mE
81014mN 81014mN

Symbol Key

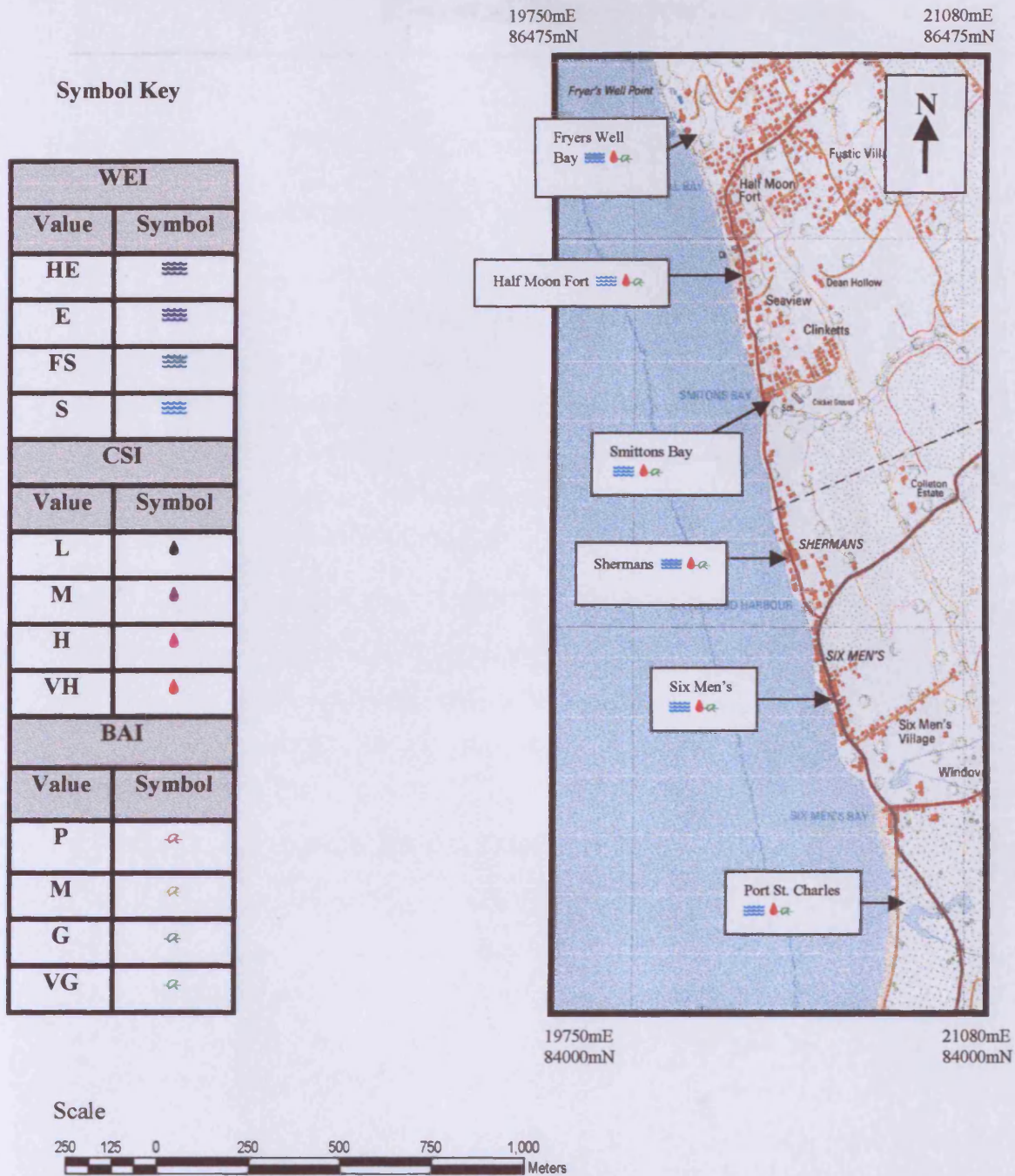
WEI	
Value	Symbol
HE	
E	
FS	
S	
CSI	
Value	Symbol
L	
M	
H	
VH	
BAI	
Value	Symbol
P	
M	
G	
VG	

Scale



20549mE 21289mE
78004mN 78004mN

Fig. 5.5f Map of West Coast – Port St. Charles to Fryers Well Bay (based on original Scale 1:10,000) (Source: Original)



Chapter 6
The Determination of the
Coastal Vulnerability Index

Chapter 6

The Determination of the Coastal Vulnerability Index

6.1 INTRODUCTION.....	206
6.2 DETERMINATION OF THE COASTAL VULNERABILITY INDEX.....	206
6.2.1 VARIABLES.....	206
6.2.2 LITTORAL VARIABLE DESCRIPTIONS	210
6.2.2.1 Morphology and Sedimentology of Coastline.....	210
6.2.2.2 Presence of Beach Associated Landforms and Human Intervention.....	211
6.2.2.3 Morphology and Sedimentology of Sea Floor	212
6.2.2.4 Physical Variables of Littoral Processes	213
6.2.2.5 Evolutionary Trend of Shoreline	213
6.3 COASTAL VULNERABILITY INDEX METHODOLOGY	213
6.3.1 PROCEDURE FOR SHORELINE CLASSIFICATION ANALYSIS.....	213
6.3.2 DEGREE OF URBANISATION PROCEDURE.....	215
6.3.3 EVALUATION OF COASTAL VULNERABILITY	215
6.3.4 DEGREE OF RISK.....	215
6.4 COASTAL VULNERABILITY INDEX RESULTS	216
6.4.1 INTERPRETATION OF RESULTS FOR DETERMINING THE COASTAL VULNERABILITY INDEX	216
6.4.1.1 Positive Correlation Coefficients for Variables Used.....	217
6.4.1.2 Negative Correlation Coefficients for Variables Used	222
6.4.2 CLUSTER ANALYSIS.....	226
6.4.2.1 Average Linkage Method.....	227
6.4.3 COASTAL SEGMENT ZONATION DETERMINED BY CLUSTER ANALYSIS.....	232
6.4.3.1 Coastal Zoning Using Pearson Correlation and ALM	233
6.4.4 COASTAL VULNERABILITY DETERMINATION USING FACTOR ANALYSIS	237
6.4.5 DEGREE OF RISK.....	252

6.5 DISCUSSION.....	255
6.6 EVALUATION OF THE TECHNIQUE USED	257
6.6.1 VARIABLES USED IN THE BARBADOS EXPERIENCE AND THEIR APPLICATION IN A WIDER CONTEXT.....	257
6.6.2 AVAILABLE DATA.....	257
6.6.3 ECONOMIC COST.....	257
6.6.4 LOGISTICS AND ADMINISTRATION	260
6.7 RECOMMENDATIONS	260
6.7.1 MODIFICATION OF THE TECHNIQUE	260
6.8 SUMMARY.....	261

6.1 INTRODUCTION

To manage the coastal zone properly, it is necessary to understand the relevant physical process and anthropogenic effects. This aids the preparation of short and long term prognoses for shoreline change and risk analysis. Chapter 6 describes the methodology used to develop the CVI and coastal classification system for the West and South coasts. This forms the second component of the model (Section 4 .2) and addresses the first three research objectives (Section 1.3.2.2).

The chapter is structured into three sections:

1. Presents the variables chosen and methodology for CVI and CC determination.
2. Presents the analysed results. As part of the analysis, the degree of risk of the coastal segments is also determined.
3. Presents an evaluation of the methods used and the applicability to other small island systems.

Subsequently, Chapter 9 identifies the way in which such methodologies can be incorporated into the Barbados CM system.

6.2 DETERMINATION OF THE COASTAL VULNERABILITY INDEX

6.2.1 Variables

This approach is based on the work of Dal Cin and Simeoni (1994), and Simeoni *et al.* (1997) in which a combination of 18 and 15 variables respectively, are used to characterise the shoreline. The list of variables applied to Barbados has also considered other variables in the literature (e.g. Procter and Redfern 1983, Dal Cin and Simeoni 1989, Gornitz and Kanciruk 1989, Gornitz *et al.* 1994, Price 1990, Amore and Randazzo 1994, UNESCO 1998 and 2003).

As part of the quantification process, the decision flow chart developed by Simeoni *et al.* (1997) has been adapted to the Barbados context. The variables used to describe the coastline (Box 6.1) have been identified in the flow chart as their numeric values (Fig. 6.1), to show their contribution to the characterisation of each coastal stretch. The flow chart is divided into three categories - 1) morphology and sedimentology of the coastline; 2) littoral processes affecting the coastline; and 3) morphology and sedimentology of marine habitats of the nearshore seafloor. Each category can be further subdivided into distinct groupings, into which the individual variables can be placed. The variables describe the coastline quantitatively in terms of its physical characterisation (see Tables 4.4, 4.5a and b).

In the CVI process, cliffed coasts require data collection for variables 2, 3, 4 and 10 (Box 6.1). Variable 2 is subdivided into the following - an active cliff (on the shoreline) and an inactive cliff (protected by a beach). If the cliff belongs to the second subgroup, then data on variable 11 is required since it is a beach being considered. Beach variables start with variable 11 and require variables 5 to 9 and 12 to 16 to fully describe the particular environment. A mixed coastline¹ is described by several variables used to characterise the other coastal types.

Additionally, coastal dynamic processes contribute to the characteristic shape and form of the coastal area, and are therefore integrated into the process. Similarly, those variables describing the nearshore sub-tidal morphology and sedimentology need to be incorporated with variables used to reflect measured littoral processes. This is achieved by the incorporation of variables 16 – 28².

¹ Intermittent beaches and cliffs being found in the same coastal segment exemplify a mixed coastline.

² From the reviewed literature other possible parameters that could be considered for inclusion are: tidal range, mean energy flux, gross and net longshore transport rates. This is dependent on whether the data required for their calculation is available. For Barbados, the data required for calculating mean energy flux, and gross and net longshore transport rates are currently not available. The tidal range for Barbados is consistently less than 1 metre and therefore, not considered of significance in terms of variation. This may be an important variable in other countries where varied sections of coasts experience differing tidal ranges.

Box 6.1 List of Variables used in Decision Flow Chart³

A. Morphology and sedimentology of coastline*

1. Presence of small scarps with maximum height of 2 m
2. Location of cliffs in relation to the shoreline
3. Cliff height (m)
4. Cliff slope (%)
5. Elevation of backshore (m)
6. Width of backshore (m)
7. Beach length (m)
8. Beach slope (%)
9. Beach volume
10. Cliff texture
11. Mean size of beach sediments (mm)

B. Presence of Beach associated Landforms**

12. Presence of dunes
13. Presence of tidal flats (cobble/rubble)
14. Presence of beach rock
15. Extent of urbanisation

C. Human Intervention

16. Presence of man-made structures/defensive structures

D. Morphology and Sedimentology of Sea Floor

17. Slope of sea floor between 0 - 3 m (%)
18. Mean size of sea floor sediment between 0- 3 m (m)
19. Distance between shoreline and 3 m (m)
20. Presence of coral reef/seagrass

E. Physical Parameters of Littoral Processes***

21. Wind speed (m/s)
22. Wind direction (°N)
23. Wave height (m)
24. Wave direction (°N)
25. Longshore current speed (m/s)
26. Orientation of coastline (°N)

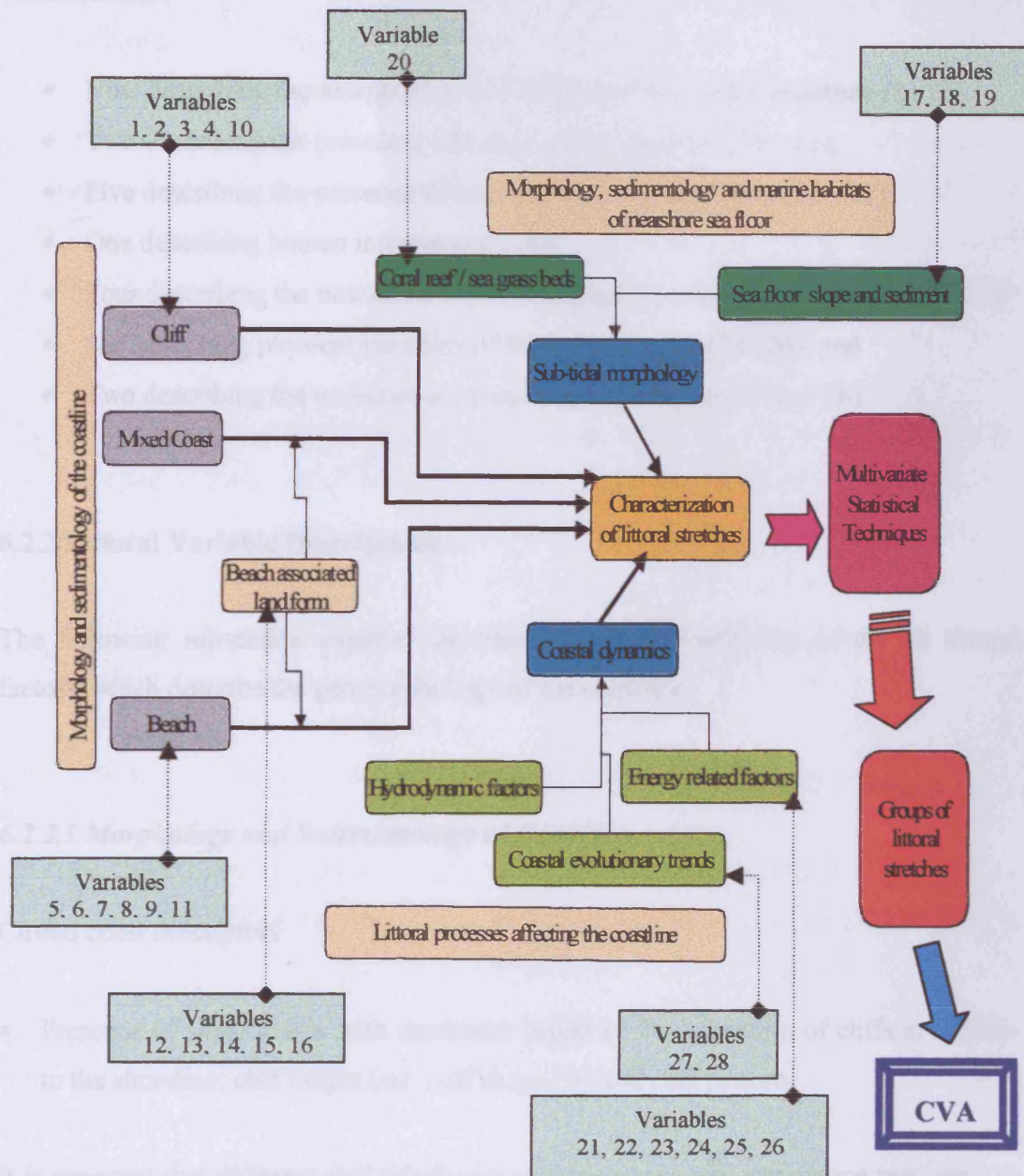
F. Evolutionary trend of shoreline****

27. Mean shoreline accretion rate (m/yr)
28. Mean shoreline erosion rate (m/yr)

³ Where the following parameters: * Width of intertidal area (m), ** presence of sedimentary slopes, *** fetch distance (km), and **** most recent storm event (yr.) can be considered for subsequent inclusion under the relevant sections and be applied at other locations; but they have not been used in the current Barbados research context.

Fig. 6.1 Decision Flow Chart of Variables⁴ used in CVI Development

(Adapted from Simeoni *et al.* 1997)



N.B. Hydrodynamic factors represent variables of mean energy flux per unit length of coastline, gross and net longshore sediment transport rates. They are not represented in this research but have been included to demonstrate the versatility of the scheme to be modified, to capture the various factors, which can influence the characterisation of the coast.

⁴ Variable numbers represent the variables in Box 6.1 that contribute to the description of the coastline.

Using this approach, the Barbados coastline was subdivided into cliffed coast, beached coast and mixed coast categories. Each segment was further described using 28 variables with:

- Nine describing the morphology and sedimentology of the coastline (1 - 9);
- Two describing the prevalent lithology of the coastline (10 - 11);
- Five describing the presence of beach associated landforms (12 - 15);
- One describing human intervention (16);
- Four describing the nearshore seabed morphology and sedimentology (17 - 20);
- Six describing physical variables of littoral processes (21 -26); and
- Two describing the evolutionary trend of the shoreline (27 and 28).

6.2.2 Littoral Variable Descriptions

The following subsection explains the rationale for the selection of the 28 littoral factors, which describe the geomorphology of the coastline.

6.2.2.1 Morphology and Sedimentology of Coastline

Cliffed coast descriptors

- Presence of small scarps with maximum height of 2 m; location of cliffs in relation to the shoreline; cliff height (m); cliff slope (%) and cliff texture.

It is expected that different cliff lithologies and structures will experience resistance to wave energy and erosive wave action (Nordstrom & Renwick 1984, Carter 1989, Bird 1994, Berger and Iams 1996, Dawson & Evans 2001). Although the cliffs in Barbados are predominantly Pleistocene coral limestone, the texture description is used to differentiate between consolidated and unconsolidated cliff material, as the latter is more prone to erosion increasing the potential risk of cliff collapse/failure in these areas.

Beach coast descriptors

- Elevation of backshore (m); width of backshore (m); beach length (m); beach slope (%); beach volume and mean size of beach sediments (mm).

The elevation of the backshore defines the height of the land directly behind the beach. It is expected that the higher the backshore lands, the less susceptible it would be to storm wave inundation or sea swells (Camber 1998, Phillips 1999). It is a useful monitoring reference point allowing for the return to the same starting height to determine if the beach shape has changed between monitoring episodes.

The other variables are subject to frequent changes either on a daily or seasonal basis. These are the dynamic variables often associated with the beach face and beach area, and are important in assessing the stability of the beach system. Along highly developed shorelines with limited buffer space between the beach and the property, it is possible that erosion will increase, and will be reflected in these variables.

6.2.2.2 Presence of Beach Associated Landforms and Human Intervention

- Presence of dunes; presence of tidal flats (cobble/rubble); presence of beach rock; extent of urbanisation and presence of man-made structures/defensive structures.

These variables characterise the coastal landform behind the beach. It would be expected that harder substrates, such as beach rock, are more resistant to erosion than softer rocks or sediments. The presence of tidal coral rubble flats⁵ also represents the erosional effects of high energy waves (Delcan 1995). The presence of dunes can indicate a level of stability, especially if they are vegetated. More importantly, in the event of increased wave activity, they act as a prime temporary supply of sand to the beach area, counteracting beach erosion (Pethick 1984, Carter 1989WCU 2001). The

⁵ Coral rubble fragments are broken from reefs during very high wave energy events and deposited onto the shore face, or in the nearshore. When normal wave conditions return, the fragments remain in their deposited locations and may be buried by sand and sediments returning from offshore areas back onshore. Their extent of burial depends on the volume of sediment, returned to the onshore sediment budget.

level of urbanisation and the presence of man-made structures on a coastline can affect local shoreline processes and morphology by actively changing the beach profile⁶ (Jackson and Nordstrom 1992).

6.2.2.3 Morphology and Sedimentology of Sea Floor

- Slope of sea floor between 0 - 3m isobath (%); mean size of sea floor sediment between 0 - 3m isobath (m); distance between shoreline and 3m isobath (m); presence of coral reefs or seagrass beds

The seaward limit of the nearshore has been selected to be a maximum of -3m, since it is the depth at which it is generally observed that the breakers start to form before reaching the shoreline. Similar depths have been applied in the literature (Amore and Randazzo 1994, Dal Cin and Simeoni, 1987, 1989a & b, 1994). While this is a suitable depth for determination of nearshore wave activity, it is recognized that this depth does not constitute the depth of closure⁷ as referred to in Bruun (1988) and Titus (1990). Nearshore reefs and seagrass beds have also been found most frequently in the 0 - 3m water depth (Delcan 1995, Terra Remote Sensing Inc. 2000a and b). Nearshore ecosystems have a direct effect on slowing and, hence, dissipating incoming wave energy, before it reaches the shore. They also aid in the retention of sediment in the nearshore (UNESCO 1983, UNEP 1989, and UNEP 1993).

⁶ As resistance factors they also alter local wave and wind processes and sediment mobility along the coastline.

⁷ The depth of closure is often identified as the point offshore where sediments are lost from the nearshore and onshore sediment transport system (see <http://www.erosion.com/document4a.html>). It is deeper than the portion of the beach profile that changes seasonally or due to storms. Depth of closure for a coastal location is calculated using known values for wave height, sand density and wave period (see <http://www.coastal.udel.edu/faculty/rad/depth.html>).

6.2.2.4 Physical Variables of Littoral Processes

- Wind speed (m/s); wind direction (°N); wave height (m); wave direction (°N); longshore current speed (m/s); orientation of coastline (°N)

These variables describe the degree of coastal exposure to open water and coastal segments that may be sensitive to oil spill effects (Sections 5.2 and 5.3). They are instrumental in providing an indication of the likely size of potential storm waves that can affect the coast (Jackson and Nordstrom 1992).

6.2.2.5 Evolutionary Trend of Shoreline

- Mean shoreline accretion rate (m/yr.) and mean shoreline erosion rate (m/yr.)

The relative stability of the shoreline is generally considered dependent on the material and energy available to the shore. Waves transport large amounts of energy and the continual dissipation of this energy can, with time: 1) remove beach sand resulting in erosion; or 2) redistribute the sand leading to accretion (Natesan & Subramanian 1994).

6.3 COASTAL VULNERABILITY INDEX METHODOLOGY

6.3.1 Procedure for Shoreline Classification Analysis

Data for the 28 variables were collated to produce a matrix of 644 elements (23 coastal sectors x 28 variables). From these, 19 shoreline variables were used to develop a 437 matrix that was analysed by Q Mode and R Mode factor analyses. It was hoped that these procedures would outline more clearly the relationship between the groups of coastal segments and the considered variables. Cluster analysis (R mode factor analysis) permits the identification of the relationships between different coastal sectors, while factor analysis (Q mode factor analysis) outlines those relationships between groups and

variables. The decision to use these methods is based on the demonstrated fact that the use of factor analysis has produced good results in similar mixed coast applications along the French coast (Camargue to the Rhone Delta), the Mid Adriatic coasts of Italy, the Southern coast of Sicily and the Strait of Magellan⁸.

Factor analysis proceeds in four steps⁹:

- First, the correlation matrix for all variables is computed. Variables that are not related to other variables can be identified from the matrix and associated statistics. The appropriateness of the factor model can also be determined.
- Second, factor extraction is performed where the number of factors necessary to represent the data and the method of calculating them is determined.
- Third, factor rotation focuses on transforming the factors to make them more interpretable. This is undertaken in order to maximise the relationships between the variables and some of the factors and minimise association with others.
- Fourth, scores for each factor can be computed for each case. These scores are the estimates of the cases on the supposed latent variables that result as mathematical axes, from the factor analysis of the data set. These scores can then be used as input for further statistical analysis.

Cluster analysis¹⁰ classifies objects so that each object is very similar to others in the cluster with respect to some predetermined selection criterion. The hierarchical cluster procedure has been used in this research. This relates the most similar observations, and then successively connects the next most similar observations. First, a matrix of similarities between all pairs of observations is calculated. Those pairs with the highest similarities are then merged and the matrix recomputed. Averaging the similarities that the combined observations have with other observations provides the result. The process is reiterated until the similarity matrix is reduced to 2 x 2. The levels of similarity, at which observations are merged, are used to construct a dendrogram (Hair *et al.* 1998, Kinnear and Gray 2000, Tabachnick & Fidell 2001).

⁸ Refer to Blanc and Forget (1979), Blanc (1980), Dal Cin and Simeoni (1987a & b, 1989a & b, 1991, and 1994), Amore and Randazzo (1994) and Simeoni *et al.* (1997) respectively.

⁹ Refer to Tabachnick and Fidell (2001), Kinnear and Gray (2000), and Hair *et al.* (1998).

¹⁰ See Townend (2002), Hair *et al.* (1998), and Klován (1975).

6.3.2 Degree of Urbanisation Procedure

As described in Section 4.6.2.2, the coastal aerial photograph series have been reviewed for background information. These images, which span a thirty-year period and were most recently updated in 2000, allow identification of temporal variations in land use categories¹¹. The current (2000) extent of urbanisation was based on the calculated percentage of land cover dedicated to accommodation, commercial and industrial purposes represented in the first 200m of the coastline¹², starting from the landward edge of the beach. It is represented by the presence of houses, hotels, commercial businesses, coastal roads, dunes, and other land use types (e.g. scrubland and woodland).

6.3.3 Evaluation of Coastal Vulnerability

In this research, coastal vulnerability relates to the onshore area behind the beach and coastline. The level of urbanisation and infrastructure investment found in this area accounts for its high economic and environmental value. Beaches are the first defence for any coastal area (being dependent on their size and quality¹³), and then the man-made structures. Factor analysis is used to identify the most appropriate factor to represent the percentage vulnerability of the coastal segments. The percentage vulnerability is represented on 1:10 000 map sheets.

6.3.4 Degree of Risk

The level of vulnerability is based on the possibility of episodic flooding along the coast and the potential damage to the coastal urbanised areas. By determining the coastal

¹¹ These aerial photographs provided an acceptable means of identifying major land use changes over the respective years, as well as the identification of major infrastructure developments that had occurred on the coast over the 40-year period.

¹² The 200m inland boundary corresponds to the legislated coastal zone management area for the island. See Barbados legislation: Coastal Zone Management Act 1998-39

¹³ Factors for consideration include beach width, maximum elevation, beach slope, beach volume, and sea floor slope.

classification in terms of vulnerability, the level of risk can be presented. Along the coastline, the degree of risk is based on the product of vulnerability to natural hazards and the value of the coastline. Those locations with high values for both variables are considered to be high-risk.

6.4 COASTAL VULNERABILITY INDEX RESULTS

This section presents the CVI results. It describes the correlations observed between the field variables measured, and then provides a description of the results of the clustering process. The factor analysis results are also presented together with the determination of risk experienced along the coastline.

6.4.1 Interpretation of Results for Determining the Coastal Vulnerability Index

Cluster analysis was performed on the littoral field variable measurements and from secondary data sources. This procedure allowed the grouping of individual objects into clusters, so that objects in the same cluster were more similar to each other rather than to objects in other clusters (Hair *et al.* 1998). It identified natural groupings between the variables and the coastal segments respectively.

The suitability of the data for correlation and representative analysis met the requirements for factor analysis as presented by Hair *et al.* (1998) and Kinnear and Gray (2000). They represent the key variables that describe the underlying factors contributing to coastal erosion and coastal vulnerability. Additionally, all the variables are considered simultaneously, with each related to all others. The factor analysis process considers those factors that maximise their explanation of the entire variable set rather than the identification of dependent variables¹⁴. In cluster analysis the variables have been selected to characterise the coastal segments being clustered, and to relate

segments to their vulnerability with respect to erosion and potential flooding. This process is intended to identify the most consistent, yet, distinct groups of objects across all variables (Hair *et al.* 1998).

The use of correlation scatter plots and their linear associations provides a useful method for determining the linear relationships between the variables. Kinnear and Gray (2000) proposed that correlation coefficients greater than 0.3 identify useful variables that are acceptable for linking into factors, hence, making it an acceptable statistic to use. The scatter plots identify the important features of the relationships between the variables. From the scatter plots, the narrow elliptical cloud of points, represents a strong association and the greater the absolute value of the Pearson correlation. It is necessary however, to view the scatter plots to determine if the correlation coefficients can be used as part of the analysis. For the majority of the correlation associations, the scatter plots demonstrate that the Pearson correlation values can be used in these analyses (Sections 6.4.1.1 and 6.4.1.2). This further supports the suitability of the data in this component of the research.

6.4.1.1 Positive Correlation Coefficients for Variables Used

All relevant correlation coefficients can be found in Appendix 6, Table I. However, the positive correlations between the relevant variables are presented in summary form in Table 6.1. Some correlations appear to have outlier points. However, these in fact, represent the actual values recorded for the data collected and represent the varied conditions experienced along the different coastal segments. The use of alternate statistical approaches (e.g. Ward's method of clustering), while reducing the influence of outlier values, on the results did not change the general scatter results. The use of Pearson Correlation method of clustering was, therefore, considered suitable. The

¹⁴ The prediction of dependent variables use analytical techniques such as multiple regression, discriminate analysis and multivariate analysis of variance to determine which one or more variables are considered the criterion or dependent variables and all others are predictor or independent variables.

coastal segment locations¹⁵ (numbers 1 to 23) are presented on the correlation coefficient graphs.

Significant correlation coefficients were observed between beach length and beach volume ($r(26) = 0.87, p < .01; r^2 = 0.75$); and wave direction ($r(26) = 0.71, p < .01; r^2 = 0.51$). These results indicate that the volume of sand controls the length of a beach. The angle of wave approach also contributes to beach length since this generally determines the prevailing direction of sediment deposition on the beach. The beach length is also likely to be controlled by the natural geomorphology of the coast.

The correlation coefficients between beach slope and mean beach sediment size (Table 6.1, Fig 6.2a), showed the strongest correlation. The most significant contribution¹⁶ came from the mean beach sediment size ($r^2 = 0.56$). These significant correlations conform to current understanding, as beach slope is determined by the sediment grain size for a particular coastal segment and its reworking by wave action, which can alter the height of the beach (Al-Bakri 1996). The angle of wave approach on the coastal segment can contribute to the change in the beach slope through sediment redistribution along the shoreline (Jackson and Nordstrom 1992).

Beach volume is positively correlated with beach width (Fig. 6.2b), coastal orientation, and the mean accretion rate (Table 6.1) with the latter two variables providing the greatest contribution to the beach volume (33 % and 32 % respectively).

¹⁵ The coastal segment locations correspond to the following: 1 = South Point; 2 = Oistins; 3 = Casuarina; 4 = Dover; 5 = St Lawrence; 6 = Worthing; 7 = Rockley; 8 = Hastings; 9 = Carlisle Bay; 10 = Bridgetown Harbour; 11 = Brighton; 12 = Batts Rock; 13 = Fitts Village; 14 = Paynes Bay; 15 = Sandy Lane; 16 = Holetown; 17 = Porters; 18 = Royal Pavilion; 19 = Gibbs Bay; 20 = Mullins Bay; 21 = Goddings Bay; 22 = Speightstown; 23 = Smittons Bay.

¹⁶ The significance of contribution is determined from the coefficient of determination (r^2).

Table 6.1 Summary of Positively Correlated Variables

Variable (d.f. = 26¹⁷)	Positively Correlated Variables	Correlation Value (r)	Coefficient of Determination (r²)	Correlation Significance
Beach length	Beach volume	0.868	0.753	**
	Beach elevation	0.528	0.279	**
	Coastal orientation	0.646	0.417	**
	Wave direction.	0.714	0.510	**
Beach slope	Beach elevation	0.582	0.339	**
	Beach sediment size	0.748	0.560	**
	Wave direction.	0.562	0.316	*
Beach volume	Beach width	0.495	0.245	*
	Coastal orientation	0.573	0.328	**
	Wind direction	0.485	0.235	*
	Wave direction	0.485	0.235	*
	Mean shoreline accretion rate	0.562	0.316	**
Beach width	Beach elevation	0.532	0.283	*
	Distance offshore to -3m.	0.535	0.286	**
Coastal orientation	Wave direction	0.796	0.634	**
Wind speed	Wind direction	0.485	0.235	*
	Wave period	0.573	0.328	**
	Longshore current speed	0.549	0.301	**
Wind direction	Wave period	0.498	0.248	*
	Mean shoreline accretion rate	0.436	0.190	*
Wave height	Longshore current speed	0.642	0.412	**
Distance offshore between 0 to -3m	Mean shoreline accretion rate	0.441	0.194	*

Table Notes:

Where ** = correlation is very significant at the 0.01 level (2 tailed); * = correlation is significant at the 0.05 level (2 tailed).

¹⁷ d.f. = Degrees of Freedom.

Fig. 6.2a Positive Correlation between Beach Slope and Beach Sediment Size.
 $(r(26) = 0.75, p < 0.01)$

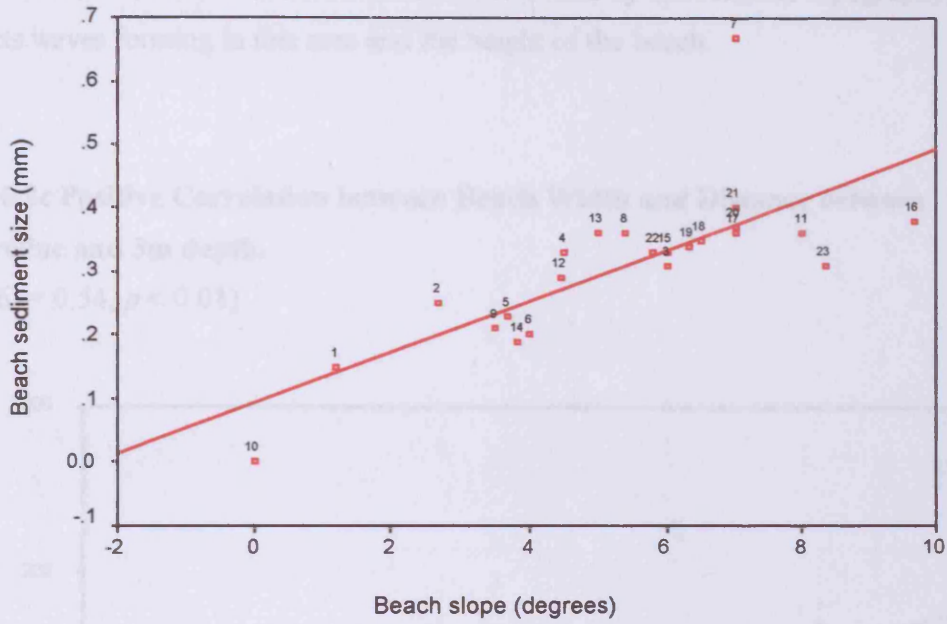


Fig. 6.2b Positive Correlation between Beach Volume and Beach Width.
 $(r(26) = 0.50, p < .05)$

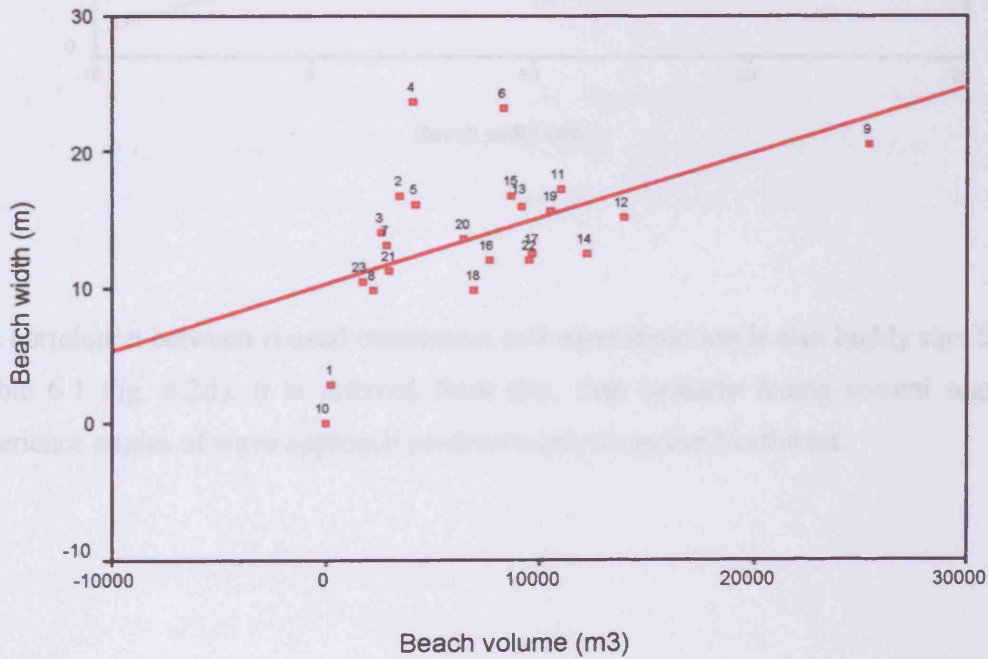
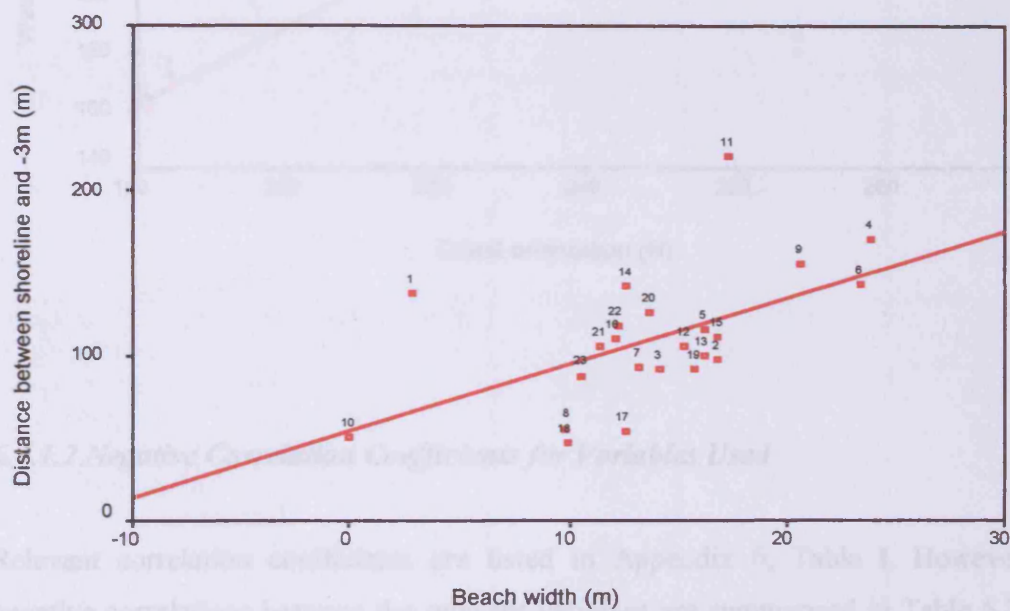


Fig 6.2c also demonstrates a high significant correlation between beach width and the distance between the shoreline and 3m depth offshore as several of the points fall close to the correlation line. The beach width is controlled by the offshore topography, which affects waves forming in this area and the height of the beach.

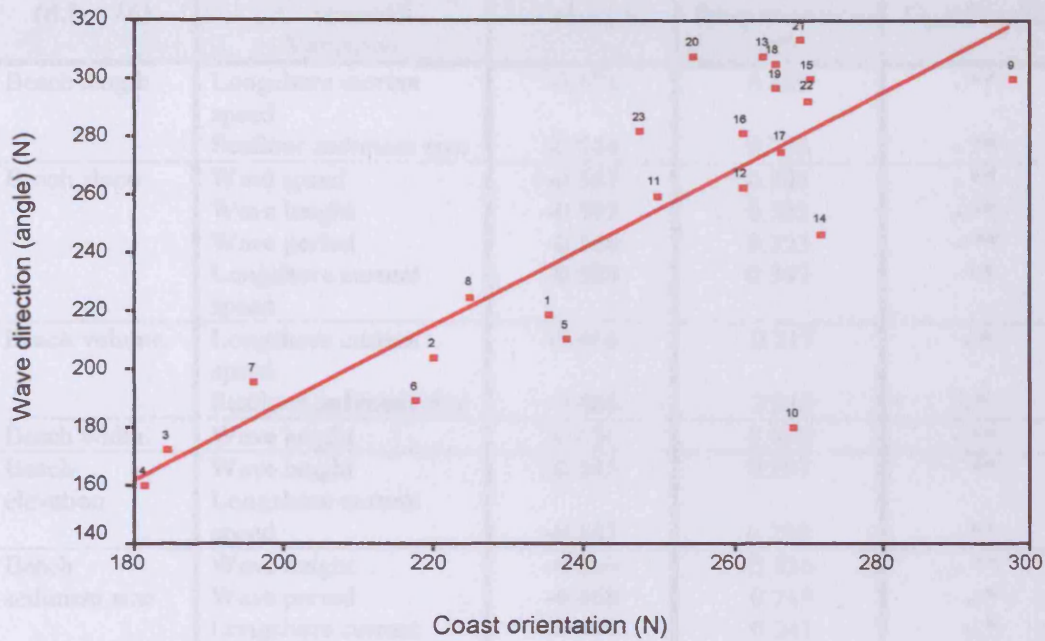
Fig. 6.2c Positive Correlation between Beach Width and Distance between Shoreline and 3m depth.

($r(26) = 0.54, p < 0.01$)



The correlation between coastal orientation and wave direction is also highly significant (Table 6.1 Fig. 6.2d). It is inferred from this, that westerly facing coastal segment experience angles of wave approach predominantly from the Northwest.

Fig. 6.2d Positive Correlation between Coast Orientation and Wave Direction
 $(r(26) = 0.80, p < 0.01)$



6.4.1.2 Negative Correlation Coefficients for Variables Used

Relevant correlation coefficients are listed in Appendix 6, Table I. However, the negative correlations between the relevant variables are summarised in Table 6.2. The same coastal segment identifiers (locations 1 to 23 in Section 6.4.1.1) are presented on the correlation coefficient graphs.

Table 6.2 Summary of Negatively Correlated Variables

Variable (d.f. = 26)	Negatively Correlated Variables	Correlation Value (r)	Coefficient of Determination (r²)	Correlation Significance
Beach length	Longshore current speed	-0.671	0.450	- **
	Seafloor sediment size	-0.544	0.296	- **
Beach slope	Wind speed	-0.567	0.321	- **
	Wave height	-0.593	0.352	- **
	Wave period	-0.568	0.323	- **
	Longshore current speed	-0.589	0.347	- **
Beach volume	Longshore current speed	-0.466	0.217	- *
	Seafloor sediment size	-0.466	0.217	- *
Beach width	Wave height	-0.636	0.404	- **
Beach elevation	Wave height	-0.545	0.297	- **
	Longshore current speed.	-0.547	0.299	- **
Beach sediment size	Wave height	-0.580	0.336	- **
	Wave period	-0.468	0.219	- *
	Longshore current speed	-0.491	0.241	- *
Coastal orientation	Seafloor sediment size	-0.833	0.694	- *
Wind speed	Wave direction	-0.570	0.325	- *
Wave height	Wave direction	-0.446	0.199	- *
Wave period	Wave direction	-0.432	0.187	- **
Wave direction	Longshore current speed	-0.624	0.389	- **
	Seafloor sediment size	-0.680	0.462	- **
Seafloor slope	Distance between 0 to -3m	-0.810	0.656	- **

Table Notes:

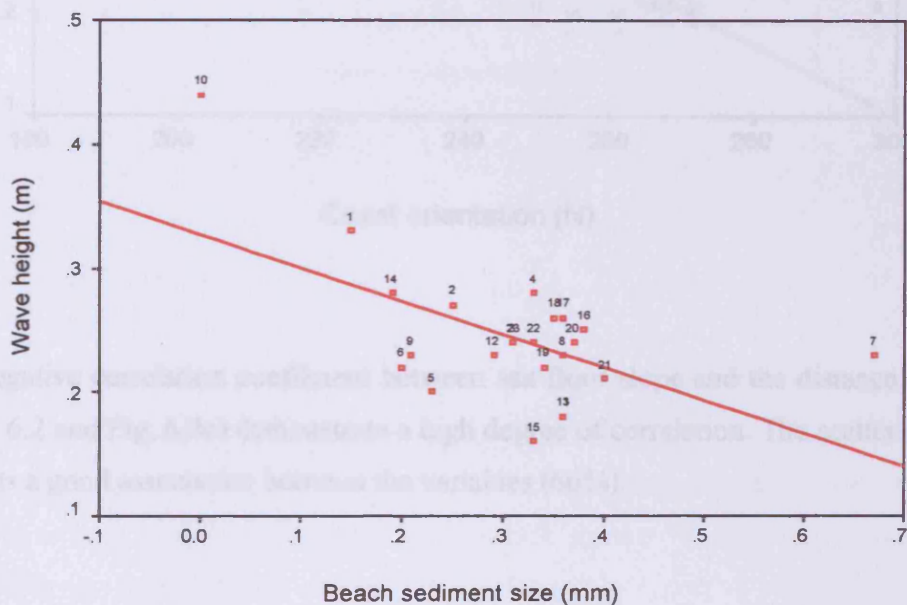
Where ** = correlation is very significant at the 0.01 level (2 tailed); * = correlation is significant at the 0.05 level (2 tailed); and - = negative.

The negative correlations between beach length and longshore current speed and sea floor sediment size (Table 6.2) demonstrate that the sediment size in the nearshore does not influence the length of the beach ($r^2 = 30\%$).

The negative correlation coefficients for beach width and wave height demonstrate strong correlation ($r = -0.64$). However, it demonstrates a low contribution ($r^2 = 40\%$) to the variation between the variables. This has been interpreted to represent the more stable (or wide) the beach is the lower the wave height experienced on the beach.

Beach sediment size shows negative correlation coefficients to wave height (Table 6.2, Fig. 6.3a). This shows that the beach sediment has a similar size range (2.0 – 3.75 mm) for most beaches.

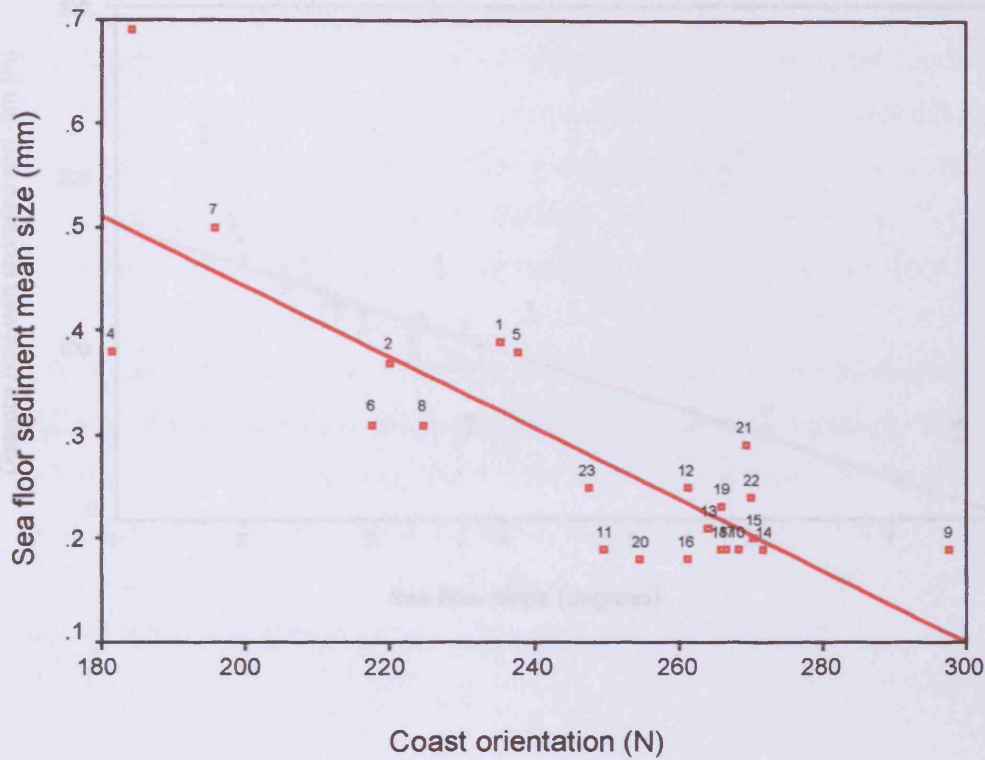
Fig. 6.3a Negative Correlation between Beach Sediment Size and Wave Height
 $(r(26) = -0.58, p < 0.01; r^2 = 0.34)$



A significant negative correlation coefficient exists between coastal orientation and sea floor sediment size (Table 6.2, Fig. 6.3b) indicating that beaches with a south westerly to westerly orientation ($250^{\circ}\text{N} - 270^{\circ}\text{N}$) appear to have finer sea floor sediments associated with them than do other southerly oriented beaches. The scatter plot shows that there is acceptable association between the variables.

Fig. 6.3c Negative Correlation between Sea Floor Slope and Distance Offshore.

Fig. 6.3b Negative Correlation between Coastal Orientation and Sea Floor Sediment Size ($r(26) = -0.83$ $p < 0.05$; $r^2 = 0.69$)



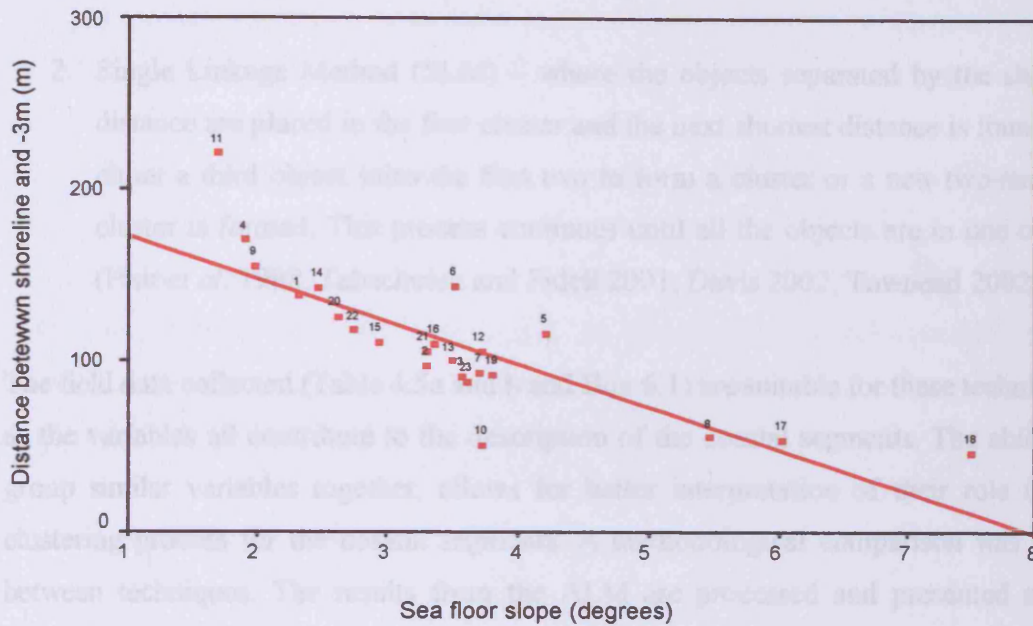
6.4.2 Cluster Analysis

The negative correlation coefficient between sea floor slope and the distance offshore (Table 6.2 and Fig. 6.3c) demonstrate a high degree of correlation. The scatter plot also presents a good association between the variables (66%).

In cluster analysis, the primary purpose is to group objects based on the characteristics they possess. It classifies objects so that each object is very similar to others in the cluster with respect to some predetermined selection criteria. The results are presented based on the following clustering techniques.

1. Average Linkage Method (ALM) – where the objects separated by the shortest distance are placed in the first cluster and the next shortest distance is found and either a third object joins the first two to form a cluster or a new two member cluster is formed. In this cluster procedure, the average distance from all individuals in one cluster to all individuals in another cluster is used (Fair *et al.*

Fig. 6.3c Negative Correlation between Sea Floor Slope and Distance Offshore.
 $(r(26) = -0.81, p < 0.05)$



6.4.2 Cluster Analysis

Having reviewed the correlation coefficients between the variables used in the littoral assessment procedure, cluster analysis was performed on the variables describing the coastal segments and related beach features. In cluster analysis, the primary purpose is to group objects based on the characteristics they possess. It classifies objects so that each object is very similar to others in the cluster with respect to some predetermined selection criterion. The results are presented based on the following clustering techniques:

1. Average Linkage Method (ALM) – where the objects separated by the shortest distance are placed in the first cluster and the next shortest distance is found and either a third object joins the first two to form a cluster or a new two member cluster is formed. In this cluster procedure, the average distance from all individuals in one cluster to all individuals in another cluster is used (Hair *et al.*

1998, Tabachnick and Fidell 2001, Davis 2002, Townend 2002). It tends to combine clusters with small cluster variations, therefore identifying clusters approximate to the same variance.

2. Single Linkage Method (SLM) – where the objects separated by the shortest distance are placed in the first cluster and the next shortest distance is found and either a third object joins the first two to form a cluster or a new two-member cluster is formed. This process continues until all the objects are in one cluster (Hair *et al.* 1998, Tabachnick and Fidell 2001, Davis 2002, Townend 2002).

The field data collected (Table 4.5a and b and Box 6.1) are suitable for these techniques, as the variables all contribute to the description of the coastal segments. The ability to group similar variables together, allows for better interpretation of their role in the clustering process for the coastal segments. A methodological comparison was made between techniques. The results from the ALM are processed and presented in the following sections. The results of the SLM are found in Appendix 6.

6.4.2.1 Average Linkage Method

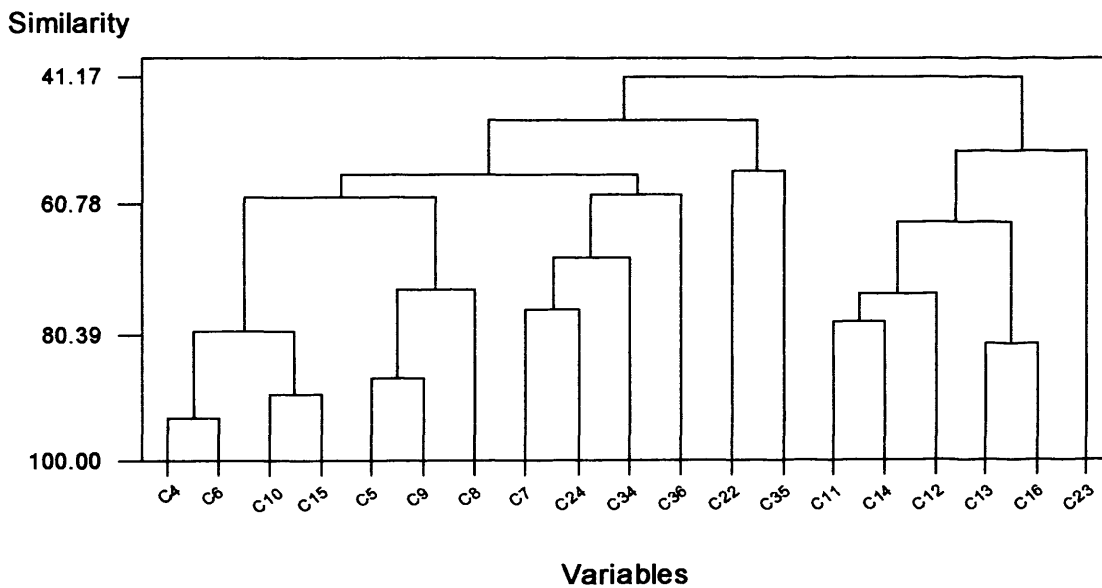
6.4.2.1a All variables

Using Minitab Software v.13 the interactions and relationships between the 19 variables, describing the coastal segments, were analysed by means of R mode factor analysis and cluster analysis. The ALM has used the normalised average scores obtained for each location using the Squared Euclidean Distance similarity coefficient. The distance method used was Pearson correlation. This was considered an effective technique to determine the similarity values between variables. The resulting dendrogram (Fig. 6.4) obtained, allows for an evaluation of the classification and relative hierarchy of the variables.

The groupings, with the highest degree of similarity, with correlation coefficients ranging between 93.41 and 68.86 are: 4 – 6 – 10 and 15; 5 - 9 and 8; 7 – 24 and 34.

These relationships demonstrate that beach length (4) and beach volume (6) are correlated with coastal orientation. This conforms to current understanding, as the exposure of the coastline is dependent on the natural orientation of the coast. The extent of exposure can have an impact on the volume of sediment, present on the beach (6) and this can influence the overall length of the beach, depending on the angle of wave approach (15). In addition, the slope of the beach (5), its sediment size (9) and its elevation (8), govern beach stability. Beach stability is also reflected in its beach width (7) and this is closely related to offshore distance to the 3m depth contour (24). These variables have a contributory role on the rate of shoreline accretion (34). While not falling within the highest similarity range, the presence of coastal structures/human intervention (36) generally contributes to overall coastal stability.

Fig. 6.4 Dendrogram of All Clustered Variables



Where: c4 = beach length; c5 = beach slope; c6 = beach volume; c7 = beach width; c8 = beach elevation; c9 = beach sediment size; c10 = coastal orientation; c11 = wind speed; c12 = wind direction; c13 = wave height; c14 = wave period; c15 = wave angle; c16 = longshore current speed; c22 = seafloor slope; c23 = sea floor sediment size; c24 = offshore distance; c34 = mean accretion rate; c35 = mean erosion rate; c36 = human intervention

These findings suggest that the factors beach length, beach volume, coastal orientation, wave angle, beach slope, beach sediment size and beach elevation all contribute to general beach accretion. On the other hand, beach width, offshore distance mean accretion rate and human intervention variables describe beach stability factors.

The variables sea floor slope (22) and mean erosion rate (35) also contribute to general beach instability. The nearshore slope has a direct relation to the ability of the coastline to retain nearshore sediment – either in the form of sandbars during storm wave episodes or loosing the sediment to deep water¹⁸. In the latter case, this will not allow the recovery of the beach areas within a reasonable time after a storm event. From the dendrogram, these factors have a low level of similarity to the other variables and, therefore, are considered outliers¹⁹.

The other groupings in the highest similarity within the correlation coefficient range are 11 – 14 and 12; 13 and 16. These variables are the coastal exposure variables (wind speed, wave period and wind direction; and wave height and longshore current speed respectively). The results have grouped them all together. Sea floor sediment size (23) is associated with this grouping as an individual outlier variable. The wave height (13), longshore current (16) and wind direction (12) all have a role in determining the prevailing wind and longshore current direction, experienced on the particular coastal segment.

6.4.2.1b Cluster analysis (excluding oceanographic variables)

An alternate cluster analysis on 13 rather than 19 variables was also performed using ALM. This analysis provided a comparison of the literature²⁰. Those methods did not make use of measured oceanographic variables but relied on other variables (e.g. mean energy flux, longshore transport and littoral drift, sediment influx from riverine sources) that would have incorporated them. The use of 13 variables is also similar to that found

¹⁸ If the sediment falls out of the overall sediment budget regime by being deposited in very deep water it would be lost from the sediment budget system permanently.

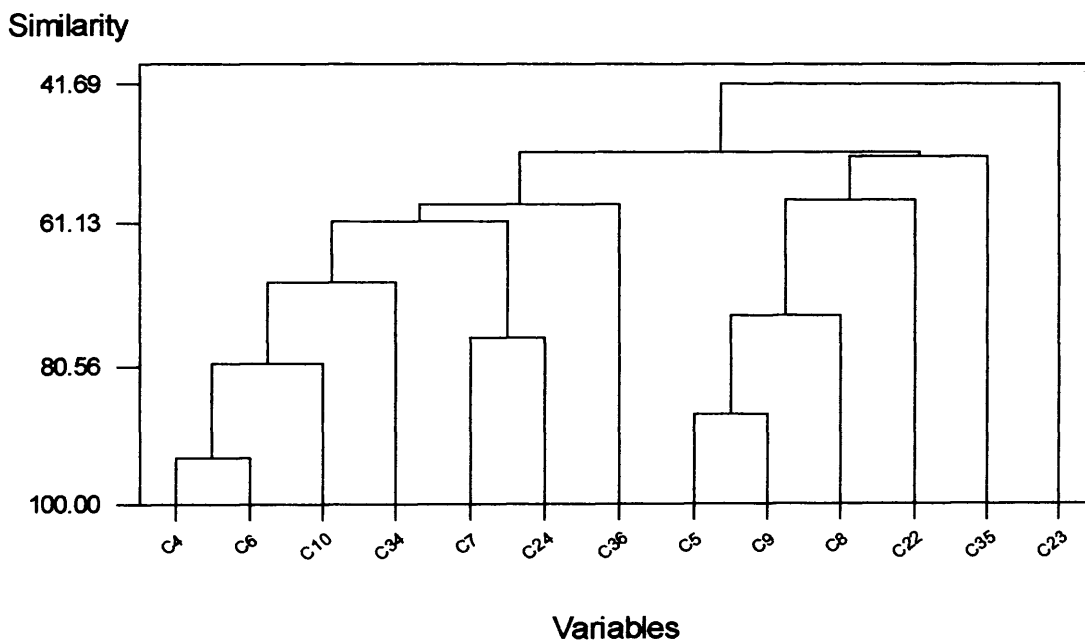
¹⁹ Outliers represent a branch on the dendrogram that did not join until very late (Hair *et al.* 1998).

²⁰ See Dal Cin and Simeoni (1989, 1991, and 1994), Amore and Randazzo (1994), Simeoni *et al.* (1997).

in the literature (e.g. 18 – Dal Cin and Simeoni 1991; 15 – Dal Cin and Simeoni 1994; 14 - Amore and Randazzo 1994). The oceanographic variables were removed to test if they might have had a reduced influence on the overall determination of the variable groupings, demonstrated in the previous cluster analysis dendrogram.

Interactions and relationships between the 13 variables were analysed similarly to Section 6.2.4.1a. The dendrogram shown in Fig. 6.5 is the result of the cluster analysis. The groupings with the highest degree of similarity, with a correlation coefficient ranging between 93.14 and 73.79 are variables: 4 – 6 – 10; 7 and 24; 5 – 9 and 8.

Fig. 6.5 Dendrogram of 13 Clustered Variables



Where: c4 = beach length; c5 = beach slope; c6 = beach volume; c7 = beach width; c8 = beach elevation; c9 = beach sediment size; c10 = coastal orientation; c22 = sea floor slope; c23 = sea floor sediment size; c24 = offshore distance; c34 = mean accretion rate; c35 = mean erosion rate; c36 = human intervention

The dendrogram demonstrates similar linkage associations as Fig. 6.4. However, it is noticeable that new groupings arise, as follows: beach length (4), beach volume (6) and coastal orientation (10). These reflect the close associations between beach length and volume and they are influenced by coastal orientation. Additionally, linked to these variables is the mean shoreline accretion rate (34). There is also association between the width of the beach (7) and the offshore distance (24) (as was observed in the former dendrogram). These variables are linked together and can be considered to reflect the variables that describe the accretionary nature of the beach segments. Associated with these is the presence of human intervention structures (36).

There is a clear relationship between beach slope (5), beach sediment size (9) and beach elevation (8). These variables are related as a change in beach sediment size affects the slope of the beach, which changes the overall height of the beach. This association is also observed in the former dendrogram. The seafloor slope (22) is also associated with these variables. The mean erosion rate (35) is independently linked to this grouping. This has a contributory role in the determination of the stability of the beach area. Sea floor sediment size (23) is another outlier that apparently has an overarching role in terms of its contribution to the stability and accretionary trends associated with the beach areas.

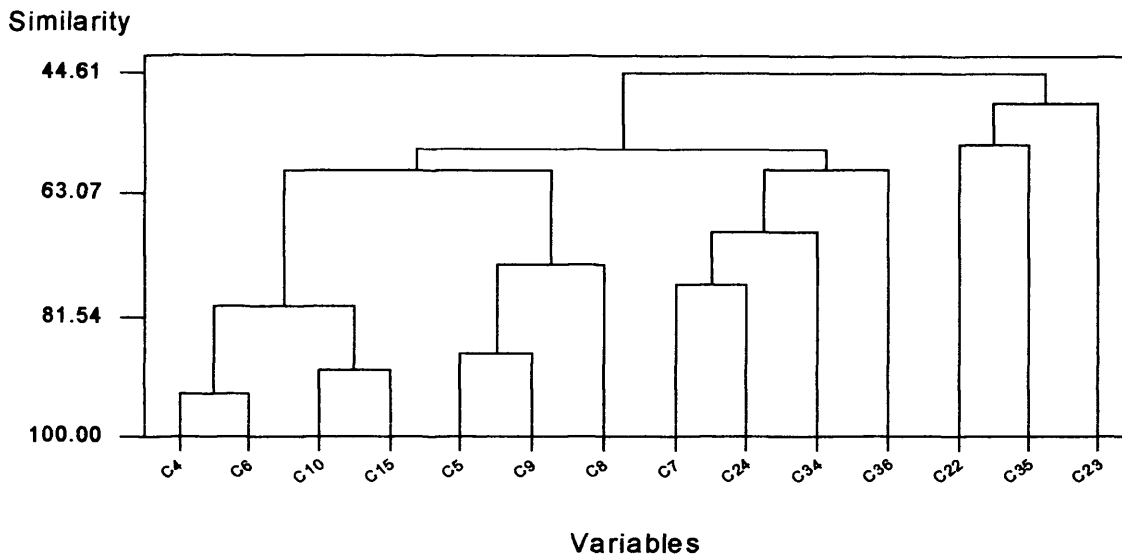
In comparing the two cluster analysis results (Figures 6.4 and 6.5), it is noted that the absence of the wave exposure variables does not largely influence the original main groupings.

6.4.2.1c Cluster analysis (including only wave angle)

As demonstrated in Fig. 6.4, the wave angle variable is the only oceanographic variable to have an independent influence in the groupings. The cluster analysis procedure is, therefore, repeated to evaluate this. As demonstrated in Fig. 6.5, the groupings become clearer with the inclusion of the wave angle (15) variable. In Fig. 6.6, the groupings are the same as in Fig. 6.3 with the exception that the following general variables - seafloor slope (22), mean erosion rate (35) and sea floor sediment size (23) - have a general

contributory influence on the cluster groups describing the beach stability and accretionary trend, respectively.

Fig. 6.6 Dendrogram of 14 Clustered Variables



Where: c4 = beach length; c5 = beach slope; c6 = beach volume; c7 = beach width; c8 = beach elevation; c9 = beach sediment size; c10 = coastal orientation; c15 = wave angle; c22 = sea floor slope; c23 = sea floor sediment size; c24 = offshore distance; c34 = mean accretion rate; c35 = mean erosion rate; c36 = human intervention

6.4.3 Coastal Segment Zonation Determined by Cluster Analysis

Cluster analysis was performed on the variables used to describe the related beach features and coastal segments. The zonation results have applied ALM and SLM clustering techniques using Pearson Correlation coefficients. The results using the SLM technique are found in Appendix 6.

6.4.3.1 Coastal Zoning Using Pearson Correlation and ALM

The coastal segment groupings have been described using 19 variables. The dendrogram (Fig. 6.7) allows the determination of the coastal classification and relative hierarchy of the coastal segments. The groupings with the highest similarities (correlation coefficient ranging between 80.73 and 69.24), are formed by the following segments: 13 -15 - 19, 20 - 22 - 21, 5 - 6, 16 - 17. Almost all the strongest associations are formed by adjacent or near adjacent segments. This illustrates that in a limited area, the coastal characteristics often vary only slightly and with continuity.

The results of the factor and cluster analyses, as well as the correlation coefficients of the variables used in coastal segment description, allow the coastline to be classified into four fundamental groups, A-B-C-D:

A: 1 – 10.

B: 9 – 14.

C: 3 – 4 – 5 – 6 – 7 – 8.

D: 13 – 15 – 21 – 20 – 22 – 19 – 23 – 16 – 17 - 18.

It is also observed that after more careful evaluation, groupings C and D can be further subdivided into the following:

C: 3 – 4 – 5 - 6 and 7 - 8.

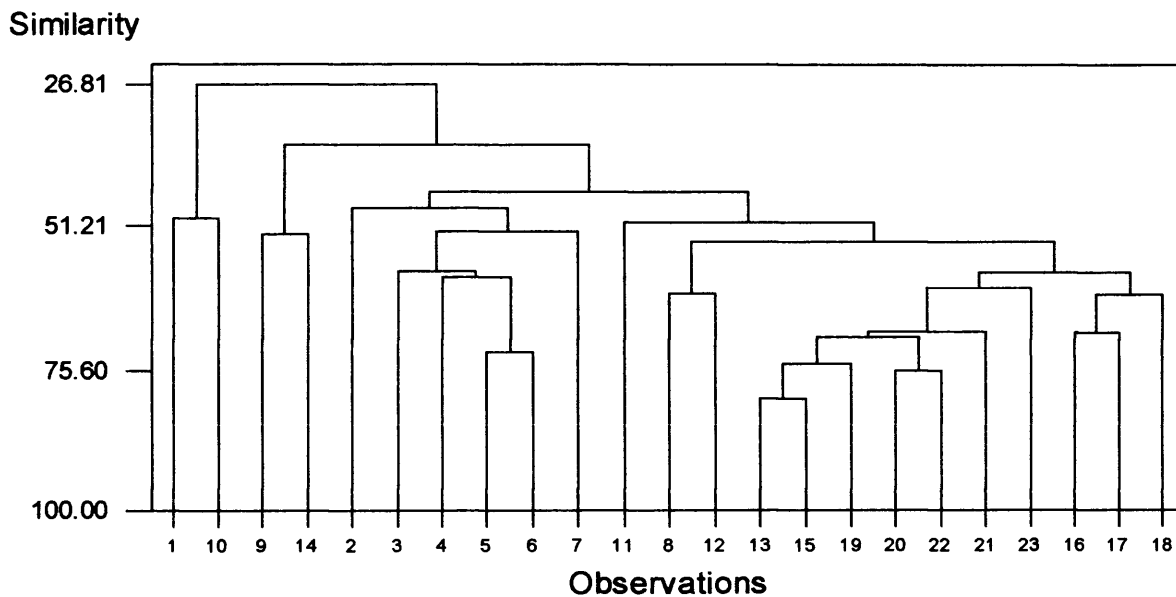
D: 13 – 15 – 21 – 20 - 22 and 16 – 17 - 18.

6.4.3.1a Group A

This group includes segments 1 – 10 and represents the coastal areas between South Point and Enterprise and between Fort Willoughby and Brighton (Bridgetown Harbour area), respectively. These coastal stretches are characteristically hard faced coasts with segment 1 being predominantly a cliffed coast, with little to no beach area associated with the cliff line; while segment 10 has harbour protection structures, along its entire length. It is, therefore, comparable to cliff coasts with no associated beaches. Coastal

engineering structures occur along both coastal areas for shoreline protection purposes. While coastal erosion factors are found along segment 1 (i.e. undercut and slumping cliffs and waves reaching building foundations); there are no erosion or accretion characteristics in segment 10, as it is a coastal protection shoreline, with a very deep nearshore.

Fig. 6.7 Dendrogram of Coastal Segment Clusters



Where 1= South Point; 2 = Oistins; 3 = Casuarina; 4 = Dover; 5 = St Lawrence; 6 = Worthing; 7 = Rockley; 8 = Hastings; 9 = Carlisle Bay; 10 = Bridgetown Harbour; 11 = Brighton; 12 = Batts Rock; 13 = Fitts Village; 14 = Paynes Bay; 15 = Sandy Lane; 16 = Holetown; 17 = Porters; 18 = Royal Pavilion; 19 = Gibbs Bay; 20 = Mullins Bay; 21 = Goddings Bay; 22 = Speightstown; 23 = Smittons Bay.

6.4.3.1b Group B

This includes segments 9 – 14, between Needham’s Point to Fort Willoughby (Carlisle Bay), and Crystal Cove to Paynes Bay (Fish Market) respectively. These segments

have narrow to medium sandy beaches, with intermittent wide beaches and coastal engineering structures, assisting with shoreline stabilisation and enhancement (nearshore breakwaters, burial revetments and seawalls). Segment 14 comprises cliffed coast or outcrops fronted by continuous beaches. Along both locations culverts and drains for surface water runoff discharge are frequent.

6.4.3.1c Group C

This includes segments 3 – 4 – 5 – 6 – 7 - 8 – 12 representing the South coast segments: Welches to Casuarina, Casuarina to Dover, Dover to St. Lawrence Bay, St. Lawrence to Cacrabank, and Cacrabank to Coconut Court respectively. The sub-grouping 3 – 4 – 5 - 6 account for a continuous coastal section. The beaches are of narrow to medium with intermittent cliffs. The segments have coastal engineering structures, predominantly groynes and revetments. Along their length, the beaches are stable to accreting with undercut cliffs at a few locations (e.g. parts of Dover segment, and Cacrabank segment). The nearshore area is generally wide and sandy, along this coast.

Segment 8 (Coconut Court to Needham's Point) represents a continuous section of coastline. It has contrasting coastal features to the other sub-groupings of the South coast. The presence of very shallow nearshore areas with rubble deposition along the majority of this segment prevents the deposition of beach sediment. The beach is generally stable to slightly eroding becoming narrow and steep close to Needham's Point, where the presence of nearshore breakwater allows for the retention of sand at the headland to form the wide Hilton Beach.

Segment 12 (Batts Rock Bay to Prospect) is linked with segment 8 and is a cliffed coast with some outcrops and narrow beach areas.

6.4.3.1d Group D

This grouping is formed by segments 13 – 15 – 19 – 20 – 22 - 21 – 23 – 16 – 17 - 18. It comprises the west coast beach locations and includes the following coastal areas: Prospect to Crystal Cove, Paynes Bay to Almond Beach Club, Tropicana to Gibbs Bay, Gibbs Bay to Road View, Fort Denmark to Little Good Harbour, Road View to Fort Denmark, Little Good Harbour to Fryers Well Bay, Almond Beach to Folkestone, Folkestone to Royal Pavilion and Royal Pavilion to Tropicana.

Upon closer review, two sub-groupings are observed: segments 13 – 15 – 19 – 20 - 22 – 21 - 23 and 16 – 17 - 18. The first sub-grouping, comprises beaches backed by lowland areas. All locations have coastal engineering structures²¹, and most beaches are stable to slightly eroding and of narrow width.

The second sub-group 16 - 17 - 18 represents a continuous section of the west coast which has narrow to eroding beaches backed by lowland areas. Similar engineering structures are found as in the first sub-group. The main erosion features are represented by waves reaching building foundations, the presence of property protection structures (revetments and seawalls) and steep beaches.

6.4.3.1e. Individual Segments

Individual segments, within the groupings identified above, are segments 2 (Enterprise to Welches) and 11 (Brighton to Batts Rock). They can be linked to Group C and Group D, respectively. The level of similarity in these cases is low (46 and 51 respectively). As segment 2 lies within the south coast it bears some resemblance to the beaches there. The difference with this segment is that it comprises a low beach backed by low land. Most of its length comprises shoreline protection structures (revetments) designed to protect the reclaimed land. These structures do not allow for the effective accumulation

²¹ The structures are predominantly revetments, seawalls, gabions and groynes.

of sediment transported in the littoral zone resulting in no beaches being associated with the coastal segments.

Segment 11 (Brighton to Batts Rock) is characterised by medium to wide beaches with intermittent narrow beaches anchored by shoreline protection structures. Combination engineering structures occur at a few locations (e.g. groyne fields with revetments, groynes and seawalls). Lowland areas predominantly back the coastal segment.

6.4.4 Coastal Vulnerability Determination Using Factor Analysis

As part of the data interpretation procedure, R Mode and Q Mode factor analysis has been performed on the variables²². The factor analysis took place in four stages as previously described (Section 6.3.1). Using SPSS statistical software, normalised values for the 19 variables, for each coastal segment, have been analysed using Q Mode factor analysis with the principal factors being extracted using principal component analysis (PCA). In this process the linear combinations of the observed variables are formed. The first extracted factor of PCA (unrotated solution) accounts for the largest amount of the variability among the variables, the second factor, the next highest variability, etc. Eigenvalues²³ were also determined and a Scree plot²⁴ was generated as part of the process in order to determine the relevance of the factors generated. All factors with eigenvalues above one on the Scree plot were considered suitable for consideration. As identified by Green *et al.* (2000) “*there is a need to make an initial decision about the number of factors based on conceptual beliefs about the number of underlying dimensions*”. The communality²⁵ of each variable was also calculated.

The result of the analysis using the 19 variables shows that, in general, the communality exceeds 0.8 and is always above 0.7. The total variance, however, is low. In fact to

²² Refer to Joreskog *et al.* (1976), Hair *et al.* (1998), Kinneer and Gray (2000), Tabachnick and Fidell (2001) and Davis (2002) for explanations as to the procedure used in determining factor analysis results.

²³ An eigenvalue is the amount of variance of the variable accounted for by a factor.

²⁴ The Scree plot is the plot of the eigenvalues vs. the component number. Its intention is to retain all factors with eigenvalues in the sharp descent part of the plot before the eigenvalues start to level off.

²⁵ The communality reflects the proportion of the variance of the test that is accounted for by the factors. The communality represents the square multiple correlation (R^2) between the variable and the factor emerging from the factor analysis (Kinneer and Gray 2000).

reach 80.7%, seven factors are necessary to be considered. This is instructive in demonstrating the high variability of environmental conditions within the same system. This was also reflected in the clustering of the coastal segments previously described (Section 6.4.3.1).

Given the low variance results, it was necessary to identify the conditions that adequately reflected the combination of coastal factors accounting for coastal vulnerability. These correspond to those coastal segment locations comprising the existence of eroding beaches, or moderately wide beaches with low elevation and low land areas lying in the back beach, and a moderately sloping nearshore area.

In an attempt to follow similar procedural stages found in the literature (Dal Cin and Simeoni, 1989 and 1994, Amore and Randazzo 1994, Simeoni *et al.* 1997), the factors were rotated using Kaiser normalisation and orthogonal (Varimax) rotation²⁶. This approach maximises the sum of the variances of required loadings of the factor matrix (Hair *et al.* 1998). From these results it was found that seven factors contributed to the vulnerability indicators for the coastal segment. Of these, it was found that Factor 1 best reflected the vulnerability indicators for the coastal segments. The Factor 1 scores have been converted to percentages to provide the vulnerability level for each coastal segment. The percentage score ranges have been converted into quartile ranges (using the same method as presented in Section 5.3.2) to determine the vulnerability scale (Table 6.4a). It was subsequently assigned a CVI value of I to IV (low to very high respectively, Table 6.4b). These values are represented as pie charts on 1:10 000 map sheets (Figs. 6.8a – d and 6.9a – f). The most vulnerable locations correspond to narrow to moderately wide beaches with lowland areas in the backshore, no nearshore reefs and few engineering structures along their length.

²⁶ Rotation is used after factor extraction procedures to maximise high correlations and minimise low ones. Varimax rotation is a variance maximisation procedure whereby the variance of factor loadings is maximised by making high loadings high and low ones lower for each factor (Tabachnick and Fidell 2001).

Table 6.3 Normalised Varimax Factor Components

No.	Segment Name	Communality	Components						
			1	2	3	4	5	6	7
1	South Point	.773	9.779E-02	-.743	-.382	-.166	.138	2.963E-02	-.135
2	Oistins	.885	-.170	-9.864E-02	-.127	-3.164E-02	-.238	5.497E-02	-.877
3	Casuarina	.806	-.823	-2.234E-02	-1.274E-02	-.222	.111	-.163	-.201
4	Dover	.809	-.623	.114	-.418	-6.915E-02	.108	-.455	-.100
5	St. Lawrence	.773	-.772	-.119	-.106	-.110	-.343	-9.214E-02	.112
6	Worthing	.835	-.295	-2.637E-02	-.619	-.123	-.305	-.505	4.317E-02
7	Rockley	.743	-.425	7.178E-02	-.182	-.588	.186	.321	-.202
8	Hastings	.840	1.257E-02	-.176	.161	-.800	.333	-.175	-4.125E-02
9	Carlisle Bay	.919	.597	.180	-.187	.180	-.626	-.232	.132
10	Bridgetown Harbour	.921	5.841E-02	-.940	-7.449E-02	-.143	-5.760E-02	-6.154E-02	-3.023E-02
11	Brighton	.892	.326	.570	-.483	.366	.112	-4.298E-02	-.282
12	Batts Rock	.969	.758	-2.155E-02	-.215	-.447	-.256	-.265	.108
13	Fitts Village	.861	.564	.592	9.690E-02	-.126	2.068E-02	.334	.233
14	Paynes Bay	.775	.432	-.351	-.429	.284	-.399	-.186	-7.963E-02
15	Sandy Lane	.868	.349	.687	.119	.138	-.153	.286	.367
16	Holetown	.742	-7.866E-02	.407	.536	.475	.190	.136	5.324E-02
17	Porters	.983	-.218	.228	.891	.215	-2.568E-02	-3.128E-02	.207
18	Royal Pavilion	.881	.281	.127	.848	-.137	.203	5.931E-02	5.827E-02
19	Gibbs Bay	.903	8.877E-02	.430	.370	.221	-.313	.225	.613
20	Mullins Bay	.893	8.507E-03	.168	-6.646E-02	.603	.418	.202	.530
21	Goddings Bay	.966	5.858E-02	.207	7.054E-02	.148	.135	.933	5.481E-02
22	Speightstown	.821	.194	.323	.354	.699	.222	.122	1.068E-02
23	Smittons Bay	.875	1.014E-02	-4.527E-02	.131	1.017E-02	.898	7.577E-02	.206

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalisation. Rotation converged in 28 iterations.

Table 6.4a Value Ranges used in CV Scale and CVI Determination for South Coast Segments

Vulnerability Rating Scale	% Score	CVI
Low (0 – 25%)	<11.75	I
Moderate (25 – 50%)	11.75 – 36.5	II
High (50 – 75%)	36.5 – 61.5	III
Very high (75 – 100%)	>61.5	IV

Table 6.4b Coastal Location Names and Boundaries for South Coast Segments

No.	Segment Name	Segment Boundaries
1	South Point	South Point - Enterprise
2	Oistins	Enterprise - Welches
3	Casuarina	Welches - Casuarina
4	Dover	Casuarina - Dover
5	St. Lawrence	Dover - Little Bay
6	Worthing	Little Bay - Cacrabank
7	Rockley	Cacrabank - Coconut Court
8	Hastings	Coconut Court - Needham's Point
9	Carlisle Bay	Needham's Point - Fort Willoughby
10	Bridgetown Harbour	Fort Willoughby - Brighton

Table 6.4c Summary of Determined CVIs for the South Coast.

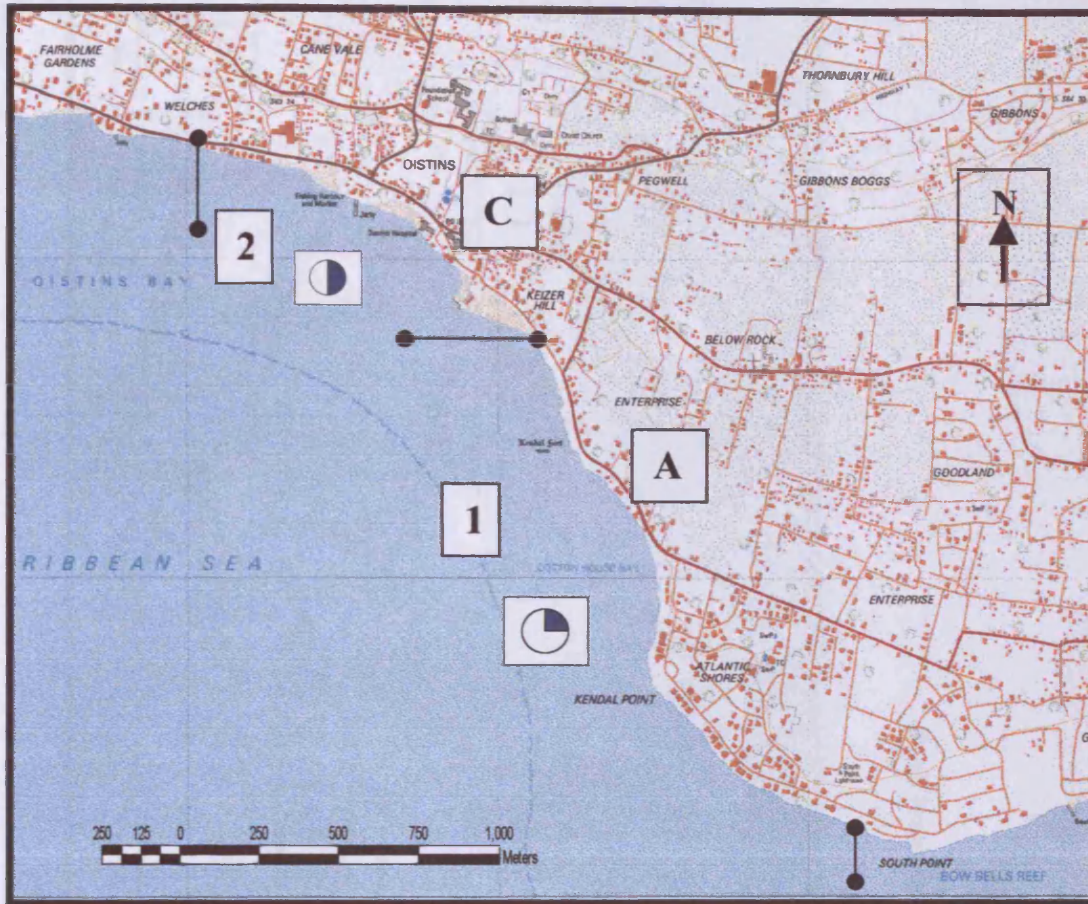
South Coast Name	% Vulnerability	Vulnerability Scale	CVI
South Point	9.8	Low	I
Oistins	17.0	Moderate	II
Casuarina	82.3	Very high	IV
Dover	62.3	Very high	IV
St Lawrence	77.2	Very high	IV
Worthing	29.5	Moderate	II
Rockley	42.5	High	III
Hastings	1.3	Low	I
Carlisle Bay	59.7	High	III
Bridgetown Harbour	5.8	Low	I

Fig. 6.8a South Coast Map - South Point to Oistins

(Scale based on original 1:10 000) (Source: Original)

63787mN
27000mE

63787mN
31125mE



61000mN
27000mE

61000mN
31125mE

Coastal Vulnerability Symbol Key for Fig. 6.8a - d

Where 1 – 23 = Identification number of coastal segment; A – D = Coastal zoning group





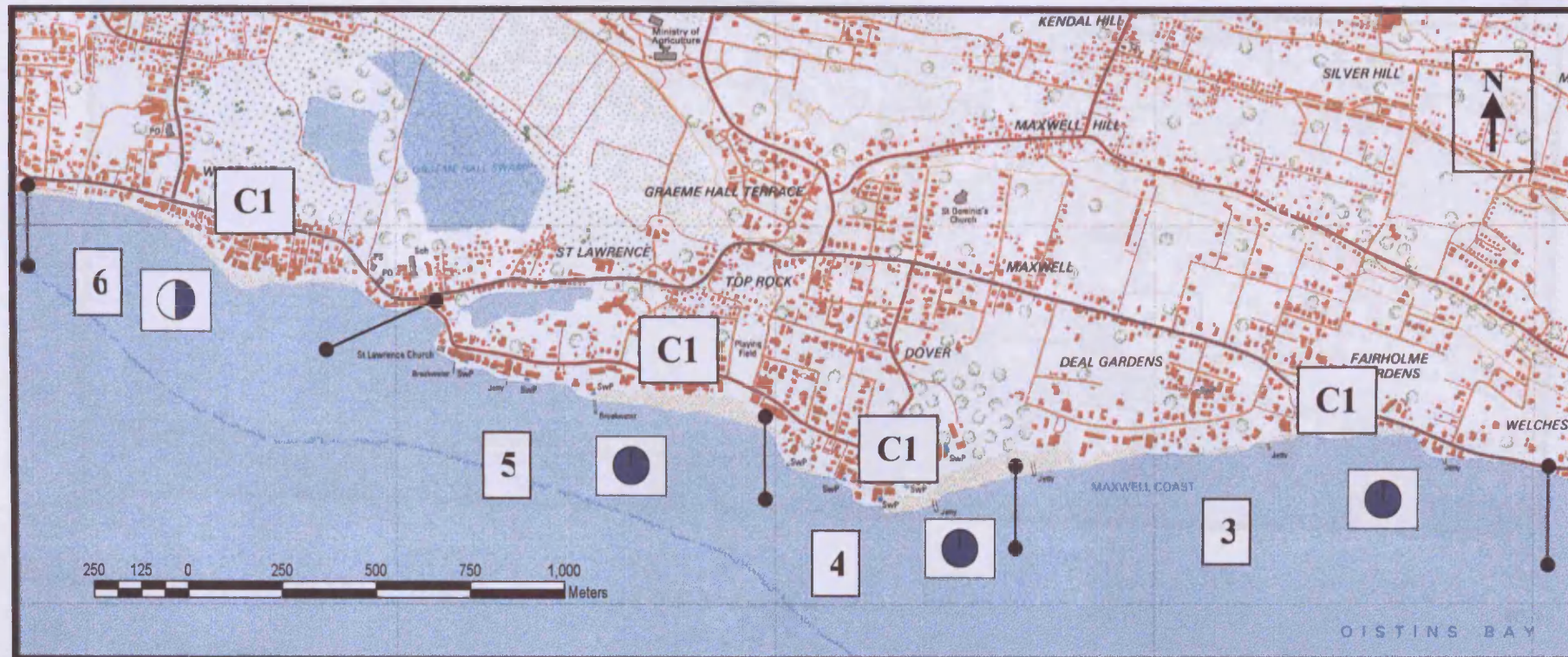
-  Low Vulnerability; CVI = I
-  Moderate Vulnerability; CVI = II
-  High Vulnerability; CVI = III
-  Very High Vulnerability; CVI = IV

Fig. 6.8b South Coast Map - Welches to Worthing
 (Scale based on original 1:10 000) (Source: Original)

63536mN
 23750mE

63536mN
 26943mE



61857mN
 23750mE

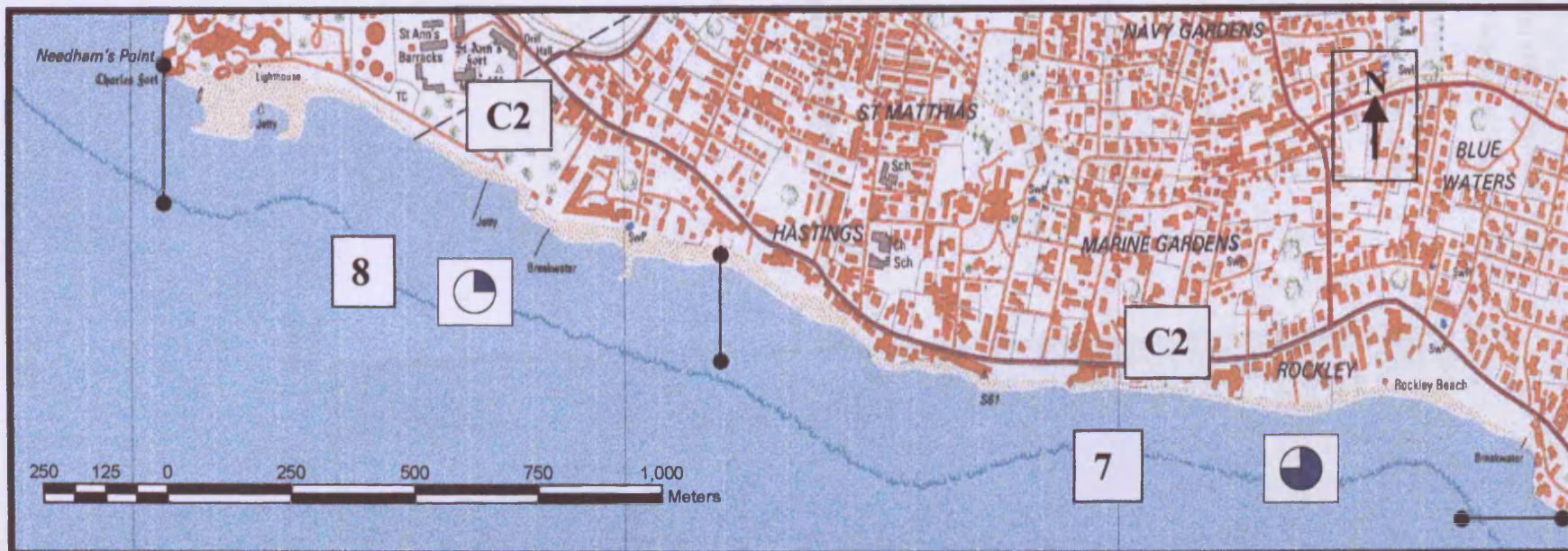
61857mN
 26943mE

Where 1 – 23 = Identification number of coastal segment; A - D = Coastal zoning group

Fig. 6.8c South Coast Map - Cacrabank to Needham's Point
 (Scale based on original 1:10 000) (Source: Original)

63939mN
 22800mE

63939mN
 24600mE



63104mN
 22800mE

63104mN
 24600mE

Coastal Vulnerability Symbol Key Where 1 - 23 = Identification number of coastal segment; A - D = Coastal zoning group



Low Vulnerability; CVI = I



Moderate Vulnerability; CVI = II



High Vulnerability; CVI = III







Very High Vulnerability; CVI = IV

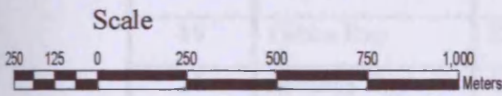
Fig. 6.8d South Coast - Needham's Point to Bridgetown
 (Scale based on original 1:10 000) (Source: Original)

Coastal Vulnerability Symbol Key

Where 1 – 23 = Identification number of coastal segment;

A - D = Coastal zoning group

-  Low Vulnerability; CVI = I
-  Moderate Vulnerability; CVI = II
-  High Vulnerability; CVI = III
-  Very High Vulnerability; CVI = IV



63501mN
20966mE

66127mN
23509mE

Table 6.5a Value Ranges used in CV Scale and CVI Determination for West Coast Segments

Vulnerability Rating	% Score	CVI
Low (0 – 25%)	<9	I
Moderate (25 – 50%)	9 – 21	II
High (50 – 75%)	21 – 35	III
Very high (75 – 100%)	>35	IV

Table 6.5b Coastal Location Names and Boundaries for West Coast Segments

No.	Segment Name	Segment Boundaries
11	Brighton	Brighton - Batts Rock
12	Batts Rock	Batts Rock - Prospect
13	Fitts Village	Prospect - Crystal Cove
14	Paynes Bay	Crystal Cove - Paynes Bay
15	Sandy Lane	Paynes Bay - Almond Beach Club
16	Holetown	Almond Beach Club - Folkestone
17	Porters	Folkestone - Royal Pavilion
18	Royal Pavilion	Royal Pavilion - Reads Bay
19	Gibbs Bay	Reads Bay - Gibbs
20	Mullins Bay	Gibbs - Road View
21	Goddings Bay	Road View - Fort Denmark
22	Speightstown	Fort Denmark – Little Good Harbour
23	Smittons Bay	Little Good Harbour – Fryers Well Bay

Tables 6.5c Summary of CVI for the West Coast

West Coast Name	% Vulnerability	Vulnerability Scale	CVI
Brighton	32.6	High	III
Batts Rock	75.8	Very high	IV
Fitts Village	56.4	Very high	IV
Paynes Bay	43.2	Very high	IV
Sandy Lane	34.9	High	III
Holetown	7.9	Low	I
Porters	21.8	High	III
Royal Pavilion	28.1	High	III
Gibbs Bay	8.8	Low	I
Mullins Bay	8.5	Low	I
Goddings Bay	5.9	Low	I
Speightstown	19.6	Moderate	II
Smittons Bay	1.0	Low	I

Fig. 6.9a West Coast Map – Bridgetown to Fitts Village
 (Scale based on original 1:10 000) (Source: Original)





20966mE
 72034mN

23509mE
 72034mN

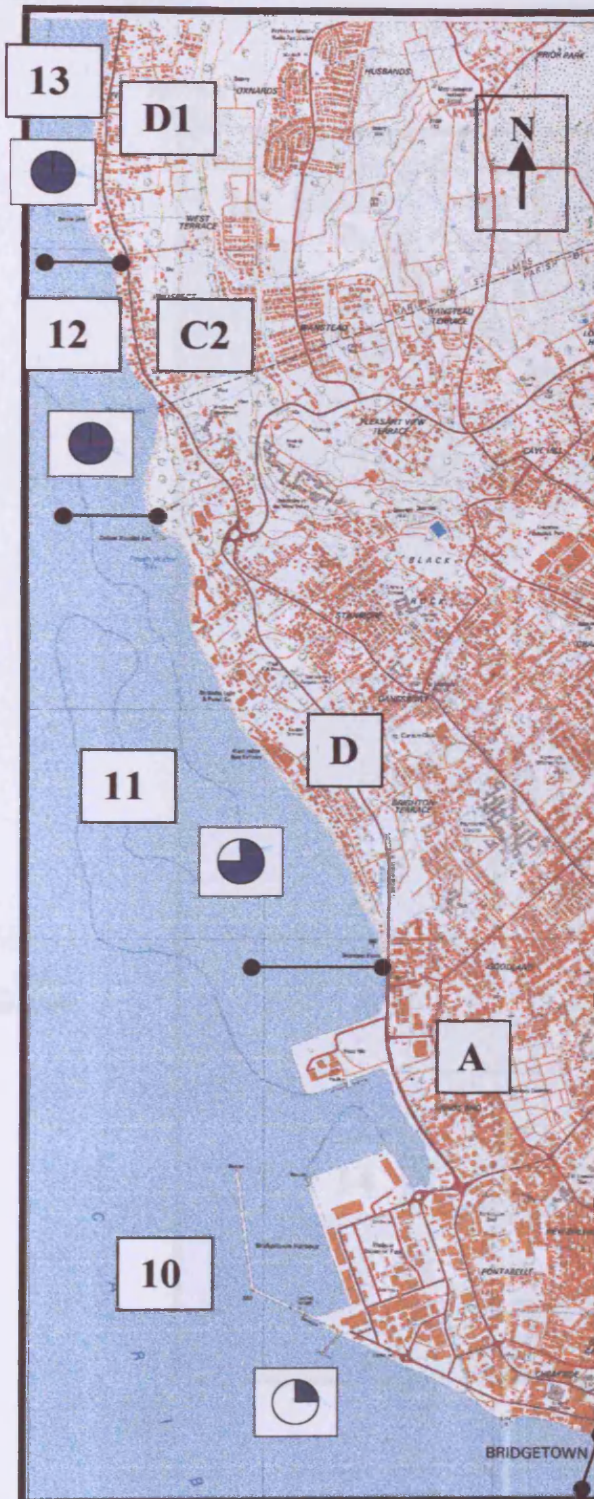
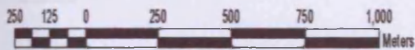
Coastal Vulnerability Symbol Key

Where 1 – 23 = Identification number
 of coastal segment;

A - D = Coastal zoning group

-  Low Vulnerability; CVI = I
-  Moderate Vulnerability; CVI = II
-  High Vulnerability; CVI = III
-  Very High Vulnerability; CVI = IV

Scale







20966mE
 65525mN

23509mE
 65525mN

Fig. 6.9b West Coast – Fitts Village to Almond Beach Club
 (Scale based on original 1:10 000) (Source: Original)

Coastal Vulnerability Symbol Key

Where 1 – 23 = Identification number of coastal segment;
 A - D = Coastal zoning group;

-  Low Vulnerability; CVI = I
-  Moderate Vulnerability; CVI = II
-  High Vulnerability; CVI = III
-  Very High Vulnerability; CVI = IV

Scale

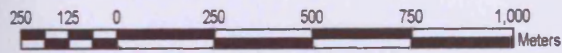


Fig. 6.9c West Coast – Regent to Mount Standfast
 (Scale based on original 1:10 000) (Source: Original)





20723mE
 78011mN

21751mE
 78011mN

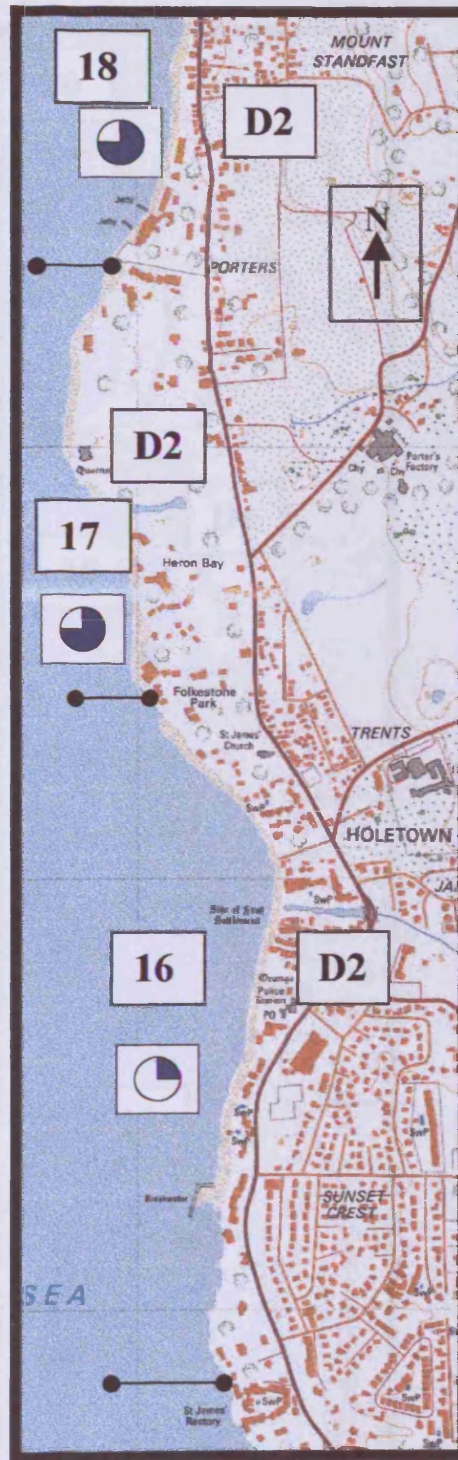
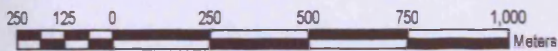
Coastal Vulnerability Symbol Key

Where 1 – 23 = Identification number
 of coastal segment;

A - D = Coastal zoning group

-  Low Vulnerability; CVI = I
-  Moderate Vulnerability; CVI = II
-  High Vulnerability; CVI = III
-  Very High Vulnerability; CVI = IV

Scale



20723mE
 746609mN

21751mE
 74660mN

Fig 6.9d West Coast – Mount Standfast to Gibbs

(Scale based on original 1:10 000) (Source: Original)





20549mE
81014mN

21289mE
81014mN

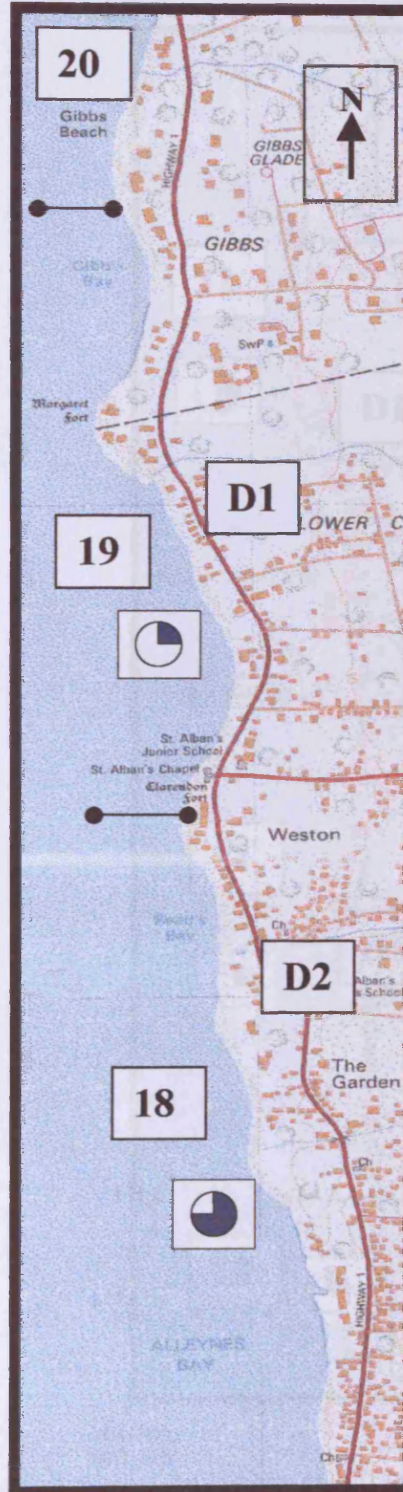
Coastal Vulnerability Symbol Key

Where 1 – 23 = Identification number
of coastal segment;

A - D = Coastal zoning group

-  Low Vulnerability; CVI = I
-  Moderate Vulnerability; CVI = II
-  High Vulnerability; CVI = III
-  Very High Vulnerability; CVI = IV

Scale







20549mE
78004mN

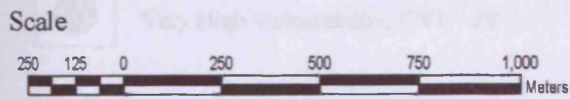
21289mE
78004mN

Fig. 6.9e West Coast – Gibbs to Almond Beach Village
 (Scale based on original 1:10 000) (Source: Original)

Coastal Vulnerability Symbol Key

Where 1 – 23 = Identification number
 of coastal segment,
 A - D = Coastal zoning group

-  Low Vulnerability; CVI = I
-  Moderate Vulnerability; CVI = II
-  High Vulnerability; CVI = III
-  Very High Vulnerability; CVI = IV



20530mE 21000mE
 84000mN 84000mN



20530mE 21000mE
 80664mN 80664mN





Fig. 6.9f West Coast Map – Port St. Charles to Fryers Well Bay
 (Scale based on original 1:10 000) (Source: Original)

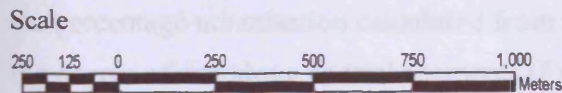
19750mE
 86475mN

21080mE
 86475mN

Coastal Vulnerability Symbol Key

Where 1 – 23 = Identification number
 of coastal segment;
 A - D = Coastal zoning group

-  Low Vulnerability; CVI = I
-  Moderate Vulnerability; CVI = II
-  High Vulnerability; CVI = III
-  Very High Vulnerability; CVI = IV



19750mE
 84000mN

21080mE
 84000mN

The summary CVA maps are useful in the interpretation of coastal segments. As with the ESI summary maps (Section 5.5), they have been digitally georeferenced, providing for integration into GIS for future use and updating.

6.4.5 Degree of Risk

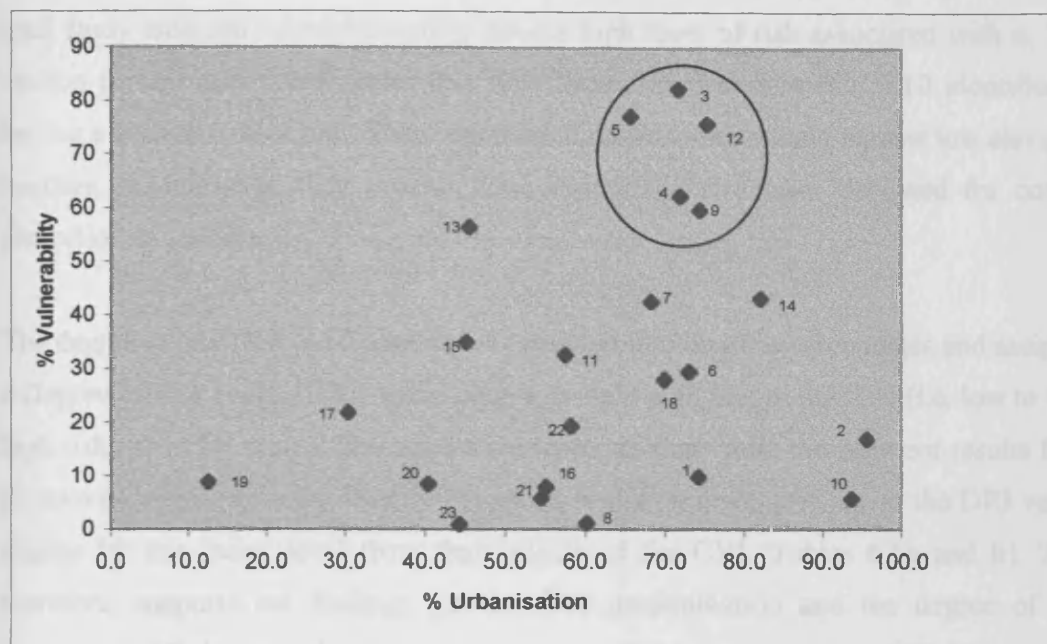
The risk posed by coastal flooding hazards along the coastal segments has been determined by reviewing historical reports of sea flooding as well as significant terrestrial runoff events (Ministry of Transport and Works 1995, and CERO 1998). This has provided useful information on various coastal stretches prone to periodic storm flooding damage. In addition, during the Pre-Investment Study in Coastal Conservation for the West and South coasts of the island (1995), Delcan International was able to determine the predicted 1:100 year flood line through storm surge modelling. It was estimated that the flood line could be predicted to extend approximately 200m inland from the coastline²⁷ or in some locations inland to the 4m contour line on the coast (Delcan 1995c, Halcrow 1999).

As stated in Section 6.4.4, Factor 1 has been used to complete the determination of the degree of risk procedure. It is the principal factor that reflects the present condition of the coastline. The Factor 1 values were converted into percentages to represent the vulnerability percentages of the coastline. These percentage values were plotted against the percentage urbanisation calculated from the aerial photographs in order to determine the degree of risk along coastal segments (Fig. 6.10, Appendix 6 Table VII).

The plotted results indicate that there are five coastal segments that show the highest degree of risk (in descending order) - Casuarina (3), St Lawrence (5), Batts Rock (12), Dover (4) and Carlisle Bay (9). The least risk locations are found in the Smittons Bay (23), Mullins Bay (20) and Gibbs Bay (19) segments.

²⁷ Refer to Delcan (1995b & c).

Fig. 6.10 Degree of Risk of Coastal Segments



Where 1 = South Point; 2 = Oistins; 3 = Casuarina; 4 = Dover; 5 = St Lawrence; 6 = Worthing; 7 = Rockley; 8 = Hastings; 9 = Carlisle Bay; 10 = Bridgetown Harbour; 11 = Brighton; 12 = Batts Rock; 13 = Fitts Village; 14 = Paynes Bay; 15 = Sandy Lane; 16 = Holetown; 17 = Porters; 18 = Royal Pavilion; 19 = Gibbs Bay; 20 = Mullins Bay; 21 = Goddings Bay; 22 = Speightstown; 23 = Smittons Bay.

This approach has demonstrated the ability to use factor analysis to relate coastal segments to the general shoreline urbanisation. In addition, it allows for the designation of a degree of risk to a coastal segment. Vulnerable locations are those with the highest percentages for vulnerability and urbanisation. Locations with more than 50% values on both scales have been selected as potentially prone to environmental risk. Thereafter, those locations with the highest percentages are identified.

From Fig. 6.10, it is observed that much of the coastline is more than 50% urbanised. However, much of the coastline demonstrates a low vulnerability to flooding. This is an appropriate representation as much of the coast is currently protected by engineering structures of varying forms and age. These structures were installed largely as a result of

coastal properties either experiencing property damage or gradual yet progressive erosion of their associated beach areas. From Section 6.4.4, approximately half of the total study area can be considered to have a high level of risk associated with it. This section (6.4.5) also corroborates this with locations circled in Fig. 6.10 identified as having a high degree of risk. They represent locations with mainly narrow low elevation beaches. Additionally, they possess few engineering structures designed for coastal protection or stability.

The degree of risk (Fig. 6.10) can also be divided into quartile percentages and assigned a Degree of Risk Index (DRI) value commensurate with that of the CVI (i.e. low to very high risk – I to IV scale). The results demonstrate that while the segment results from the two approaches are not exactly the same, in only a few instances do the DRI values change by one index level from that calculated for CVI (Tables 6.6a and b). This, therefore, supports the findings for the CVI determination and the degree of risk associated with the coastal segments.

Table 6.6a Comparison of South Coast Results

Segment No.	CVI	DRI
1	I	I
2	II	I
3	IV	IV
4	IV	III
5	IV	IV
6	II	III
7	III	III
8	I	I
9	III	III
10	I	I

Table 6.6b Comparison of West Coast Results

Segment No.	CVI	DRI
11	III	III
12	IV	IV
13	IV	III
14	IV	III
15	III	III
16	I	I
17	III	I
18	III	III
19	I	I
20	I	I
21	I	I
22	II	I
23	I	I

6.5 DISCUSSION

This aspect of the research has allowed for the determination of coastal groupings and has been able to test a method of low cost coastal zoning based on multivariate statistical analysis of almost uniform coastal sectors. This has been achieved by the combined use of morphological and physical variables. The applied techniques have demonstrated flexibility, with both the types of variables and their numbers being able to be changed according to the data available and the research needs. This characteristic is consistent with that presented in the literature (Dal Cin and Simeoni 1987, 1989, 1991 and 1994, Amore and Randazzo 1994, Simeoni *et al.* 1997). While Dal Cin and Simeoni (1991 and 1994) only used three factors (with a high variance of 83%) to determine the coastal vulnerability for their study area, Amore and Randazzo (1994) found that their research area was described by six factors (with a low variance of 73%). They determined that these six factors were necessary to show the variation in environmental

conditions within the same system. The results from this current research, more closely resemble those described by Amore and Randazzo as a total of six factors (with a variance of 80%)²⁸ have been identified to describe the variation in environmental conditions along the study area.

The results illustrate that 52% of the west and south coasts are highly vulnerable to potential erosion and storm inundation (Tables 6.4c and 6.5c). Along the south coast, 50% of the locations are highly vulnerable with the continuous coast segments from Welches to Little Bay of very high vulnerability. On the west coast, 54% of the locations can be characterised as highly vulnerable with the continuous segments from Batts Rock to Paynes Bay of very high vulnerability. The results have significant implications for the current coastal land use categories. They have identified that along the south coast tourism and related accommodation are the main land affected. On the west coast, a wider diversity of affected land use classifications includes industry, local residential accommodation (both high income and low income accommodation), and tourism accommodation (hotels and villas).

For coastal risk determination, Segments 3, 4, 5, 9 and 12 display similar results using both methods. These results, therefore, support each other, identifying areas worthy of prioritised attention. However, the use of the level of coastal urbanisation adds an additional dimension to the research, identifying the coastal segments with the greatest degree of risk to be associated with them.

The required accuracy of the collected data is critical. The equipment used to measure the variables (Table 6.7 and Section 5.4.6.3) allows for cost savings and provides an effective starting point for the acquisition of field equipment necessary in CVI determinations. The ability to describe similar or homogenous coastal segments presents an effective tool for the general management of the Barbados coast; however, the variables identified are sufficiently generic to allow their further application to other small island situations.

²⁸ The use of three factors only accounts for 53% of the variance while seven factors account for 83% of the variance.

6.6 EVALUATION OF THE TECHNIQUE USED

6.6.1 Variables Used in the Barbados Experience and their Application in a Wider Context

The variables have fully captured much of the littoral description for all the coastal segments. Their use in a monitoring programme allows for the comprehensive collection of relevant on-site data, and is, therefore, useful in the establishment of baseline data, on which trend analysis can be eventually performed.

As part of this research, the use of cluster analysis has demonstrated that oceanographic variables do not have a direct influence on the overall variable groupings. The wave angle variable appears to be the only variable with direct relation to any particular variable grouping. Despite this, it was decided to retain all the oceanographic variables, as their information is also required in the determination of the WEI. It has been demonstrated that the ALM is the most appropriate clustering method for grouping the coastal segments. This is consistent with the literature (e.g. Dal Cin and Simeoni 1989, 1991 and 1994, Amore and Randazzo 1994, and Simeoni *et al.* 1997).

6.6.2 Available Data

Generally, the results have been generated from *in situ* primary data sources and, where appropriate, the incorporation of appropriately referenced and accurate data.

6.6.3 Economic Cost

The economic cost associated with technique includes the cost of equipment, transportation to site and man-hours for collecting the data (Table 6.7). The only new equipment item for consideration is the laser hypsometer range finder, used to measure object distances and heights of objects. This equipment, costing approximately US \$679 (GB £431), is recommended, given its level of accuracy (Table 5.16). Once calibrated,

the speed with which distance can be measured is enhanced. The only restriction to the instrument is that it requires the manual recording of data on field sheets. If the Pulse Total Station, previously identified, has been purchased, there is no need for the purchase of this equipment as much greater accuracy is achieved with the Total Station.

The greatest cost associated with this procedure is the actual processing and interpretation of the collected data, using the multivariate analysis techniques. It can be expected that in the initial stages, this procedure and the interpretation of the results will take in excess of 60 days (Table 6.7) to learn. As presented here, the cost to perform the necessary analyses including training time and the additional time required for data processing and analyses is GB £2893 (US \$4824). However, this cost should naturally reduce over time, as the procedure becomes more familiar to personnel performing the analysis. Additionally, as new data are entered as part of the updating process on the computer system, the method would allow for the rapid reprocessing and further updating of the results. The transportation, man-hour and the training costs have been previously considered in Section 5.4.6.3 and referred to in Section 5.2.5.3. They are, therefore, not included in the new totals.

Table 6.7 Cost Associated with the Determination of CVI (indicated as man week costs)

Activity Determination of CVI	Number of staff (weekly rate) and staff time (days) required to do survey	Cost GB £ (US \$)
Field equipment cost*		1254 (2046)
Optical laser hypsometer and range finder (to measure height of and distance to objects)		431 (679)
Transportation cost **		15 (23)
Man week cost (data acquisition)**	2 staff (week rate £121 (US\$ 199) per man); 5 days	1210 (1990)
Man week cost (data processing)	1 staff (week rate £ 168 (US\$ 277)); 60 days	2102 (3324)
Training cost	1 staff (week rate £455 (US\$ 750)); 10 days	910 (1500)
Total***		4120 (6870)

Table Notes:

*Refer to Appendix 5 for equipment listing.

** Man week costs are salary rates based on current Government monthly salary scales for the positions of Chainman (for field data collection) and Clerical Officer (for data processing) as these are the level of staffing required to perform these works. These costs which are weekly rates are not included since they have been already quoted.

*** Costs not included here would be the purchase of direct capital costs (e.g. computer hardware (including colour printer and incidentals for computer usage) and associated software (Microsoft Office Suit and SPSS). Costs not accounted for here also include the equipment cost and the transport cost as they have already been presented previously.

6.6.4 Logistics and Administration

The same logistical issues, as previously described for the CSI determination (Section 5.3.5.4) apply to this index development. In this research, the use of current beach profile locations made the selection of monitoring sites effective for repetitive use. The ability to return to the same site also aids in determining the seasonal and long-term trends and improves the research validity for each location.

Careful consideration has to be given to the future selection of adequate personnel for processing and interpretation of the data. The multivariate analysis, in particular, requires proper training in the applied statistical techniques. This is the most difficult of the procedures used in the development of the LVAP, and is also the most critical as it assists in the prioritised identification of risk areas.

6.7 RECOMMENDATIONS

Currently, the proposed variables for field data collection are multifaceted. The field data sheet, developed for the determination of CVI, is appropriate for general data collection. Additionally, as the variables are cross-functional, the use of the one-data sheet is appropriate for its proposed function. Therefore, modification of the field sheet is not currently recommended. However, as the capacity to measure new variables is achieved, modifications can occur.

6.7.1 Modification of the Technique

With improved capability for data collection, and the use of shoreline modelling software, other potential variables could include the gross and net longshore sediment transport rates, and mean energy flux per unit of coastline for coastal segment²⁹. These

²⁹ These parameters can be calculated directly from some existing software e.g. CEDAS (Coastal Engineering Design and Analysis System) (see <http://chl.wes.army.mil/software/cedas/>) and Delft3D (see <http://www.wldelft.nl/d3d/mor/index.html>).

variables might allow for the general removal of the oceanographic variables and, once the wave exposure index for coastal segments has been clearly defined, it is highly unlikely that it would change rapidly over time. The drawback to this is the need for the use of specialised coastal modelling software. Associated with the use of this software is the need for specific training. However, in the long term the application of such analytical techniques has to be considered as their level of accuracy has improved significantly within recent times, resulting in the numerical models being based on a high level of standardisation to improve their “predictive reliability” for real world conditions/scenarios.

6.8 SUMMARY

Chapter Six has presented the CVI procedure and findings. The methodology has relied on the use of *in situ* field measurements of coastal descriptors and their interpretation through the use of multivariate analyses. The results have demonstrated that the ALM, used in the cluster analysis, best represents the variable associations for the 19 variables used. These variables, when applied to the coastal segments, identify four main group types: cliffed coasts, coasts with structures, narrow mixed coast beaches, and wide to moderately wide beaches. However, the main feature shown is the dissimilarity between the two coastlines, with most coastal segments grouping together according to their respective coastline designations and having association with their adjacent shoreline segments. Factor analysis has aided the easy identification of vulnerable areas. When plotted against the calculated percentage urbanisation for the coastal segments it allows for the determination for the degree of risk for the coastal locations.

In general, it can be concluded that this approach has allowed for effective data use, routinely collected as part of a beach monitoring programme, to produce useful characterisations of the coast. Additionally, the ability to classify coastlines objectively based on their physical and human characteristics ensures the removal of “bias” in coastal development considerations.

Chapter 7

Quantification of Coastal Risk Using Geographic Information System Analysis

Chapter 7

Quantification of Coastal Risk Using Geographic Information System Analysis

7.1 INTRODUCTION	262
7.2 REVIEW OF GEOGRAPHIC INFORMATION SYSTEM USE IN COASTAL MANAGEMENT.....	262
7.3 QUANTIFICATION OF SHORELINE RISK METHODOLOGY	265
7.3.1 INTRODUCTION	265
7.3.1.1 Quantification Matrix.....	266
7.3.1.2 Data Categorisation.....	269
7.3.1.3 Population.....	270
7.3.2 RESULTS OF GIS RISK QUANTIFICATION	271
7.3.2.1 Risk Quantification for Coastal Features found in the Study Areas.....	271
7.3.2.2 Risk Quantification for Areal Coastal Features.....	271
7.3.2.3 Risk Quantification for Linear Coastal Features	274
7.3.3 DISCUSSION.....	278
7.3.3.1 Evaluation of the Technique.....	278
7.3.3.2 Recommendations.....	282
7.4 METHODOLOGY FOR ECONOMIC VULNERABILITY DETERMINATION	283
7.4.1 INTRODUCTION	283
7.4.1.1 Land Parcel Database	284
7.4.1.2 Degree of Coastal Urbanisation.....	284
7.4.1.3 Vulnerability of Developed Land Parcels.	285
7.4.2 RESULTS OF ECONOMIC VULNERABILITY DETERMINATION	285
7.4.2.1 Total Combined Study Areas	286
7.4.2.2 Combined West Coast Study Areas.....	287
7.4.2.3 Combined South Coast Study Areas.....	288
7.4.2.4 Individual Study Areas.....	291

7.4.3 DISCUSSION.....	304
7.4.3.1 Evaluation of the Technique.....	307
7.4.3.2 Procedure Used in the Barbados Experience and their Wider Application	309
7.4.4 RECOMMENDATIONS.....	310
7.4.4.1 Modification of the Technique	311
7.4.4.2 Limitation to this Research Process.....	312
7.5 SUMMARY.....	314

7.1 INTRODUCTION

Chapter Seven describes the third stage of the research methodology (Fig. 4.1) presenting the analysis of a generalised physical hazard rating for the coastline, using socio-economic data for five case study areas. This approach provides a monetary assessment of the risk of property loss associated with the case study sites and addresses the research objectives 1, 3, and 6 identified in Section 1.3.2.2. Chapter Seven presents the next stage of the LVA process by identifying and linking the basic economic variables that can be applied in coastal vulnerability determination, in terms of the cost of potential property loss.

This chapter is divided into four sections, describing the relevant procedures used within the research data collection and analysis processes:

- Section 7.2 presents the rationale for GIS use in the research;
- Section 7.3 introduces the methodology used in the quantification of shoreline risk, based on land use classifications.
- Section 7.4 presents the results and main findings of coastal economic risk quantification using socio-economic variables, associated with the coastal study areas.
- Section 7.5 provides a chapter summary relating the general findings of this research component.

7.2 REVIEW OF GEOGRAPHIC INFORMATION SYSTEM USE IN COASTAL MANAGEMENT

Most environmental managers consider data acquisition an important and integral part of any managerial process. Primary data can be collected by field surveys and questionnaires using direct methods¹ or remote sensors (e.g. aerial photography,

¹ As described in Chapters 4, 5, and 8.

LIDAR, satellite images² or automatic data recorders). Secondary data is also useful in environmental management (e.g. pre-existing maps, aerial reconnaissance, census data and other documented data and information). This data gathering can be time consuming, and costly (to get an effective understanding of the management requirements for a given area).

Having acquired the data, it is necessary to use it in an informative manner. Geographic Information Systems (GIS) are being increasingly used for this purpose, as part of mainstream environmental management decision support systems³. GIS application, within the area of ICZM, has also increased over the last decade as its recognized versatility has become more readily available and even more importantly, more user friendly⁴ (Box 7.1).

It is clear that the size of the database is only limited according to/dependent on:

- (1) the quantity of information that can be collected and stored for inclusion in the analysis (Hastings & White 1996).
- (2) The technical ability of the GIS operator to manipulate the software to extract the maximum amount of interrelated and correlated information, available in the established/existing system.
- (3) The ability of the processing system chosen to functionally manipulates the data.

The advantages and disadvantages of using GIS are presented in Appendix 7.1.

² Refer to Green *et al.* (2000), Stock *et al.* (1992), Curr *et al.* (1997), Edwards *et al.* (1998), and Klemas (2001).

³ Refer to Enache (1994), Masikerei (1995), Mejia-Navarro and Garcia (1995), Lobo-Ferrera (1997), Moore *et al.* (1997), Ferrario *et al.* (1998), Luger *et al.* (2000).

⁴ For the variety of applied uses of GIS in the field of coastal management refer to the uses examples demonstrated by Townend & Leggett (1992), Grano and Roto (1992), Gornitz *et al.* (1994), Raper *et al.* (1994), Garofalo *et al.* (1997), Berry *et al.* (1998), Thieler and Hammar-Klose (1999), Greve *et al.* (2000), Hennecke and Cowell (2000), Finkl (2000), Dobosiewicz (2001), and Esnard *et al.* (2001).

Box 7.1 Significant Data Management Advantages of GIS Use

(Source: Siderelis 1991)

- Provision of a common database to support technicians, scientists, planners, and decision-makers.
- GIS use can foster institutional change through forging new working relationships between agencies.
- Allied technologies (e.g. remote sensing) can be incorporated into the production setting.

The interdisciplinary nature of ICZM emphasises the need for (a) readily accessible data and information, delivered in a timely and reliable manner, and in a suitable form for the required tasks; and (b) the need for a large capacity to store data and information (Rhind 1981). AGI (1994) have identified the following explanations for encouraging the support of GIS use in ICZM:

- It has the ability to handle much larger databases and through data integration and synthesis can incorporate data from a much wider range of relevant criteria. This produces more balanced and coordinated management strategies over greater areas of application⁵ than could be formerly achieved through manual methods.
- GIS applications require the use of standardised data. It highlights the issues associated with the standardisation of coastal data definitions, data collection and storage. This promotes improved data compatibility and consistency, and easier processing techniques. This is especially applicable for government departments and agencies that may have interrelated requirements for shared information.
- GIS allows for the effective modelling of alternate management scenarios before a strategy is applied to actual management situations.

Maps allow for large quantities of data to be easily represented in a form for easy understanding and interpretation (Owen 2002) and can accurately reflect an “inventory

⁵ The extended spatial coverage can incorporate coastal and inland areas and their impinging effects more effectively.

of where at risk categories exist” also provides an invaluable tool in the management of areas⁶. This is especially true when considering coastal hazard mitigation and vulnerability assessments. These maps provide an invaluable tool for emergency managers and disaster responders from both the public and non-profit sectors (e.g. disaster relief agencies). In short, the use of GIS allows “*planners to integrate social and geographic data in order to understand disaster as a social phenomenon*” (Dash *et al.* (1997) cited Heinz Centre 2000a).

7.3 QUANTIFICATION OF SHORELINE RISK METHODOLOGY

7.3.1 Introduction

This research component demonstrates how coastal characterisation data, in combination with additional data sources from relevant government departments, can be effectively used to provide a preliminary determination of the vulnerability to economic loss, along the coastline. It describes the methodology used to fulfil the aims of the initial research objectives (Section 1.3.2.2). It identifies the necessary basic data, used as the building blocks for the general quantification of risk, experienced along the coastal segments. It demonstrates an alternative approach for vulnerability assessment and risk analysis techniques for various aspects of land use planning and management.

There has been previously little work undertaken in the Caribbean region or on small islands in this field, on which to base the research methodology. The application of this technique, therefore, provided an important contribution to the research literature.

⁶ Refer to Gornitz *et al.* (1994a), Gornitz *et al.* (1997) and Thieler and Hammar-Klose (1999) regarding GIS mapping applications for coastal vulnerability assessment; Parthiphan and Kirshnan (1994), and NOAA (1997) for GIS mapping applications for environmental sensitivity assessment to oil spills; the Heinz Centre (2000 b) and Fisher & Overton (2002) for GIS mapping application for the identification of erosion hazards and potential economic loss along coastal frontages.

7.3.1.1 Quantification Matrix

The principle sources of information were derived from the most up to date 1:10,000 and 1:5,000 scale topographic maps, obtained from the Lands and Surveys Department (1988) and the Land Valuation Department respectively (2000). Digital aerial photographs (2000) at 1:10,000 scales were obtained from the CZMU. As with the field survey approach, (Chapter Five), the primary interests were the shorefront properties.

A quantification matrix was developed for the five study areas. The data focus on the immediate 200m of the coastal fringe, within the landward limit of the CM area for the island. As part of the Feasibility Study in Coastal Conservation for the Barbados West and South Coasts, Delcan (1995) delineated this 200m CM area boundary, based on the identification of the potential 1:100 year storm surge inundation line (David Smith, *pers. comm.* 2001). This information was required to establish the legal boundary as identified in the Coastal Zone Management Act (1998) for the island and to provide a boundary designation for determining the location of potentially vulnerable infrastructure, should the coast be affected by storm surge. However, this research concentrates on the first 50m immediately adjacent to the shoreline, the area that would sustain the greatest impact from storm wave damage and which is always under constant threat from coastal hazards.

The determination of the risk associated with each of the five study areas, was modified from the International Sea Level Rise Studies Projects Quantification Matrix (Table 7.1 and Table 7.2). These data were collected for each of the five study areas.

Table 7.1 International Sea Level Rise Studies Project Risk Quantification and Data Matrix. (Source: Psuty & Devine 1992)

Type of Measurement required	Zone 1 (Depressions)	Zone 2 (0 – 2.5m above sea level)
<p>Linear (Length of feature in Kilometres)</p>	<p><u>Natural Features</u> Marsh/mud/tidal flat Mangrove/swamp Coral reef Beaches (with/without dunes) Cliffs/Rock platforms</p> <hr/> <p><u>Cultural Features</u> Seawalls/jetties Bridges Dikes/canals</p>	<p><u>Natural Features</u> Cliffs Dunes</p> <hr/> <p><u>Cultural Features</u> Harbour frontage Bridges/roads/railways Commercial/industrial frontage Tourist resort frontage Residential frontage</p>
<p>Areal (Area in square kilometres)</p>	<p><u>Natural Features</u> Marsh Mud flat Mangrove/swamp</p> <hr/> <p><u>Cultural/Economic Features</u> Pasture (diked and undiked) Agriculture Aquaculture Industry Parks/Recreation Settlement</p>	<p><u>Natural Features</u> Forest/Scrub Grassland/Savannah</p> <p><u>Settlement types</u> Urban/rural distinctions Residential/informal sector Agriculture/fisheries Resorts/tourism</p> <hr/> <p><u>Cultural/Economic Features</u> Pasture (diked and undiked) Agriculture/aquaculture Industrial/commercial Parks/recreation/historical Harbour facilities, docks</p>
<p>Quantities</p>	<p><u>Cultural/Economic Features</u> Bridges (number affected) Farms (fish and crops) Groynes jetties and other infrastructure</p>	<p><u>Population</u> Urban/rural/informal settlement Farms, fishing centres</p> <hr/> <p><u>Economic Features</u> Ports, airports, marinas Industrial commercial sites Tourism (# of resorts/rooms etc.) Harbour statistics, Air traffic</p>
<p>Weight</p>	<p><u>Economic production</u> Agriculture Fishing Industrial</p>	<p><u>Economic production</u> Agriculture Fishing Industrial</p>
<p>Value (in U.S. \$)</p>	<p><u>Economic production</u> Agriculture Fishing Industrial</p> <p><u>Other</u> Structural protection (seawalls etc) Harbour facilities</p>	<p><u>Economic production</u> Agriculture Fishing Industrial</p> <p><u>Other</u> Residential Commercial</p>

Table 7.2 Risk Quantification and Data Matrix for the Barbados Coast.

(Source: Original)

Type of Measurement required	200m Boundary from Coastline
<p>Linear (Length of feature in Kilometres)</p>	<p><u>Natural Features</u> Coral Rubble tidal flats Coral reef Beaches (with/without dunes) Cliffs Rock platforms</p> <p><u>Cultural/Economic Features</u> Commercial/industrial frontage Tourist resort frontage Residential frontage</p> <p><u>Coastal Engineering Features</u> Seawalls, revetments, jetties and other infrastructure</p>
<p>Areal (Area in square kilometres)</p>	<p><u>Natural Features</u> Mangrove/swamp/wetland Forest/Scrub Grassland/Savannah</p> <p><u>Cultural/Economic Features</u> Agriculture Aquaculture Industry Parks/Recreation Settlement Residential Tourism Tourism Resorts</p>
<p>Quantities</p>	<p><u>Population</u> Urban/rural settlement Fishing villages</p> <p><u>Economic Features</u> Ports, marinas Industrial commercial sites Tourism (# of resorts/rooms etc.)</p> <p><u>Coastal Engineering Features</u> Groynes, revetments, seawalls and other infrastructure</p>

7.3.1.2 Data Categorisation

Data were categorised into the following types, which capture the major land use classifications within the case study areas:

- (1) Areal features – predominantly land use classifications; and
- (2) Linear features – predominantly linear geomorphological features, including land use frontages, and coastal structures.

7.3.1.2a Areal feature

A series of land use classifications categories were applied, conforming with those developed by British Ordnance Survey for the Land and Surveys Department. The classifications have been consistently used in the development of the island's topographic maps since 1958 (Lands and Surveys Department *pers. comm.* 2001). Terra Remote Sensing Inc., as part of the 2000 aerial photographic surveys, also used these categories. Symbols were used to identify the major land use classification, as follows:

- Beach (including the cliff line in some locations);
- Cliff;
- Woodland;
- Grassland;
- Scrub land;
- Swamp;
- Tourism;
- Industry/commercial (includes some small tourism infrastructure);
- Recreation;
- Residential (includes some tourism infrastructure).

In some densely developed coastal sections, it is difficult to differentiate between all tourism developments (e.g. apartments, villas and guesthouses). As a result, it is acknowledged that some would be subsumed in the residential development category

(used specifically to identify houses). A similar situation also exists for the differentiation of commercial vs. tourism, and commercial vs. residential properties. Only those large hotels and tourism resorts, and main commercial complexes that are clearly definable are identified and, therefore, captured within the photographic classification.

The spatial areas for each classification within the case study areas were determined from direct measurements on the most recent ortho-corrected geo-referenced aerial photographs (2000) using ArcView GIS Version 3.2. As part of the measurement process it was necessary to define the cut off point representing the end of the dry beach. For some aerial photographs, it was difficult to determine the low water mark or the “wet line” on the beach. This has resulted in an error in determining the beach area for those segments with unclear waterlines.

7.3.1.2b Linear Features.

Using the land use classifications, it was also possible to identify and measure the linear features associated with the coastline for each study area. The frontage classifications were:

- Vacant lots;
- Tourism facilities;
- Residential facilities;
- The lengths of parallel and perpendicular coastal protection structures (e.g. revetments, groynes, seawalls, jetties).
- Roads found within the buffer area.

7.3.1.3 Population

There is very limited information directly available on the actual number of persons living directly on the coastline (Barbados Statistical Services Department *pers. comm.*

2001)⁷. As part of the postal questionnaire to coastal property owners (Section 8.5.2), information has been requested on the number of persons living or working at the property. It was anticipated that this part of the questionnaire would be completed to at least provide a representation of the potential number of persons that could be directly affected in the event of storm wave damage. Information on residential populations within CVA has been identified in the literature as important components of socio-economic analysis, within the CVA process (e.g. Zeidler 1995, Rotnicki *et al.* 1995, El-Raey 1997, NOAA 1999, Malvarez-Garcia and Pollard 2000, McLaughlin 2001, and McLaughlin *et al.* 2002).

7.3.2 Results of GIS Risk Quantification

This section presents the risk quantification results for the coastal features found within the study areas. It also provides insight into the difficulty that SIDS, like Barbados, face in terms of 1) implementing the response strategies for ICZM in the absence of a well grounded understanding of the issues involved in planning shoreline developments; and 2) the proposed universal application of IPCC adaptation guidelines and response strategies for dealing with the issues of climate change.

7.3.2.1 Risk Quantification for Coastal Features found in the Study Areas.

This section is divided into three: the first and second review the coastal land use features and the linear features found along the coastal areas, respectively. The third presents an evaluation of the techniques.

7.3.2.2 Risk Quantification for Areal Coastal Features.

When considering the total combined study area, the area at risk within the first 200m encompasses 230.6 ha. Of the total area at risk, 13% is beach, 64% is urbanized (Fig.

⁷ Population numbers were specifically related to enumeration district boundaries. Given the scalar extent of these boundaries, it was determined not to use the data at this time.

7.1a). Of all the coastal segments, the locations with the greatest beach area are Rockley and Brighton (26% each), followed by Casuarina (21%) (Fig. 7.1b). Although Rockley beach appears to have a comparatively large beach area, this was one of the coastal segments with unclear water line definition in the aerial photograph. From field investigation, it was observed that several of the beaches along the segment were narrow to intertidal.

In reviewing the results for commercial coverage it is noteworthy that Rockley (66%) and Holetown (20%) have the greatest percentage coverage (Fig. 7.1c). Nonetheless, in some instances, with aerial photography, it is difficult to differentiate commercial properties from tourism infrastructure. It is to be noted, however, that there were no clearly definable commercial businesses in either the Brighton or Royal Pavilion segments.

Royal Pavilion (32%) and Casuarina (28%) have the greatest percentage coverage of residential properties (Fig. 7.1d). However, while some properties may be tourism related, other properties known to be tourism villas have also been classified in the tourism category. The remainder have been grouped as the residential.

Fig. 7.1e, illustrating the combined total of the areal coverage for residential and tourism development, clearly identifies residential development as occupying the greatest of spatial area. This is expected, since most tourism development is found on the seaward side of the coastal road while all major residential developments are located on the landward side. Fig. 7.1e shows that the Casuarina segment had the largest coverage for tourism development (approximately 52000sq.m) of the 5 study areas.

Fig. 7.1a Areal Urbanisation types along the Study Coastlines.

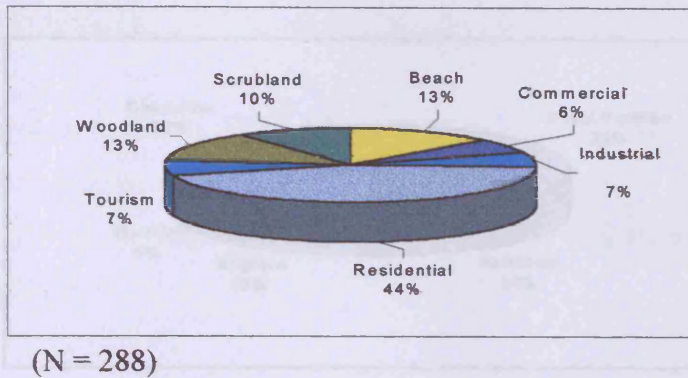


Fig. 7.1b Percentage Total Areal Beach Coverage for the Study Areas.

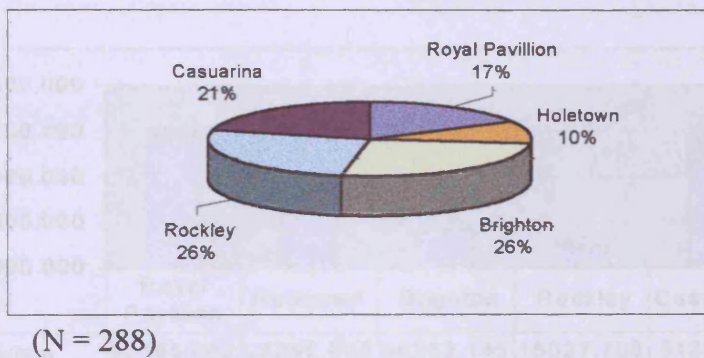


Fig. 7.1c Percentage Areal Commercial Coverage for the Study Areas.

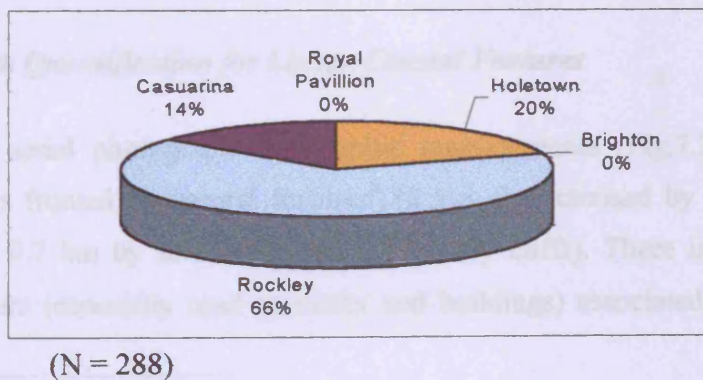
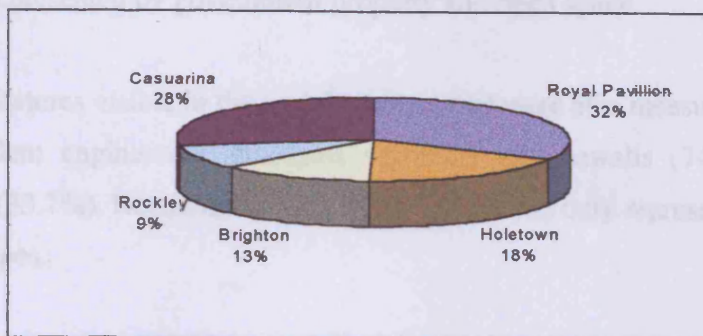
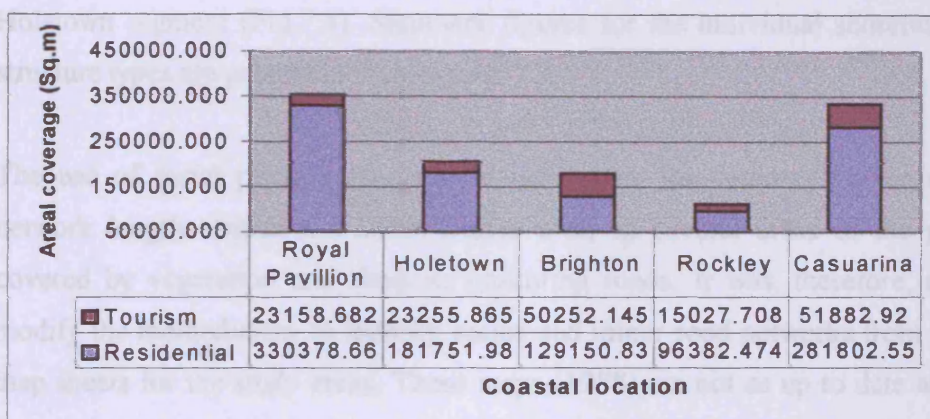


Fig. 7.1d Percentage Areal Residential Coverage for the Study Areas.



(N = 288)

Fig. 7.1e Percentage Areal Residential Coverage for the Study Areas.



7.3.2.3 Risk Quantification for Linear Coastal Features

Based on aerial photograph topographic measurements (Fig.7.2), 11.1 km of the shoreline is fronted by natural features⁸ (8 km characterised by beaches, 1.5 km by woodland, 0.7 km by scrubland, and 0.7 km by cliffs). There is considerable urban infrastructure (especially road networks and buildings) associated with these features.

⁸ While these natural features are present, they cannot be considered to be pristine (i.e. undeveloped) locations.

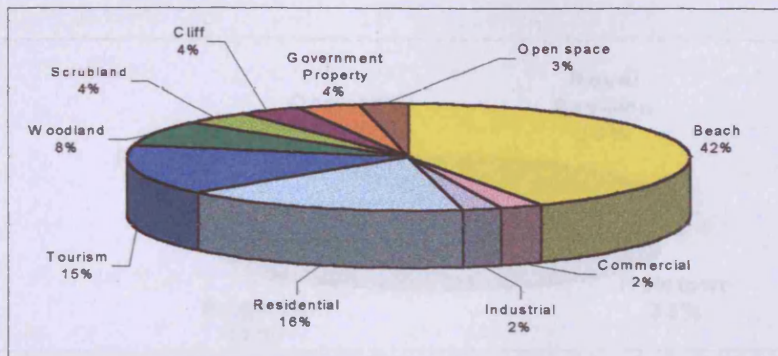
Approximately 1 km of the linear frontage is represented by commercial and industrial development, with residential and tourism development accounting for 6km and the remainder represented by government property and open space.

The linear features visible in the aerial photographs were also measured (Fig. 7.3). The most prevalent engineering structures segments are seawalls (34.2%) followed by revetments (33.7%). Retaining walls (acting as seawalls) only represent 18% of the total structural types.

The greatest use of shoreline protective structures (seawalls and revetments) occur in the Holetown segment (32%), followed by the Rockley segment (20%). The use of retaining walls as property protection occurs extensively in the Royal Pavillion segment. The use of revetments for property protection is found most frequently in the Holetown segment, while the greatest variation of combined use of structures is found in the Holetown segment (Fig.7.4). Summary figures for the individual shoreline protection structure types are presented in Appendix 7.2.

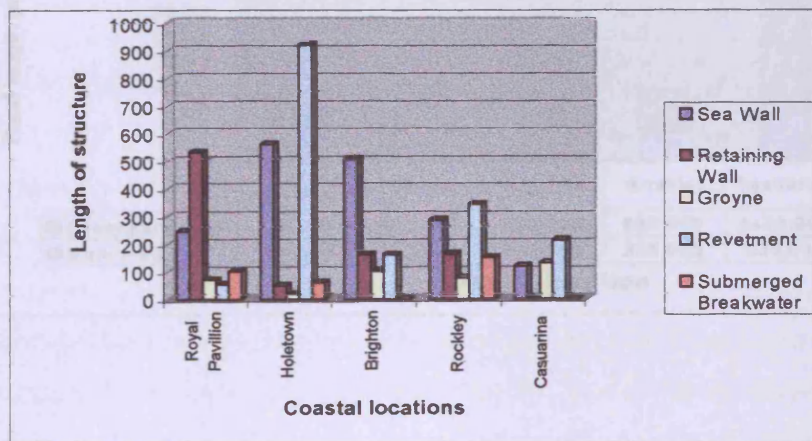
The use of aerial photographs proved ineffective for determining the risk to road network lengths within the 200m buffer area, as several areas of the photos were covered by vegetation and shadow, obscuring roads. It was, therefore, necessary to modify the methodology to identify major and minor road networks from the 1:10000 map sheets for the study areas. These maps (1988) are not as up to date as one would have preferred, but are the most recently available from the Lands and Surveys Department (Fig. 7.5).

Fig. 7.2 Proportion of Linear Features along the Study Areas.



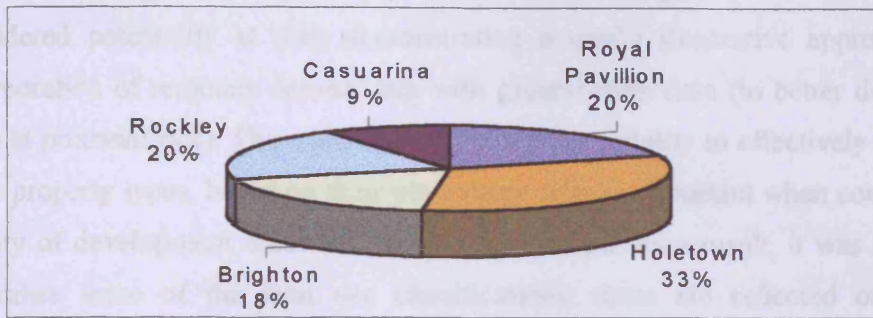
(N = 288).

Fig. 7.3 Total Length of Structures found along the Study Areas.



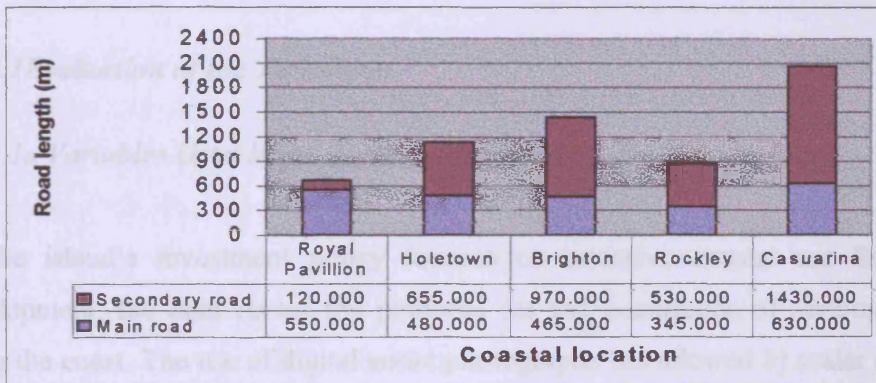
These results indicate that, with the exception of the Royal Pavillion location, there is significant total infrastructure at risk. Most secondary walls provide direct access, associated with the residential development, within the identified risk zone. All locations (with the exception of Royal Pavillion) have relatively low-lying areas behind the beach and revetment, in some instances, the coasting from the 1:10,000 maps. It was also observed that the 5m or 10m contour did not occur within 300m of the coast. The Royal Pavillion location was the exception, and the coast within these elevations were not considered, as they are not directly affected by storm flooding compared with other sites.

Fig. 7.4 Percentage of Total Structure Length for the Study Areas.



(N = 288)

Fig. 7.5 Cumulative Road Network Lengths for the Study Areas.



These results illustrate that, with the exception of the Royal Pavilion location, there is significant road infrastructure at risk. Most secondary roads provide direct access, associated with the residential developments, within the identified risk areas. All locations (with the exception of Royal Pavilion) have extensive low-lying areas behind the beach and represent, in some instances, the coastal road. From the 1:10,000 maps, it was also observed that the 5m or 10m contour did not occur within 200m of the coast. The Royal Pavilion location was the exception, and the roads within these elevations were not considered, as they are not directly affected by storm flooding compared with other sites.

7.3.3 Discussion

This methodology has allowed the determination of generalised coastal features, considered potentially at risk, demonstrating a useful illustrative approach for the incorporation of remotely sensed data with ground-truth data (to better determine the areas at potential risk). The main limitations are the inability to effectively differentiate some property types, based on their plan views. This is important when considering the density of development landward of the coastal road. As a result, it was necessary to generalise some of the land use classifications; these are reflected on the aerial photographs in Appendix 7. In addition, those properties and road networks, hidden by tree cover, have been omitted and, thus, only an approximate account can be made for the total urbanisation within the defined risk area.

7.3.3.1 Evaluation of the Technique

7.3.3.1a Variables Used in the Barbados Experience

As the island's investment policy focuses on intensive coastal use for economic development, the data reveal the potential for the occurrence of serious dislocation along the coast. The use of digital aerial photographs has allowed 1) scalar enlargement manipulation while maintaining high resolution quality; and 2) on screen measurements with reasonable levels of accuracy⁹. In addition, the level of survey accuracy established and incorporated as part of the survey methodology provides reliability and accuracy justification for the measurements taken; this ensures that they lie within scientifically acceptable and valid limits. Also, as part of the methodology appropriateness, all the equipment was calibrated to within their specifications prior to initiating the survey and data collection procedures. Both the Canadian Hydrographic Services and the International Hydrographic Organization accept the standards used by Terra Remote Sensing Inc. for nautical navigation chart development (Harry Olynyk, *pers. comm.* 2002).

⁹ As the digital images have been georeferenced, they can be increased or reduced in scale, which allows for accurate digital on screen measurements to be performed.

7.3.3.1b Available Data and Economic Cost

This research demonstrates the need for a significant quantity of available data to process the information. In using this technique, the best information has principally been derived from aerial photographs and generic land use maps. This data was easily available and accessible for use.

The economic costs for this component specifically relate to the acquisition of the aerial photography and associated costs (Table 7.3). This information has been obtained from Terra Remote Sensing Inc.¹⁰ The price reflects the approximate consulting costs for the work. As this sort of data collection is highly specialized, it is viewed as an individual/independent project cost rather than a recurring one. The aerial photography work will only be repeated every 5 or 10 years depending on the required needs of the CZMU (Rick Quinn, *pers. comm.* 2002). An individual breakdown of appropriate price components is, however, not presented due to company confidentiality¹¹; only the approximate total costs provided by the company are presented for each sub-component.

The costing clearly demonstrates the financial requirements. While the cost may initially seem prohibitive, provided that the long-term benefits can be justified, it does make for a worthwhile investment. The use and application of the Videomap approach is similar to that described by Leatherman *et al.* (1994) and Leatherman & Yohe (1996). The main advantage of this method is that all video points are digitally coordinated using GPS. Thus, the information can be loaded into a GIS system from which the requisite data tables can be constructed, to build efficient information data sets on the features observed within the video.

¹⁰ Terra Remote Sensing Inc is a Canadian consulting firm that specializes in the acquisition, processing and interpretation of remotely sensed data. It performed the 2000 aerial photographic survey covering the West and South coasts of the island and the associated ortho-correction of the images, and interpretation of the collected data for the CZMU in 2000/2001 (Lynn Armstrong *pers. comm.* 2002).

¹¹ Permission was obtained from both the CZMU and Terra Remote Sensing Inc. for use of the consultation cost prices.

Table 7.3 Cost Associated with the Risk Quantification for the Case Study Areas

Activity Determination of coastal risk quantification	Number of staff and staff time (days) required to do survey	Cost GB£ (US\$)¹²
<i>Aerial Photographic and Hydrographic Study</i> ¹³ Mobilization and demobilization*		31189 (50000)
<ul style="list-style-type: none"> • Aerial Photography and mapping (At 1:10000 capture scale and printed at 1:5000 scale) Camera installation and testing and flight line determination to cover study area Processing printing of film Scanning of diapositives Land use mapping and digital compilation Ground control (12 stations) 	5 days, 3 crew	10604 (17000) 1372 (2200) 2121 (3400) 6238 (10000) 3119 (5000)
Subtotal		23454 (37600)
Options:		
Digital ortho-photo correction**		12476 (20000)
Digital mosaic compilation**		4990 (8000)
Sub total***		40920 (65600)
Standby cost (due to inclement weather) ^{&}	(1871 (3000) per day for 5 days)	9357 (15000)

¹² Conversion performed using <http://www.xe.com/ucc/convert.cgi> on 24/5/03.

¹³ Source Terra Remote Sensing Inc © (1998). Information used by permission of Terra Remote Sensing Inc. Cost provided in US \$ are the 1998 costs used on the project for the Government of Barbados project for the Aerial hydrographic and photographic survey for the West & South Coast of Barbados.

LIDAR is a Light Detection And Ranging bathymetric survey system which accurately and efficiently measures coastal water depths between 0 – 50m. The operational procedure has been described in the literature – see Irish and Lillycrop (1997), Parson *et al.* (1997), Gorman *et al.* (1998), and Terra Surveys Ltd. (1998).

Table 7.3 Cost Associated with the Risk Quantification for the Case Study Areas (cont'd).

Activity Determination of coastal risk quantification	Number of staff (weekly rate) and staff time (days) required to do survey	Cost GB £ (US \$)
<ul style="list-style-type: none"> • LIDAR¹⁴ Data Acquisition costs LIDAR Videotape system including DGPS system and tide gauges Aircraft , Living expense and transport cost Aircraft operation Production cost per km² of data collected 	3 Crew; 3 days 3 days 2 staff	
Subtotal		12476 (20000)
Standby cost (due to inclement weather) ^{&}	(1871(3000) per day for 5 days)	9357 (15000)
<ul style="list-style-type: none"> • Data Processing Costs Preparation of field sheets Quality control Digital data of all water depth data ArcView format Data processing cost per km² 		15595 (25000)
Total cost (including stand by time)	Total time required for data collection is 1 week****	114757 (190600)

Table Notes:

Where * = Mobilisation cost here covers the cost for both the aerial photogrammetry and aerial hydrography using LIDAR surveying techniques for accurate nearshore bathymetric determination.

** = Optional items available for use in the project or can be performed at a subsequent time should funding be limited.

*** = Subtotal cost including optional items but not including mobilisation¹⁵.

**** = The time for data processing is incorporated into the cost and not reflected as a time component here. However, a minimum of three months is required for processing data collected for the scale of Barbados, which includes time for client review of the data presentation format and draft report.

& = Refundable cost for down time due to inclement weather that prevents the surveys from occurring. Any unused monies are refunded at the end of the survey.

¹⁴ LIDAR is a Light Detection And Ranging bathymetric survey system which accurately and efficiently measures coastal water depths between 0 – 50m. The operational procedure has been described in the literature – see Irish and Lillycrop (1997), Parson *et al.* (1997), Gorman *et al.* (1998), and Terra Surveys Ltd. (1998).

¹⁵ Mobilisation and demobilisation includes office preparation, packing, planning of project, shipping equipment, ancillary costs (airfares, customs clearance) equipment installation in aircraft and aircraft transit to and from Barbados.

7.3.3.1c Logistics and Administration

The main problem with this aspect of the research is gaining access to some of the information represented above given:

- (a) Their stored data formats (various forms of electronic format, hard copy format and as a result of infrequent updating of the data).
- (b) The limited access time to source the information out.

This clearly highlights the need for some form of systematic data standardization process within the government agencies so that data can be easily accessed and transferred for different application uses, especially GIS. As the data is copyrighted, permission had to be sought from the Lands and Surveys Department, the CZMU and Terra Remote Sensing Inc. This resulted in delays in accessing the data.

As the data collection component is based on a project approach, it is clear that project management considerations have to be given to the effective execution of the work. As part of this process, it is necessary to ensure that the work coincides with the best time for performing the aerial photography as well as ensuring that the LIDAR hydrographic surveying can simultaneously take place to minimize the overall mobilisation cost. In addition, adequate provision has to be made to minimise standby and down time. This is achieved by scheduling the project to occur either in the dry season (preferred option), or the transition months between dry to wet season.

7.3.3.2 Recommendations

It is recommended that this procedure be applied to the remainder of the west and south coasts to get a much clearer determination of all the potential areas of risk to flooding damage. Since the CZMU holds the information, it should be incorporated into its GIS to assist in the expanded database of resources and infrastructure found along the coast, which might be potentially at risk.

Other possible variables for inclusion are population numbers at risk, the number of fish landing sites and their markets and their associated market infrastructure, the commercial harbour and main fishing harbours, and historic locations. Finally, if appropriate information on coastal contour elevations can be obtained¹⁶, it would be a worthwhile to perform the study to reflect the possible effects of sea level rise for areas between 0m to 3m above sea level as has been applied in the literature by Leatherman *et al.* (1994) and Rotnicki *et al.* (1995).

7.4 METHODOLOGY FOR ECONOMIC VULNERABILITY DETERMINATION

7.4.1 Introduction

The differences between both sections of coast have been previously discussed (Section 4.4.3.1). While noting that the coastal segments are not sequential or equidistant, their variety of land use classifications provides meaningful information on the vulnerability of properties. Here, property damage is used as a proxy to identify potential loss and hence, vulnerability. This approach is of significance given the overall value of coastal property to the island's economy, in terms of direct and indirect social and economic factors.

The information generated here identifies the potential socio-cultural and economic consequences that can affect the island through the potential dislocation of the intensively urbanised coast. All land valuation information has been obtained from the Barbados Government Land Valuation Department in 2002. The land value figures presented have been rounded off for the sake of data management ease. The land

¹⁶ Discussions held with the Lands and Surveys Department indicated that the level of contour accuracy less than 5m (i.e. along the coastal fringe) is very limited. It is not reflected in all maps at scales of 1:2500 since in the past the maps were all drawn with 5m to 10m contour levels as these frequently coincided with prominent land form changes.

valuation classification descriptors used, are those used within the Land Valuation Department.

7.4.1.1 Land Parcel Database

The coastal land parcel databases for the case study areas as well as their respective land valuation maps were obtained from the Land Valuation Department. This information contained parcel boundary information and land values. For this analysis, the most important information related to the property owner's address, land parcel size, land parcel code number, property value and property type. The Land Valuation Department's property classifications have been used in the research to ensure conformity in the data analysis.

7.4.1.2 Degree of Coastal Urbanisation

Using the aerial photography, a buffer zone was developed at a distance of 200m inland from the coast to determine the significance in the level of urbanisation, experienced along the coast. This boundary was chosen as it conforms to the policy arrangements that are followed by the CZMU:

- (a) The Unit receives all coastal physical development applications for assessment from the Town and Country Planning Department. These applications all lie seaward of the main coastal road and/or are immediately adjacent to the coastline (normally within 50m of the coastline).
- (b) As previously referred to in Section 7.3.1.1, the inland boundary of the coastal planning area is identified in the ICZMP.

7.4.1.3 Vulnerability of Developed Land Parcels.

The 50m landward boundary from the beach edge is the area that would be most significantly impacted in terms of the loss of coastal infrastructure,¹⁷ which significantly contributes to the sustained maintenance of the tourism product of the island (Sections 2.7.3 and 5.4). The loss of such infrastructure would have significant negative implications on the economic viability of the island.

The land use classifications applied in Section 7.3.1.2, were grouped to provide the percentage urbanisation for each stretch of coast studied. The land use information was then used to identify vulnerable land parcels along the coast, their value and size. This provided an estimate of the potential total property types at risk and their potential threatened/loss value.

7.4.2 Results of Economic Vulnerability Determination

This section presents the analysed case studies of economic vulnerability, based on land/property values. It is divided into two sections, which, respectively, review:

- The total economic value of the combined case study areas;
- The economic values of the individual coastlines;
- An evaluation of the techniques used.

As part of this analysis it has been necessary to present some standardised classification data considerations; these are shown in Box 7. 2.

¹⁷This has implications not only for local residential houses, but also tourism infrastructure, coastal roads and coastal engineering structures.

Box 7.2 Classification considerations associated with specific land use types

* = Some land value information not available
** = Combination of hotels, guest houses and apartments
*** = Combination of residential types and condominiums
**** = Combination of restaurants, private clubs and shops
***** = Combination of mineral processing and industry types

7.4.2.1 Total Combined Study Areas

Analysis of the combined study areas (Fig. 7.6¹⁸ and Appendix 7.2, Table 1) identifies 288 coastal properties, representing a land value of GB £519.66 million. Of these, 62% represent residential accommodation, with a land value of GB £177.0 million; approximately 15% represent tourism accommodation, with a land value of GB £217.6 million. Of the total land area, 63% is used in tourism and residential accommodation. Industrial land use accounts for 18% and only 3% are used for government buildings.

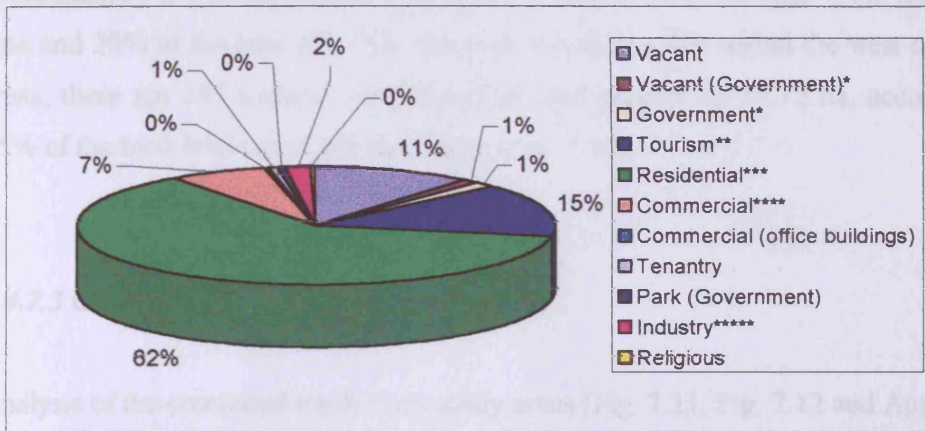
The analysis also shows that tourism development carries the greatest land value (Fig. 7.7). As the land valuation classifications are not clear in their descriptions of tourism accommodation results, it may not accurately capture the “actual” type of residential use¹⁹. Within this analysis, hotels and apartments were also grouped together to identify tourism properties. However, although condominiums would be expected to be included within the tourism category, they were grouped into the residential classification, as the existing land valuation classifications for this category were unclear.

The policy of making optimum use of coastal lands, primarily for tourism and residential accommodation, is therefore, clearly demonstrated. Also, for the combined total study area, there is only a total of 11% of coastal land available for development (i.e. vacant land in private ownership that can be developed).

¹⁸Asterisk explanations can be found in Appendix 7 in the Tables related to each respective figure.

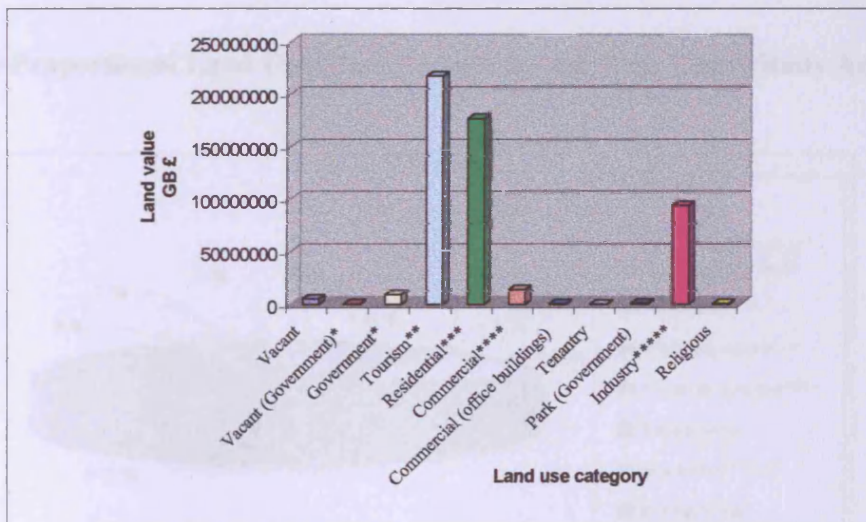
¹⁹Some properties identified as single or double residences may be actually tourism villas.

Fig. 7.6 Proportional Land Use Classification for the Case Study Areas.



(N = 288)

Fig. 7.7 Potential Vulnerability Loss Value Per Land Use Category for the Combined Study Areas.



7.4.2.2 Combined West Coast Study Areas

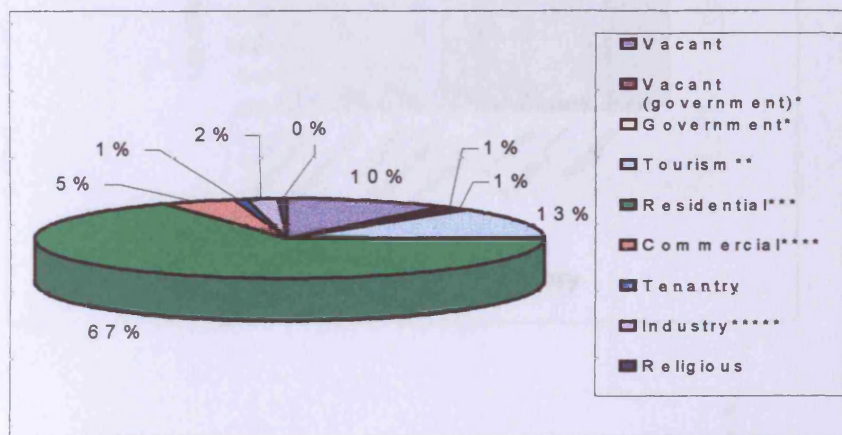
Analysis of the combined west coast study areas (Fig. 7.8, Fig. 7.9 and Appendix 7.2, Table 2) shows approximately 80% of the coastline is dominated by tourism and

residential land use. This accounts for a land value of GB £348.3 million (or 75% of the total land value for the combined west coast study area). Industrial land use represents approximately 2% of the number of lots, but reflects 20% of the land value for the study area and 20% of the land use. The analysis also shows that within the west coast study areas, there are 187 tourism and residential land parcels on 55.12 ha, accounting for 65% of the total land use of the study area (Fig. 7.10).

7.4.2.3 Combined South Coast Study Areas

Analysis of the combined south coast study areas (Fig. 7.11, Fig. 7.12 and Appendix 7.2 Table 3), shows tourism and residential accommodation account for 64% of the total number of lots. This reflects a land value of GB £47.1 million (or 77% of the total land value), representing 57% of the land use. Of the lots within the combined study areas, 13% are vacant, representing 24% of the land use.

Fig. 7.8 Proportional Land Use Classification for the West Coast Study Areas.



(N = 235)

Fig. 7.9 Potential Vulnerability Loss Value Per Land Use Category for the Combined Study Areas.

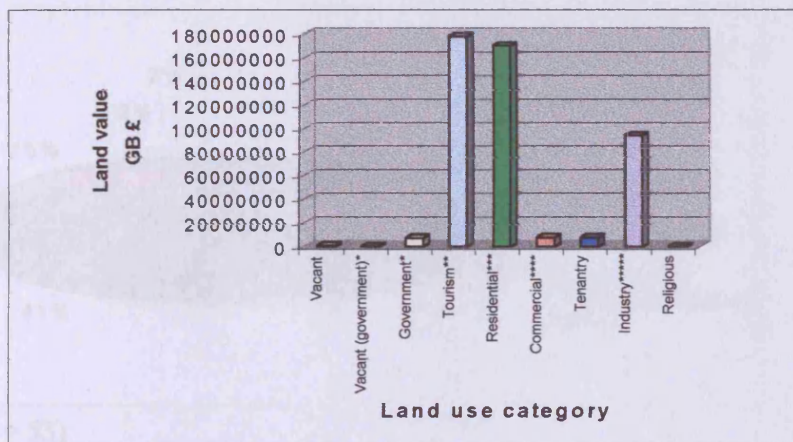


Fig. 7.10 Potential Land Area Vulnerable to Loss in the West Coast Study Areas.

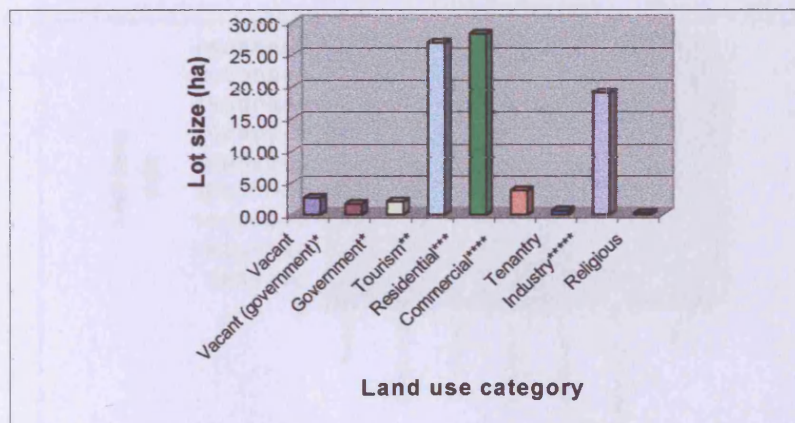
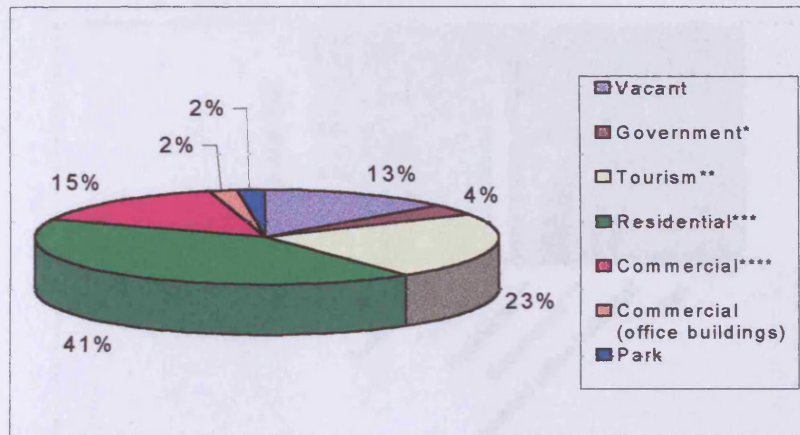


Fig. 7.11 Proportional Land Use Classification for the South Coast Study Areas.



(N = 53)

Fig. 7.12 Potential Vulnerability Loss Value Per Land Use Category for the Combined Study Areas.

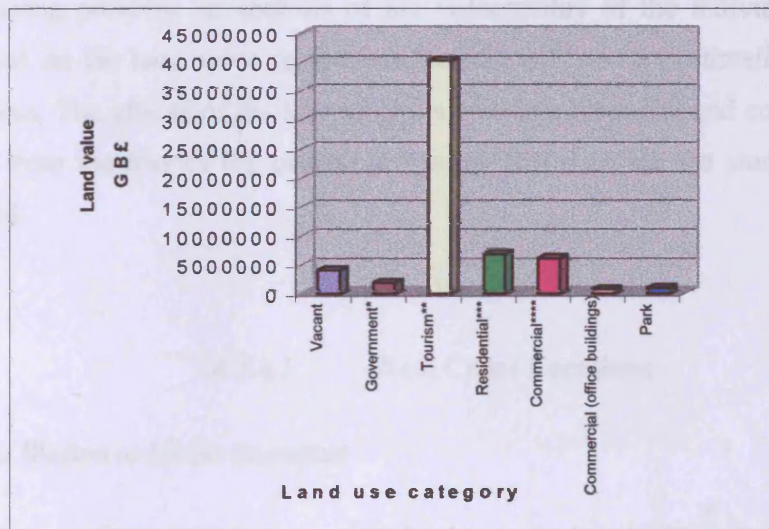
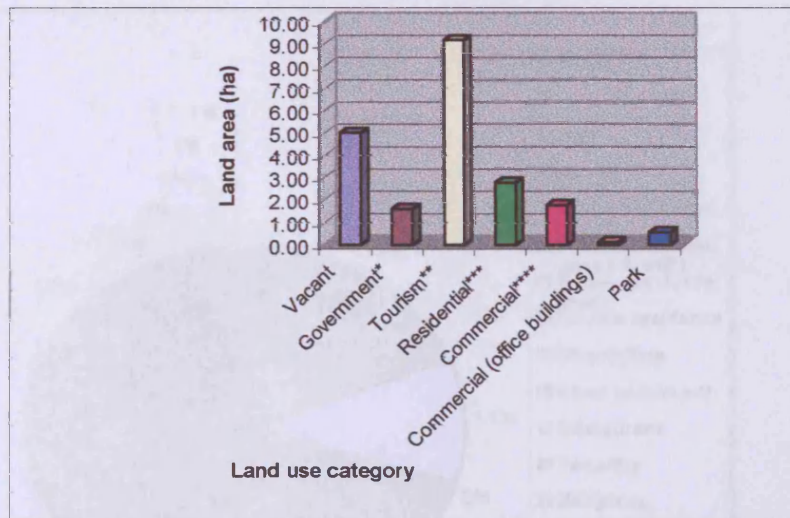


Fig. 7.13 Potential Land Area Vulnerable to Loss in the South Coast Study Areas



7.4.2.4 Individual Study Areas.

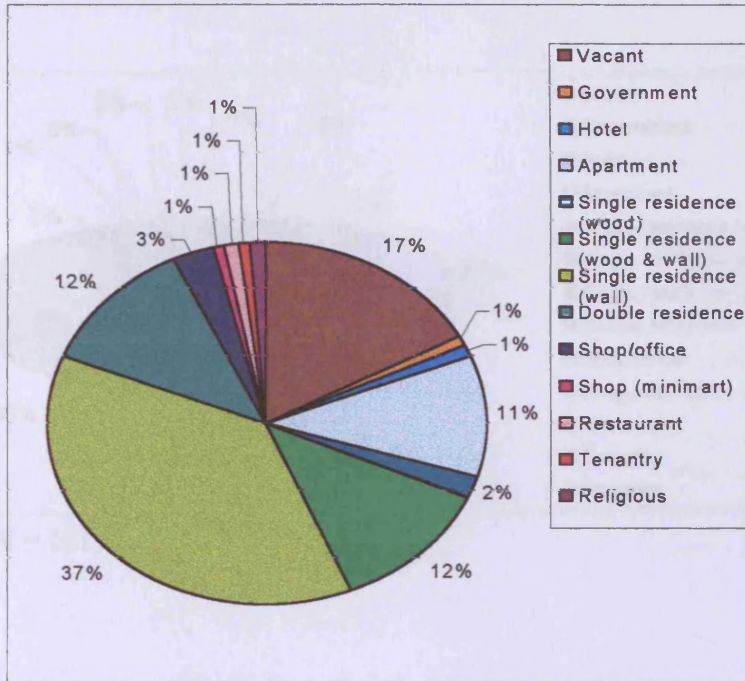
The following provides an analysis of the vulnerability of the individual case study areas based on the land value representing vulnerability as an estimation of potential damage loss. The effects of the loss of direct and indirect social and economic factors resulting from the loss of the coastal properties found within the study area are not considered.

7.4.2.4.1 West Coast Locations

7.4.2.4.1a Weston to Mount Standfast

Along this coastal segment there are 101 land parcels. It is highly urbanised with only 17% of the coastal land being vacant. Approximately 75% of the lots are used in residential and tourism development (Fig. 7.14, Fig. 7.15 and Appendix 7.2 Table 4a. representing a total land value of approximately £86.4 million (i.e. 90% of total land value). This also reflects 82% of the total land use for the study area.

Fig. 7.14 Proportional Land Use Classification for the Weston to Mount Standfast Coastline.



(N = 101)

Fig. 7.15 Potential Vulnerability Loss Value Per Land Use Category for the Weston to Mount Standfast Study Area.

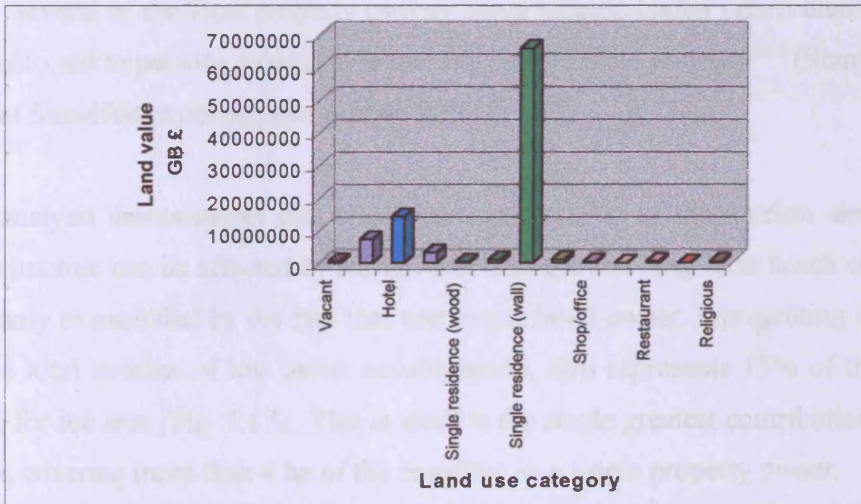
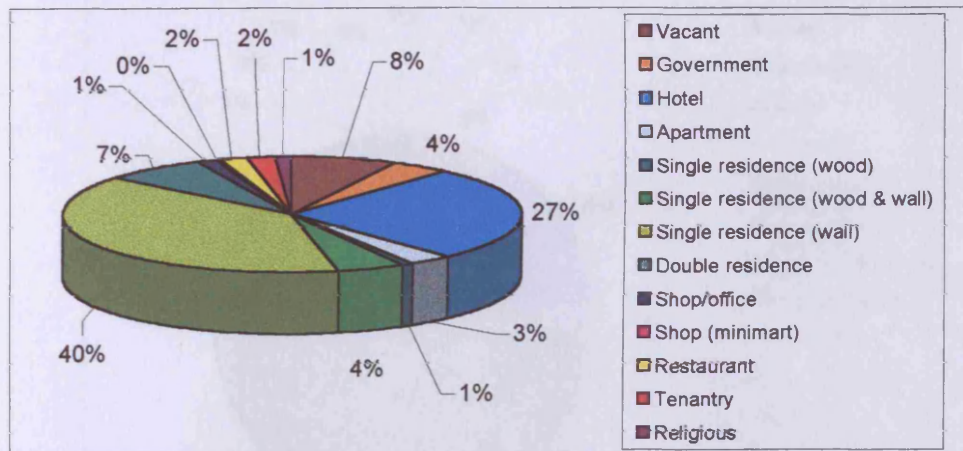


Fig. 7.16 Percentage Land Area Vulnerable to Loss in the Weston to Mount Standfast Study Area.



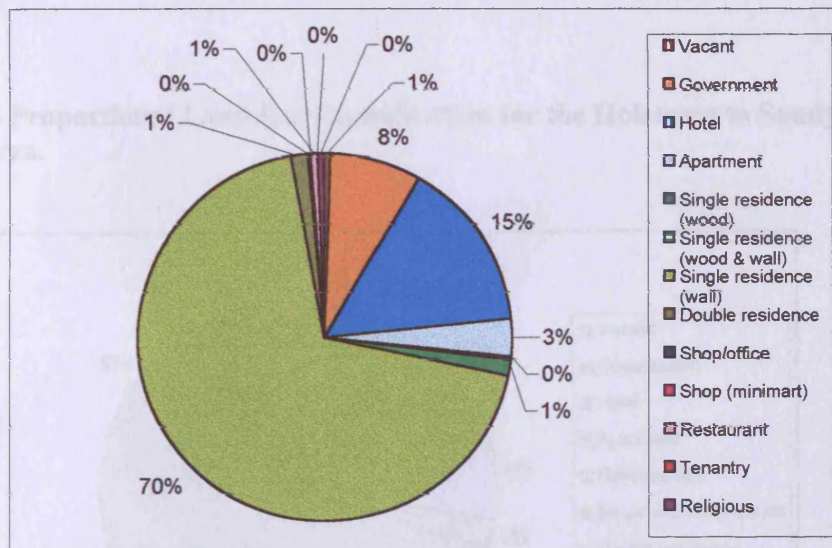
(N = 101)

Three classifications are provided for single residences (wood, wood and wall, and wall). The first two represent the former traditional chattel houses that once existed across much of the island. The coastal geomorphology gives the perception of 'private pockets of sand', thus, making the area especially ideal for tourism villa development. Discussions with local beach users reveal a perceived threat from tourism expansion, with "several of the local property owners being offered higher prices than current land values to sell to persons interested in owning coastal front property"²⁰ (Stanton Thomas, Mount Standfast resident, *pers. comm.* 2001).

The analysis demonstrates that all the economic value of the tourism and residential infrastructure can be affected by storm wave damage and long-term beach erosion. This is clearly exemplified by the fact that one major hotel owner, representing less than 1% of the total number of lots under consideration, also represents 15% of the total land value for the area (Fig. 7.17). This in itself is the single greatest contribution to the land value, covering more than 4 ha of the coastline as a single property owner.

²⁰ Independent expatriates and some real estate companies based locally are making such approaches scouting for properties for foreigners (for residential purposes or as business investments).

Fig. 7.17 Percentage Contribution To Land Values For Weston To Mount Standfast Study Area.



(N = 101)

7.4.2.4.1b Holetown to Sandy Lane Bay

This coastal section with 40 coastal lots, is highly urbanized with only 5% of the available lots being vacant (Fig. 7.18, Appendix 7.2 Table 4b). In excess of 20% of the land parcels are used in tourism (the combination of hotel, apartment, and condominium classifications), with an estimated land value of approximately GB £133.8 million (Fig. 7.19). This reflects 38% of the total land area considered vulnerable within this coastal segment (Fig. 7.20).

The results reveal that the greatest property types at risk are the tourism and residential i.e. 75% of the total land area found along the coast. This represents more than 80% of the total land value - represented by hotel accommodation having 57% of total land value in the study area - (Fig. 7.21).

Analysis also shows that there are 38 developed parcels, occupying approximately 23 ha. The total land value of these parcels is greater than £234.3 million. Attempts were made to get a valuation of the only government property found in the study area but this

was not available from the Land Valuation Department. This information would have been warranted since the area under consideration houses several civic offices (a police station, a post office, a public library, government offices, and a concession restaurant).

Fig. 7.18 Proportional Land Use Classification for the Hometown to Sandy Lane Study Area.

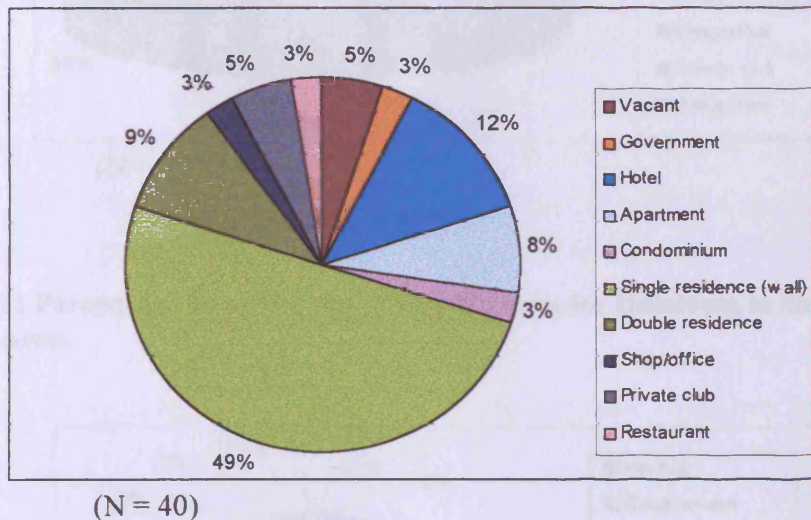


Fig. 7.19 Potential Vulnerability Loss Value Per Land Use Category for the Hometown to Sandy Lane Study Area.

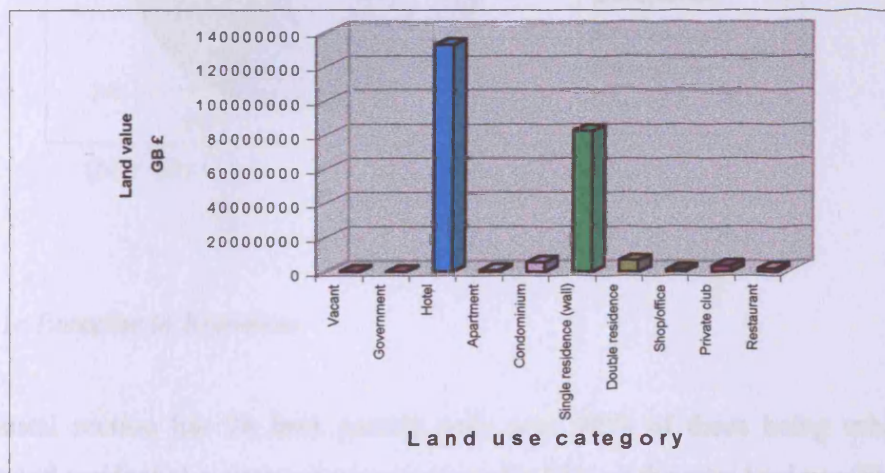
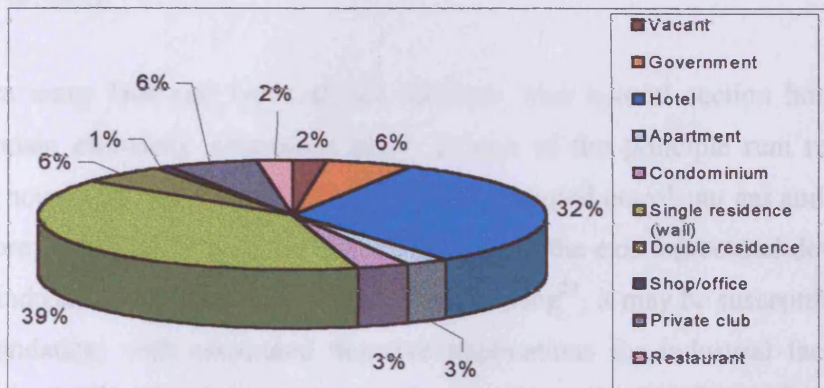
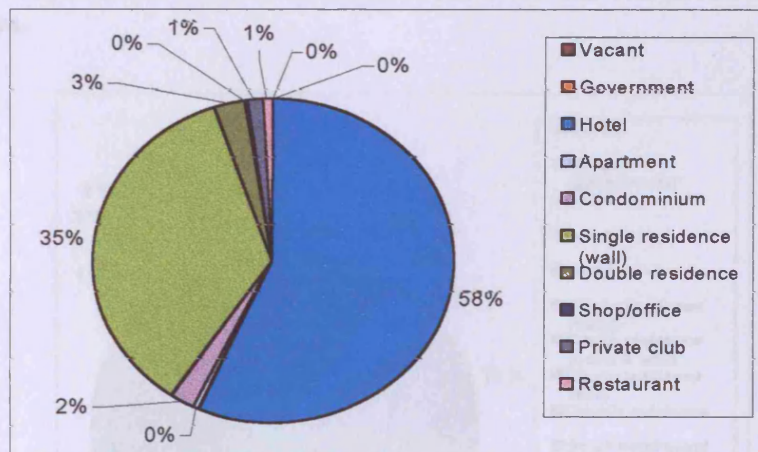


Fig. 7.20 Percentage Land Area Vulnerable to Loss in the Holetown to Sandy Lane Study Area.



(N = 40)

Fig. 7.21 Percentage Contribution to Land Values for Holetown to Sandy Lane Study Area.



(N = 40)

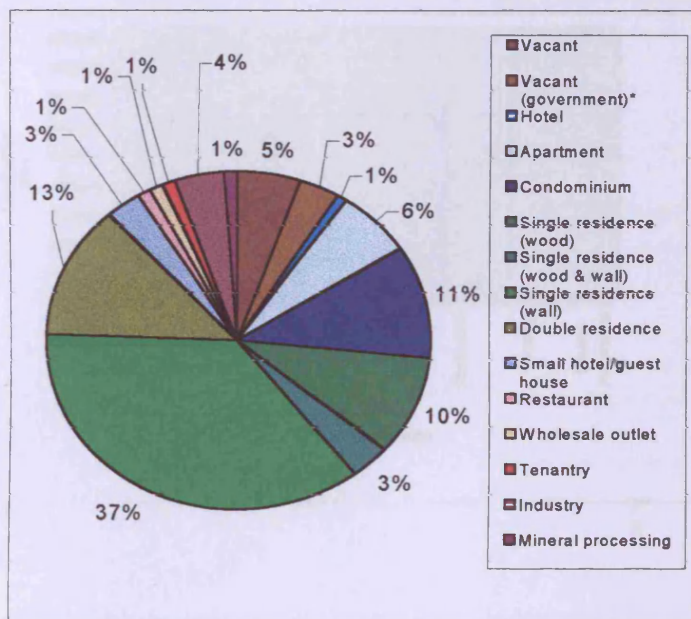
7.4.2.4.1c Paradise to Brandons

This coastal section has 94 land parcels with over 90% of these being urbanised. Tourism and residential accommodation account for 83% of the total land use (Fig. 7.22 and Appendix 7 Table 4 c), representing £33.6 million in land value. This further

represents 26% of the total land value (Figs. 7.23 and 7.24). Industry covers 5% of the land parcels found in the area, with a land value of £94.1 million, (73% of total land value) (Fig. 7.25).

There are many land use types at this location. This coastal section houses 1) the island's main electricity generation plant; 2) one of the principle rum refinery and blending houses, as well as 3) a storage location for liquid petroleum gas and fuel oil. It is therefore, important to note the close proximity of the existing coastal developments to these industries. As this coastal section is low-lying²¹, it may be susceptible to storm surge inundation, with associated negative implications for industrial facilities. The value of the industrial infrastructure here is also of significance. It is the only location on the island where such industries are nested together, and, if lost, would constitute significant direct and indirect economic losses for the island.

Fig. 7.22 Proportional Land Use Classification for the Holetown to Sandy Lane Study Area.



(N = 94)

²¹ The area is below the five metre contour.

Fig. 7.23a Potential Vulnerability Loss Value per Land Use Category for Paradise to Brighton Study Area (For Property Values over GB £ 10 Million)

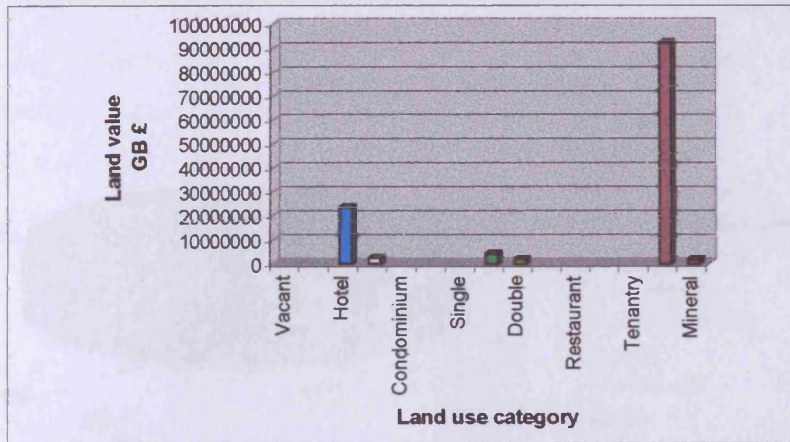


Fig. 7.23b Potential Vulnerability Loss Value per Land Use Category for Paradise to Brighton Study Area (For Property Values under GB £ 1 Million)

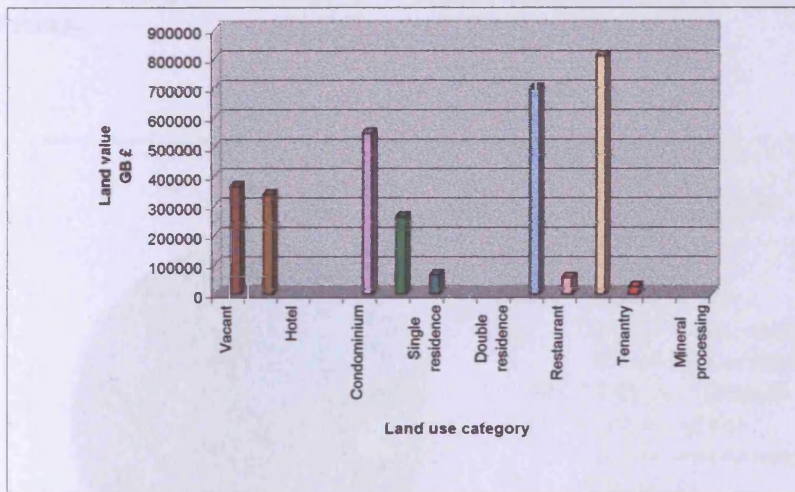
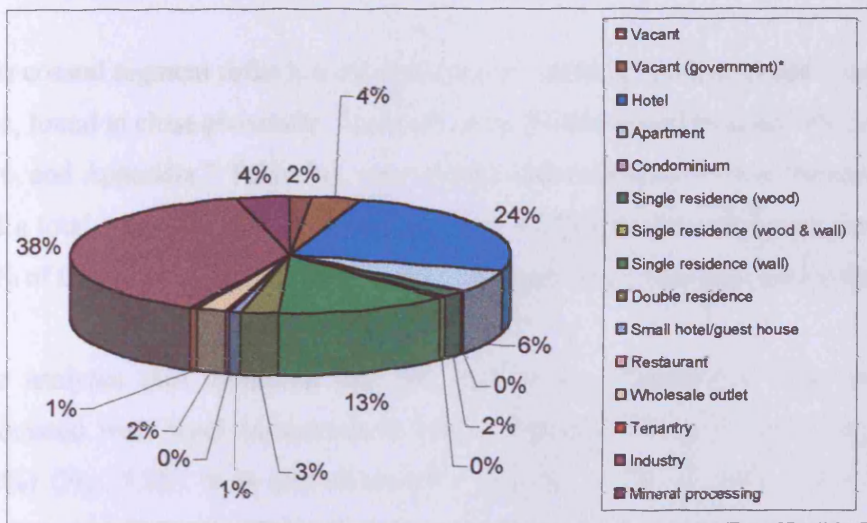
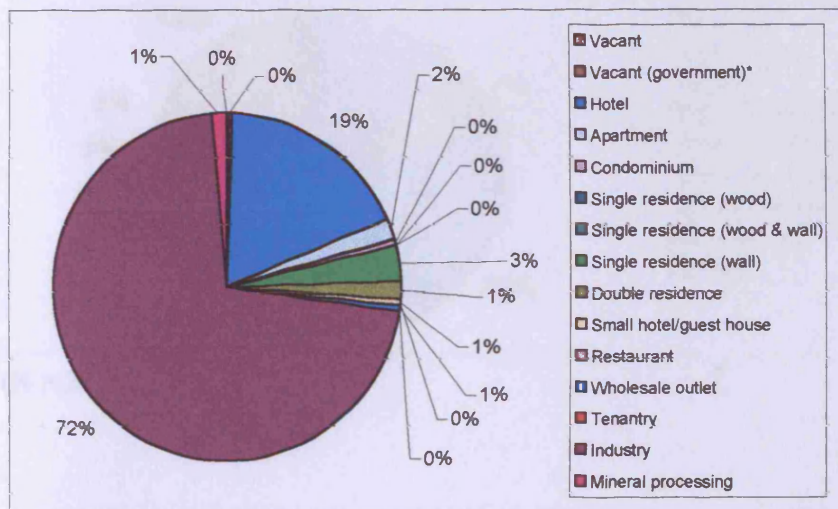


Fig. 7.24 Percentage Land Area Vulnerable to Loss in the Paradise to Brighton Study Area.



(N = 94)

Fig. 7.25 Percentage Contribution To Land Values For Paradise To Brighton Study Area.



(N = 94)

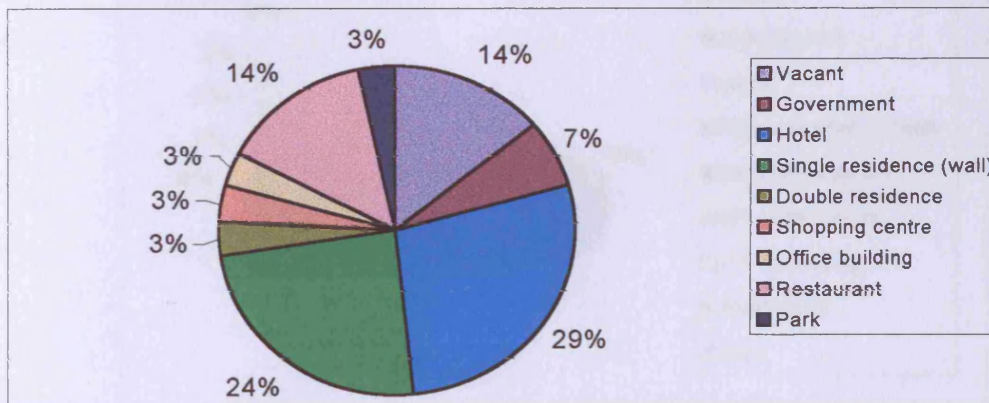
7.4.2.4.2 South Coast Locations

7.4.2.4.2a Hastings to Rockley

This coastal segment reflects a cross section of tourism, residential and commercial land uses, found in close proximity. Analyses show 24 developed land parcels on 7.5 ha (Fig. 7.26, and Appendix 7 Table 5a), representing approximately 83% of the coastal segment and a total land value of £25.6 million (Fig. 7.27). Commercial businesses account for 21% of the land parcels on 1.06 ha and represent 13% of the total land value.

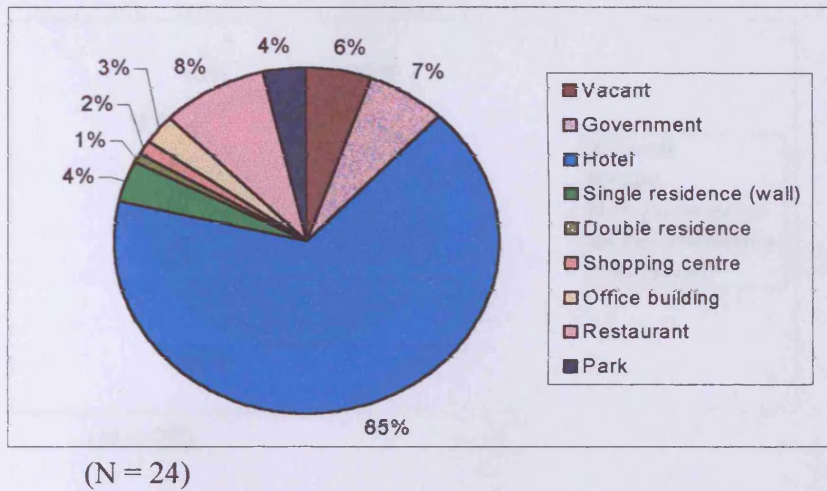
The analyses also identified that the land most vulnerable to loss comprises that associated with hotel infrastructure (48%) followed by land owned by government (18%) (Fig. 7.28). It is also noteworthy that the hotel infrastructure constitutes the greatest contributor to the land values found along this segment (65%), followed by restaurants (8%) and then government lands (7%).

Fig. 7.26 Proportional Land Use Classification for the Hastings to Rockley Study Area.



(N = 24)

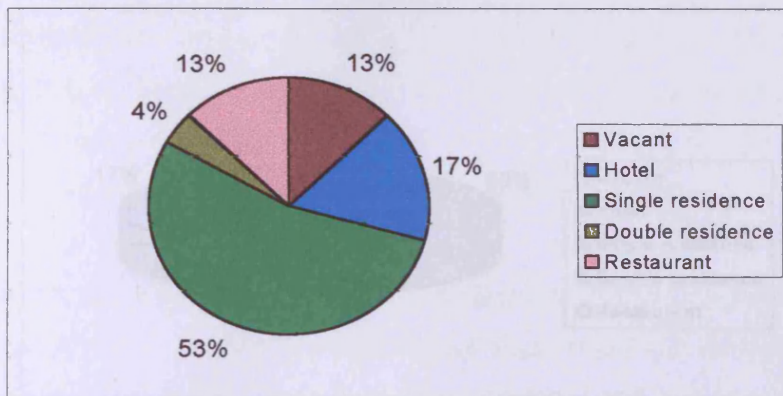
Fig. 7.29: Percentage Contribution to Land Values for Hastings to Rockley Study Area.



7.4.2.4.2b Dover to Welches

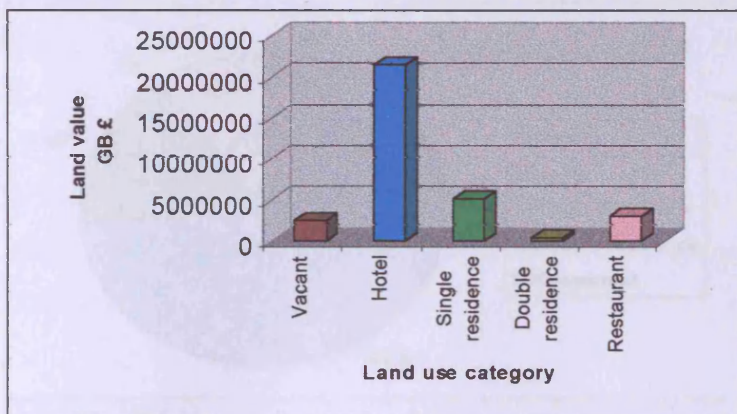
Analysis of this coastal segment (Figs. 7.30 and 7.31, and Appendix 7 Table 5b) shows there are 29 developed land parcels on 8.3 ha (approximately 65% of the coastal segment). The area is predominantly residential (58%), with an assessed value of approximately £5.5 million (17% of the total value of the study area). Commercial use constitutes 12.5% of the land parcels, having a value of approximately £3.2 million (10% of total land value). Tourism accommodation occupies 17% of the land parcels, 22% of the total land value.

Fig. 7.30 Proportional Land Use Classification for the Dover to Welches Study Area.



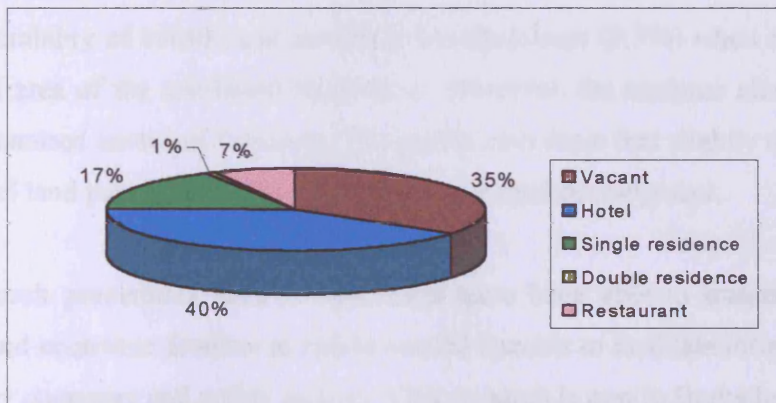
(N = 29)

Fig. 7.31 Potential Vulnerability Loss Value Per Land Use Category for Dover to Welches Study Area



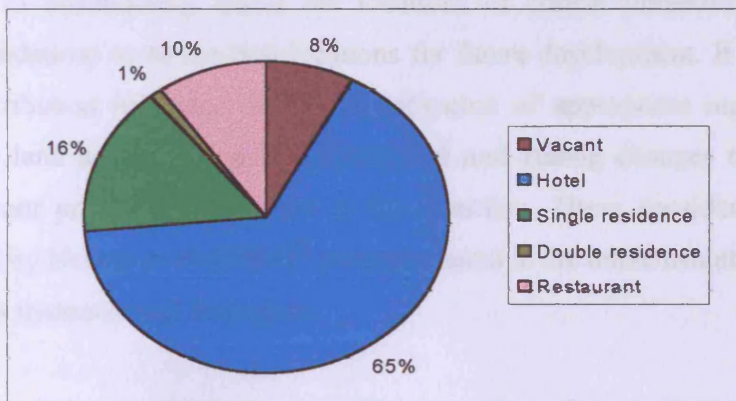
The results also demonstrate that the 75% of the land area most vulnerable to loss is associated with hotel and vacant lands (Fig. 7.32). Tourism accommodation represents 65% of the total land value (Fig. 7.33).

Fig. 7.32: Percentage Land Area Vulnerable to Loss in the Dover to Welches Study Area.



(N = 29).

Fig. 7.33: Percentage Contribution to Land Values for Dover to Welches Study Area.



(N = 29)

7.4.3 Discussion

The overall analysis has indicated that for the combined study areas, 88% of the total parcels have been developed along the immediate coastline. These represent a total land value of £514.1 million (99% of the total land value for the combined study area).

Additionally, the area under consideration can be deemed highly vulnerable to the coastal hazards associated with storm surge and beach loss.

The vulnerability of vacant land parcels is not significant (8.7%) when considering the total land area of the combined study area. However, the analyses clearly reflect the highly urbanised nature of the coast. The results also show that slightly more than 10% of the total land parcels is available for future potential development.

The research procedures used in this stage have been able to quantify the natural cultural and economic features at risk to coastal hazards to facilitate informed decision-making by managers and policy makers. This research is new to Barbados and provides a useful contribution to the island's literature. Given the ease with which the assessments can be made it would be advisable to extend this research to the remainder of the island's coast, focusing on the coastal hazard zone area. The existing source information database can be used, and the new contribution developed as part of this research can be considered for incorporation into the island's existing CM system. It can be used to continuously assess the locations of critical infrastructure and provide recommendations as to the best locations for future development. It is hoped that this new contribution will assist in the identification of appropriate regulatory measures including land acquisition, public investment and zoning changes to ensure the best management practices are applied to the coastline. These considerations have been identified by Hickey *et al.* (1997)²² as instrumental in the implementation of appropriate regulatory measures and incentives.

This research has contributed to a better awareness of the potential economic losses from coastal hazards and will contribute to proactive management and policy formulation. This approach has also prepared the way for greater evaluation of the potential effects of ASLR on the Barbados coast in the longer term, as these methods can be suitably adapted to incorporate the effects of ASLR. However, to be effective, there is need for greater contour detail along the coastal margin, as the ASLR scenarios

²² Hickey *et al.* (1997) suggest that with the implementation of appropriate regulatory measures and incentives (e.g. best management practices, voluntary construction and the use of appropriate building code standards), development can be essentially steered away from hazard areas and other areas of environmental sensitivity.

normally require estimations of impact effects at elevations of 0m, 0.2m, 0.5m, 1m, 2.5 and 3m. Such contour detail does not currently exist for Barbados, with the first elevation contour on most maps being the 5m contour. This characteristic is also normally true for most SIDS, which has placed them at a disadvantage, when situations warrant the use of the ASLR models developed for global application.

The research has demonstrated how GIS applications in collaboration with public domain data sets can be used to extract meaningful information on the vulnerability of coastal properties. The compiled information and subsequent analysis have focused on property damage as a priority for potential economic loss rather than direct and indirect social and economic factors. The ability to use such information is relevant to property insurers, property owners and coastal planners. Furthermore, this approach can be extended, with the use of storm surge models, to more accurately identify flood inundation zones, and coastal areas that are prone to flooding from torrential runoff. This work has not been attempted in an integrated manner to date in Barbados and provides for future research. The existing coastal GIS for Barbados provides a useful foundation for the management of the coastline. However, it is in need of systematic updating and expansion to include:

- Flood lines under a range of scenarios;
- Building footprints;
- Accurate coastal protection structure information;
- Population information (e.g. population numbers and demographics of populations at risk);
- Other socio-economic characterisation (e.g. potential population unemployment and displacement, economic loss in land cover within inundation limits).

Such additional information will contribute to an enhanced ICZMP for the island. It will also contribute to a basis for the implementation of appropriate regulatory measures (e.g. the designation of coastal flood zones, identification of areas for land acquisition, public investment and the use of best management practices for the coastline).

As identified in the criteria for selection of the case study areas (Section 4.4.3.1), there is clear differentiation between the sites in terms of their features considered at risk, as well as in the spatial magnitude of the areas at risk (Appendix 7 Tables 1a to 1d). As the chosen coastal locations are not continuous, it is difficult to determine their overall significance in terms of the need for mitigation efforts in the event of potential storm surge effects. It is clear, however, that each location is highly urbanised within their small geographical setting. The data reveal however, that there is the potential for serious dislocation and loss to property, economic activity and settlement, given the proximity of these resources to the coastal hazard zone.

The measurements (land use and engineering structures) taken in the study areas reflect the existing condition of the coastline, and provide no consideration for the potential improvement of shoreline defence strategies that might be initiated. The limited available open space²³, along the coastline, provides evidence that future coastal development can be considered to be restricted. However, within the last five years the concept of “consolidation of existing coastal land” has also been slowly developing, where in some instances adjacent properties have been purchased at a premium price by either real estate agents, adjacent neighbours or individuals and combined to make one large property (Town Planning Department *pers. comm.* 2001).

7.4.3.1 Evaluation of the Technique

7.4.3.1a Variables Selected

The variables selected have been useful in their ability to capture the main land use type most at risk along the shoreline, and to provide an actual economic impact estimation, based on property loss. The assessment has also allowed for a comparison of potential monetary loss of land use areas with the proportions of those classes that might be susceptible to loss. The ability to combine different data sets with the GIS has allowed for effective levels of interpretation.

²³ This is determined from the review of the land valuation database, which indicates that more than 95% of the coastal lots are in private ownership, and there is very little coastal land freely available for purchase.

7.4.3.1b Available Data and Economic Cost

This approach has demonstrated the potential benefit in having various data sets available for incorporation into a GIS system, for coastal planning purposes. The data gathered were not easily accessible, as the relevant government agencies have strict control procedures in place, to ensure the privacy of property owners is retained. In addition, the issue of 'territorial data control' was also apparent, as some departments were not fully cooperative in the access to and the release of their data²⁴.

Considerable time has been spent within many departments finding relevant information. It must be acknowledged that there were only specific days and times when access to the information was made available. This cost would be reflected in the overall man-hour time allocated to such activities (Table 7.4). Costs associated here would also include:

- The purchase of the necessary GIS software (ArcView).
- The cost of copying the relevant map sheets and digitizing in the property boundaries, from the land valuation map sheets.

7.4.3.1c Logistics and Administration

The concerns here have been identified previously (Section 7.3.3.1c). There is a need to confirm the data by field verification, to ensure that the property information is up to date. In a few instances, it was observed that the properties were either amalgamated into one property, which could have resulted from acquisition subsequent to the most recent land valuation event in 2002.

²⁴ This was despite repeated reassurances by this researcher that the confidentiality requirements as stipulated by the relevant department were to be adhered to.

Table 7.4 Cost Associated with Economic Impact Determination for the Case Study Area.

Activity Determination of Coastal Economic Impact (property damage) quantification	Number of staff (weekly rate) and staff time (days) required to do survey	Cost GB£ (US\$)
ArcView Ver. 8 software and associated hardware options ²⁵		3240 (5100)
Man week cost (data acquisition)^	2 staff (week rate £168 (US\$ 277) per man), 20 days	699 (1100)
Man week cost (data processing)	1 staff (week rate £ 191 (US\$ 300)); 20 days	763 (1200)
Cost of copying maps	20 maps at £ 3.00 (US \$ 5)	64 (100)
Total		7941 (12500)

Table Notes:

^ = Data acquisition cost is the cost associated with acquiring land valuation data and mapping data. It does not include the cost for the general establishment of the GIS. This latter cost is a recurring cost, which has to be systematically reflected in the ongoing budget of the agency responsible.

7.4.3.2 Procedure Used in the Barbados Experience and their Wider Application

As demonstrated in the literature²⁶, the use of GIS technology provides an effective way to combine and layer planimetric and engineering data, physical science data, and social science data, to derive information on vulnerable coastal locations and potential economic impact (i.e. property loss). This also has future potential for application to the remainder of the island's coast.

²⁵ This costing was obtained directly from the ESRI Company website. ESRI is the patent license holder and creator of the ArcView suite of GIS software:

http://www.esri.com/partners/hardware/av_dellprecision.pdf

²⁶ Refer to El Raey (1998), Malvarez-Garcia *et al.* (2000), Estnard *et al.* (2000), Greve *et al.* (2000), Finkl (2000), and Carvalho (2002).

7.4.3.2a Application of Areal and Linear Variables in a Wider Context

The procedure is easily adaptable to most small island situations and, therefore, has achieved objectives 3 and 6 (Section 1.3.1.2). The high cost of undertaking such work may be considered to be cost prohibitive²⁷ initially, but, as identified in Section 7.3.3.1b, given the rapid data collection methodology and the quantity, and quality of data, it is well worth the investment. Such work, however, cannot be considered to be a routine operation of any government department. From its outset, it ought to be considered to be a project-driven operation in which the information can provide essential baseline information; furthermore this provides the essential building blocks for a functional GIS applicable to the coastal zone. Its application becomes even more apparent, especially in situations where it will provide accurate baseline data of the shoreline condition, through the collection of physical bathymetric and socioeconomic data.

7.4.3.2b Application of Land Valuation Variables in a Wider Context

The procedure, easily adaptable to most small island situations, is dependent on the land valuation information, presently available and its ability to be incorporated into the GIS system. In a situation where there is no existing GIS, the cost to establish such a system could be considered to be initially high, since there would be a need to establish the system from inception. If this is the case, such work should be considered to be a one off project, as similarly described in Section 7.2.3.2. This should be considered as an individual project and not a recurring cost as the system, once established, is capable of systematic expansion.

7.4.4 Recommendations

It is recommended that the procedure be applied to the remainder of the coastline to determine the potential overall economic impact to the island, in the event of any serious loss due to a hazard event. However, greater consideration also has to be given

to the necessary procedures required for collecting coastal socio-demographic information and employment statistics. This may require the use of on-site administered questionnaires to gather information on these variables.

Representation of risk has been shown to be important to the general evaluation of the coastline. It has significant long-term implications as its periodic updating can also reflect general changes in coastal land use patterns and values. The most highly visible and immediate threat to the coastline is the risk of storm wave inundation along low-lying areas. This is made apparent when considering the level of urbanisation experienced along the coastline. For the five study areas this accounts for 64% of the total combined coastlines and encompasses approximately 280 land parcels covering 105.6ha and a total land value of GB £513.1 million.

While no cultural features have been identified within the study areas, these do exist along the remaining coastline and should also be considered in future work. Such features include fishing harbours and fish landing sites, a port and marina, as well as historical fort locations. It is clear that these coastal developments represent significant investments (and historic significance, where appropriate), on the part of both the Government as well as private sector.

Additional research is required on the cost of coastal structure maintenance per kilometre of shoreline. Many structures within the combined study areas are on private property and, as a result, access to this information could not be obtained. It is known, however, that property owners do not routinely maintain their coastal structures (Miriam Khalid, *per. comm.* 2001).

7.4.4.1 Modification of the Technique

Another possible variable for inclusion in determining risk areas is the loss of land use classes according the distance inland from the shoreline. The greatest difficulty with this would be the long-term need to gain access to the land valuation information and

²⁷ As identified in Section 7.2.

general areal extent, on which to perform these analyses. This would be highly time consuming but would assist in the development of accurate risk maps to be used for more site specific planning. Additionally, it would also be useful in the establishment of other potential options such as:

- The identification of development exclusion areas;
- The inclusion of estimated market values for the coastal properties to get a more accurate reflection of the current economic value of the coastline;
- The development of surge flooding models to show what kinds of areas become increasingly involved in higher levels of surge.

7.4.4.2 Limitation to this Research Process

Access to available information on land parcels was restricted by the Land Valuation Department to those properties immediately adjacent to the coastline. Hence, only these are presented in the land valuation tables (Appendix 7 Tables 2 - 4). However, scope exists for future work to collate additional information for properties within the 200m boundary defined in the ICZMP. By generating such a database, it can provide a useful foundation for a comprehensive coastal land management system. Once properly developed, it can be used by planners for the continuous assessment of public coastal infrastructure and critical facilities, and planning future developments. It is anticipated that this would help steer growth development along the coastal fringe away from hazard prone areas and others considered environmentally sensitive. This portends to be an important contribution to the coastal planning system in Barbados, providing clearer justifications as to why construction in potential hazard risk areas should not be allowed.

However, it is accepted that, as a small island, Barbados cannot afford to turn away relevant foreign investment or to restrict coastal development, without a clear and decisive shift in the current policy related to the physical planning and development within/along the coastal fringe. This is a serious concern, addressed further in Chapter 8. However, it is examined here, since there are implications for:

- a) those private property owners who may wish to protect their properties (and can afford to do so);
- b) government, which if it recommends the lack of/or restriction of development of a coastal area, should be providing the means for acquisition of lands for the public use and good; this in an effort to ensure that coastal strips are preserved and protected for the posterity of the local populace.

Other limitations related to this aspect of the research include the following:

1. Buildings and some shoreline areas were obscured in the aerial photographs by vegetation or vegetation shadow. This resulted in the coastline being ground truthed in order to verify what was on site.
2. Given research time constraints, generalized classifications were used. In this respect, residential areas defined, include some hotels, villas and great houses. Some residences on the coast might have been obscured by wooded areas and might not have been included in terms of total residential coverage.
3. Road networks were not measured from the aerial photographs as tree cover obscures some lengths. However, roads are to be considered as part of the overall percentage urbanization for the area. The road network provided the vital arteries of transport communication along the coastline and in some locations could be identified to be the only means of communication (i.e. no existing or definable alternate vehicular routes to get into or out of some locations). The measurement figures presented reflect those measured from the most currently available 1:10 000 topographic map sheets produced by the Land and Surveys Department. Although these maps were printed in 1988, it is clear that there would have been modifications to the road network; however, this has not been captured.

7.5 SUMMARY

The Barbados coast is highly urbanised with several vulnerable ecosystems and cultural features that are at risk from coastal hazards. The vast economic commitment to the development of the coast implies that coastal infrastructure will need to be protected as a first option for the sustained economic growth of the island. It is anticipated that political conditions will continue to pursue this line of development associated with the coastal industry²⁸. Alternatives will, therefore, need to be presented for the protection of the existing infrastructure using new technology (as is currently being investigated in the Coastal Infrastructure Programme for the island²⁹).

The research has illustrated how secondary data can assist in the identification and quantification of coastal areas at risk. Further research could consider the expansion of measured variables for the remainder of the coast in order to provide improved representation of areas at risk. The research underscores the importance of incorporating LVA considerations into all future coastal development and proposed coastal modification. In addition, it highlights the need for greater emphasis on socio-economic considerations and the modelling for potential ASLR inundation initiatives. Scientific and institutional efforts to deal with these effects require an associated public education component to acquaint private landowners, developers and the general public with the potential impacts of ASLR on the CZ as well as the implications for the changing evolution of the CZ. Public perceptions on CZ issues have been explored at varying levels³⁰ (Jonathan McCue and Susan Gubbay *pers. comm.* 2000). In order to represent all issues for consideration in LVA, public perceptions on coastal hazards and vulnerability issues associated with the coast are explored in Chapter Eight.

²⁸ Coastal industry includes initiatives and development incentives for continued tourism and residential development (Gabrielle Springer, *pers. comm.* 2001), and the expansion of harbour and marine areas. In the latter cases, projects are currently on stream for their implementation (Richard Alleyne and Charles Holder, *pers. comm.* 2000).

²⁹ The Coastal Infrastructure Programme is the fourth phase of the coastal conservation project for Barbados and is jointly funded by the InterAmerican Development Bank and the Government of Barbados (A. Rowe *pers. comm.* 2002).

³⁰ All major government projects have a public consultation component to allow for information dissemination and feed back integrated in their structures.

Chapter 8
Public Perception and
Littoral Vulnerability Assessment

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8.1 INTRODUCTION	315
8.2 REVIEW OF PUBLIC PERCEPTION AND LITTORAL VULNERABILITY	316
8.2.1 INTEGRATION OF PUBLIC PERCEPTION	318
8.2.2 LINKAGE BETWEEN PUBLIC PERCEPTION AND LVA	319
8.3 PUBLIC PERCEPTION QUESTIONNAIRE AIMS.....	320
8.3.1 BEACH USER QUESTIONNAIRE AIMS.....	321
8.3.2 PROPERTY OWNER QUESTIONNAIRE AIMS	322
8.4 QUESTIONNAIRE METHODOLOGY.....	323
8.4.1 QUESTION DESIGN AND STYLE	323
8.4.1.1 Public Notification	324
8.4.2.1 Pilot Survey	325
8.4.2.2 Pilot Survey Response Comments	325
8.4.2.3 Beach User Perception Questionnaire Survey Method.....	326
8.4.2.4 Questionnaire Description	326
8.4.3 COASTAL PROPERTY OWNER SURVEY	329
8.4.3.1 Rationale for Postal Survey	330
8.4.3.2 Pilot Survey	331
8.4.3.3 Property Owner Perception Questionnaire Survey Method	332
8.4.3.4 Questionnaire description.....	333
8.4.3.5 Methodology for Questionnaire Application.....	335
8.4.3.6 Limitations to Applied Survey Techniques.....	336
8.4.4 RESPONSE RATES.....	337
8.4.4.1 Limitations to Response Rates.....	339

8.4.4.2 Data Storage and Processing	340
8.5 QUESTIONNAIRE RESULTS.....	341
8.5.1 PUBLIC BEACH USER QUESTIONNAIRE	341
8.5.1.1 Part 1 Beach User Personal Details.....	341
8.5.1.2 Part 2 Beach Characteristics Preferences	345
8.5.1.3 Part 3 Preference of Beach Amenities and Beach Quality	348
8.5.1.4 Part 4 Beach User Perception of Vulnerability Issues Affecting the Coast	350
8.5.1.5 Part 5 Public Perception of Beach Quality	352
8.5.2 PROPERTY OWNER QUESTIONNAIRE RESULTS.....	355
8.5.2.1 Part 1 Property Location.....	355
8.5.2.2 Part 2 Property Owner Perception of Coastal Issues	357
8.5.2.3 Part 3 Property Owner Perception of Hazard Risk to Coastal Property	361
8.5.2.4 Part 4 Property Owners and the Coastal Zone Management Plan.....	364
8.6 DISCUSSION.....	373
8.6.1 BEACH USER PERCEPTION SURVEY	373
8.6.2 PROPERTY OWNER PERCEPTION SURVEY.....	376
8.7 EVALUATION OF THE TECHNIQUE USED	379
8.7.1 QUESTIONNAIRE STYLES AND ADMINISTRATION USED IN THE BARBADOS EXPERIENCE AND THEIR APPLICATION IN A WIDER CONTEXT.....	380
8.7.2 ECONOMIC COST.....	380
8.7.3 MODIFICATIONS TO QUESTIONNAIRES	383
8.8 SUMMARY.....	384
8.8.1 BEACH USER SURVEY.....	384
8.8.2 PROPERTY OWNER'S SURVEY	386

8.1 INTRODUCTION

This thesis has systematically built on quantitative and semi-quantitative approaches to LVA. In keeping with this, a public consultation process has been developed, in which public perceptions of beach aesthetics and coastal hazards and vulnerability issues have been included. The link between public perception and LVA is important in attempting to prioritise the coastal hazards and beach amenity issues, as perceived by the public. Such information can contribute to effective decision-making within the ICZM process. Within the literature (Section 8.2) there have been varying attempts at developing descriptive and interpretive approaches to evaluate coastal aesthetics. This chapter presents the fourth stage of the research (Section 4.2.1), relating to the utility of beach user and coastal property owner perception questionnaires. It is structured into four main sections:

- Section 8.2 presents a synoptic literature review on the public perception and littoral vulnerability themes and their importance in LVA.
- Section 8.3 describes the questionnaire aims and the rationale for choosing these techniques.
- Section 8.4 outlines the approaches used for questionnaire design and style, and the applied methodologies used in the development and administration of the public perception questionnaire surveys.
- Section 8.5 presents the analysed results of the beach user perception questionnaires and the fifth the analysed results of the property owner postal questionnaire survey.

This part of the research aims to assess (1) the beach users' and (2) the coastal property owners' opinion and perception of the beach environment and its vulnerability. This is the first time that the perceptions of beach users and property owners have been collected to provide an aesthetic setting and risk assessment for Barbados' beaches.

Public perceptions have been identified in the literature as key elements of successful ICZM (UN 1992, Gubbay 1994, Waite 1982 cited Pond and Rees 1997). The use of public perception within the LVA process provides a generic approach to determining

the “value” that the public places on coastal areas and beaches in general. It also has implications for the perceived value of the coastal resource with regards to its economic value. This process also allows for the gathering of perceptions on the public’s concerns over hazard/risk areas along the coast as well as their perceptions on the best options for the effective management of the coast. This approach provides indirect feedback to the ICZM process.

8.2 REVIEW OF PUBLIC PERCEPTION AND LITTORAL VULNERABILITY

Recently, there has been interesting literature on beach user perception in the context of beach management. However, a literature search has found no information specifically identifying public perception of littoral vulnerability although other aspects of vulnerability perceptions are reported (e.g. hazards, floods, and erosion). Research has primarily focused on the public perception of specific topic areas (Table 8.1), with the predominant themes being:

- The amenity and aesthetic quality of the beach;
- Beach management;
- The motivation factors related to beach use;
- Nearshore water quality and pollution issues; and
- The perception of beach/ coastal erosion and property damage.

The literature has demonstrated that public perception coastal surveys are frequently associated with general beach management issues. Their focus has been to evaluate measures to optimise the social and ecological functions of beaches. As presented by Morgan (1999), they are important in assisting the evaluation of existing management measures and strategies implemented, and identifying areas needing improvement.

Table 8.1 Main Public Perception Themes Covered in Literature (Source: Original)

Theme	Authors
Beach/Coastal erosion	Mitchell (1974); Ives & Furuseth (1988); Ricketts (1989); Dilley & Rasid (1990); Smith (1994); Heinz Centre (2000a); Houston (1995)
Coastal hazards	Williams & Williams (1988); Heinz Centre (2000b); Reddy (2000); Gough (2000)
Nearshore water quality/Coastal pollution	Dinius (1981); West (1989); Smith <i>et al.</i> (1991); Nelson (1998); Nelson <i>et al.</i> (1999); Nelson <i>et al.</i> (2000); Georgiou <i>et al.</i> (2000); Morgan (2000)
Public safety	Fletcher <i>et al.</i> (1989); Williams & Williams (1991); Short & Hogan (1994)
Beach aesthetics & Beach amenity	Simmons & Williams (1992); Williams <i>et al.</i> (1992); Williams <i>et al.</i> (1993); Williams & Morgan (1995); Morgan (1996); Morgan <i>et al.</i> (1995); Morgan <i>et al.</i> (1993); Morgan <i>et al.</i> (1996); Young <i>et al.</i> (1996); Leatherman (1997); Villares <i>et al.</i> (1997); Pond & Rees (1997); Morgan (1999); Randazzo <i>et al.</i> (2000); Williams <i>et al.</i> (2000) Clean Beaches Council (2001)
Beach site selection	Hecock (1983); Cutter <i>et al.</i> (1979); de Ruyck <i>et al.</i> (1997); Micallef <i>et al.</i> (1999)
Beach value	King (1999); Marlowe (1999); Stronge (2000); Houston (1996 and 2002)
Property damage	Keillor & Miller (1989); Friedman <i>et al.</i> (2002)
Beach management	Houston (1996); James (2000); Unal and Morgan (2000)
Environmental changes/management	House and Sangster (1981); Eastwood and Carter (1984); Noe <i>et al.</i> (1997); Tunstall (2000)
Coastal zone management/planning	Fenton & Syme (1989); Fischer <i>et al.</i> (1995); Breton <i>et al.</i> (1996);

Generally, little consideration has been given to coastal hazard perception (with the exception of beach erosion and flooding) and the related management of the coastline. This current gap is addressed as part of the main substance of the questionnaires. It reflects the concerns identified by Smith (1994) and WCU (2002) - that a beachfront resident's preference for living on the beach is so great, that the possibility of coastal hazards and risk events occurring are rejected or kept out of mind. Coch (1994) notes that this often results in a "high level of complacency" as residents accept the degree of risk exposure, once the time between major or significant events has been considered "long". Smith (1994) and the Heinz Centre (2000b) have found this too. Thus, the short-term experiences of residents reduce their ability to recognise or accept that long-term variations.

Most of the literature case studies have been drawn from the USA, UK, Europe, Mediterranean, and Australia. No surveys could be found which queried public perception/attitudes or local official attitudes towards issues of littoral/coastal vulnerability for the Caribbean region. This is of relevance to Barbados, as previously discussed (Sections 2.6.3 and 2.6.4)

8.2.1 Integration of Public Perception

There is increasing recognition of the significance of public awareness of and attitudes towards environmental resources for environmental management. Tunstall (2000) has these suggested three reasons:

- a) Growing acceptance that the public should be involved in environmental decision-making.
- b) Economic and political reasons which require public support.
- c) Environmental managers require the active cooperation of the public for many policies to be effective because they involve behavioural changes by members of the public.

The public's perception of potential risk or acceptable level of risk from natural hazards is informed by factors that do not always seem relevant to experts making technical assessments of the same risks. Individuals and communities respond to risk and risk information according to their perceptions and understanding of the risks, though the links may at times be complex (Rogers 1997). The level of acceptable risk is often defined by third parties (e.g. engineers, politicians) (Uribe *et al.* 1999), although increasing emphasis is being placed on the public to accept greater responsibility for managing natural hazard risks. To do this requires good information about the risks of relevance to the community (Gough 2000).

It has been shown by Parker and Harding (1979) that there is a hazard perception threshold, applicable to individuals, below which hazard adjustment is not considered. They, further, note that the ability of the individual to fully comprehend the effects of

random hazard events is mainly restricted to their personal experience¹. Furthermore, these considerations are strengthened by Smith (1994) who found that the short-term experience of coastal residents reduced their ability to accept the long-term variations that will affect coastal areas. The inclusion of public perception and participation in the process allowed a level of sensitivity and realism to the ICZMP and research as a whole.

8.2.2 Linkage between Public Perception and LVA

As demonstrated in the preceding chapters (Chapters Five to Seven), there are several measured variables that, when integrated, provide a method of vulnerability determination along the littoral. There is still a need to understand the public's perception of the resource and their perception of adjustments to coastal hazards. This is because an individual's understanding and awareness of natural hazard issues significantly affects the way the individual or a community responds to an event. The use of these techniques provides a means of communication - between the general public, residents of the various areas and the relevant government authority - to further assist in the cross-transfer of information about coastal hazards and the need for priority attention, at some locations. This is an important component of the ICZM process. In the long-term, public perception assessments can contribute to the explicit development and clear articulation of a balanced policy framework for general littoral management and ICZM processes.

As identified in Fig 4.1, the use of public perception is a necessary component of the socio-economic subcategory. For approximately 20 years, Barbados has been implementing a systematic CZM programme (Section 9.3.1). Throughout this time, there have been several public consultations (as part of the various project execution phases²), which have contributed to the current CM programme.

¹ These include the magnitude and frequency of the hazard, perception of the seriousness of the hazard the recency and frequency of personal experience, future hazards expectancy and perceived hazard occurrence probability.

² The phases of the Barbados coastal conservation programme are 1) Diagnostic and Pre-Feasibility studies for the West and South Coasts, 2) Feasibility and Pre-Investment studies for the West and South coasts, 3) Institutional Strengthening study, and 4) Diagnostic and Pre-Investment studies for the North, East and Southeast coasts. Refer to section 9.3.1 for details.

As part of this approach, several CZ hazard types were presented in both questionnaires. These hazards were selected for each survey type to focus the respondent's attention to the primary hazards experienced, based on their knowledge and use of the area. The hazards identified in the beach user survey were cliff erosion and slumping, beach erosion and water pollution. These are included because the respondents are only temporary beach visitors and, thus, their main concerns focus on the aesthetics of the area. The possibility of loss of recreational area due to beach narrowing is therefore of concern. In the postal survey the listed hazards included tropical storms, sea level rise, accidental spills, coastal flooding from land and sea, land runoff, cliff and beach erosion. The rationale for these hazards is that the property owners being "resident" in the area can relate to hazard effects and potential impacts of loss of use of their property, and, associated recreational beach area, where applicable. Hence, a wider representation of potential hazards is presented for consideration.

8.3 PUBLIC PERCEPTION QUESTIONNAIRE AIMS

This research component required a rapid approach to collecting information from the public. It was, therefore, necessary to define the extent of the investigation and to identify the best sampling procedure to allow for the rapid collection of data from a sample of subjects to whom questions could be directly addressed. Given research time constraints, responses had to be predominantly descriptive, with choices provided, and having as few open-ended questions as possible. In reviewing the various interrogation methods (Creative Research Systems 2001, UIAH 2003), it was determined that the questionnaire approach would be the best suited, meeting all requirements presented in Box 8.1.

Box 8.1 Questionnaire Conceptualisation Requirements (Source: UIAH 2003)

- The problem is well defined and will not be modified during the project.
- All the questions to be answered are known in advance.
- All questions are clear and unambiguous.
- The range of possible answers is known in advance.
- The questions involve mostly facts, quantities are easily definable physical matters.
- There are questions that some respondents might prefer to answer anonymously.

The application of the questionnaire methodology needed further refinement, for the two sample populations – the beach users and the coastal property owners. These required different sets of question types to obtain semi-quantitative data, providing comprehensive representation of the information at the time of questionnaire administration. As the beach user survey had to be applied *in situ*, it was necessary to design the questionnaire to suit a structured interview context, with option choices provided, yet sufficiently clear so that if the respondents wished to complete the form themselves, this could be easily fulfilled. On the other hand, given the spatial extent of the property owners, the use of the personal/individual administering of questionnaires was considered inappropriate. It was determined that the use of a postal survey technique would be the most effective for information dissemination and receipt (Section 8.4.3). The information content required from each respondent was specifically defined within the survey form and required little additional input or controlled application by the interviewer. It was, therefore, necessary to develop a questionnaire, directed at the specific concerns of the property owners and their level of knowledge of the existing coastal planning process and policies, and their perception of coastal hazards/risk issues.

8.3.1 Beach User Questionnaire Aims

As part of the LVA process this questionnaire needs to identify the quality of beaches frequently used by the public. The main aims are to assess beach user selected

preference(s) and priorities for visiting a beach and their knowledge of coastal issues related to beach vulnerability. This is achieved through their preference selection of a) beach characteristics, b) beach amenities, and c) their perception of the quality of the visited beach. Additionally, perception of beach vulnerability to wave action and to beach aesthetic quality is sought. This provides a link to the WEI and the identification of preferred coastal types for recreation.

8.3.2 Property Owner Questionnaire Aims

The developed postal survey aims to identify coastal property owners'³ perceptions on coastal information they consider important. This is achieved through an inventory of property owners' description of the beach areas associated with their property, their perception of beach erosion and its control, the government's role in relation to coastal risk issues, and their perception of the level of risk to their property. In previous studies considering perception of coastal erosion by local communities (e.g. Ricketts 1989, Smith 1994, Heinz Centre 2000a), it appears that the degree of understanding of the process involved affects attitudes towards hazard mitigation. Given the varying level of development along the study areas, it was thought that coastal hazards and vulnerability issues would also vary. Additionally, the questionnaire aims to establish the main coastal concerns of property owners and their approaches to addressing coastal vulnerability. This fits well within the LVAP process, providing a descriptive approach for considering socio-economic concerns and the value that respondents' place on their properties. Both questionnaires contribute to the descriptive perceptions of the LVAP for each coastal segment (Fig. 4.1).

³ Coastal property owners found in the five case study areas.

8.4 QUESTIONNAIRE METHODOLOGY

This section explains the methodologies used in developing and administering of the two questionnaires.

8.4.1 Question Design and Style

To determine the most appropriate questionnaire technique the literature on effective questionnaire development was reviewed⁴. In both cases, single response options were used to indicate interviewee preference or selection choice. They were structured to be easy to answer, rapid questionnaires. Box 8.2 outlines the procedures used in questionnaire development.

Box 8.2 Summary Procedures for Developing a Questionnaire Survey

(Sources: Malhotra & Birks 1999, Creative Research Systems 2001, North Carolina State University 2003, and Georgia Institute of Technology 2003)

1. Establish questionnaire goals (what do you want to learn?).
2. Identify your sample group type (who will you interview?).
3. Identify questionnaire type and question content (how will you interview?).
4. Determine response format (how will response information be collected?).
5. Determine question sequencing (create the questionnaire).
6. Pre test the questionnaire and suitably modify if necessary (determine the ease of application and level of understanding).
7. Administer the questionnaire.

The use of open-ended questions was avoided since they often are: 1) difficult to analyse statistically; 2) highly subjective in interpretation; 3) often very time

⁴ See Berdie (1973), Roscoe *et al.* (1975), Geer (1988), Yin (1989 and 1993), Futrell (1994), Rasinski *et al.* (1994), Malhotra & Birks (1999) and Creative Research Systems (2001).

consuming; and 4) omitted by respondents as they “sometimes require too much thought”⁵.

In both questionnaires, an attempt was made to provide a range of options that were self explanatory, with as little ambiguity and redundancy as possible. The questionnaire sections were progressive to ensure that the respondent could understand the topics and their response requirements. Hence, the more general questions were placed first to allow a certain minimum comfort level to be attained in the completion of the questionnaire and provide for a more free flow of responses as the sections progressed.

8.4.1.1 Public Notification

An interview with Mr. Terry Ali (an environmental journalist with The Barbados Advocate Newspaper) was held in April 2002. The article informed the general public of the forthcoming beach user and coastal property owner surveys in July 2002.

8.4.2 Beach User Survey

This questionnaire has been applied in person using a rapid face-to-face structured interview format. It was important to establish a representative opinion about coastal issues at different beach locations. A total of 213 respondents have been interviewed as part of the beach user survey. This represents an acceptable sample error ($p < 0.05$) of 7% (De Vaus 1986). It was essential that these respondents were sufficiently familiar with the areas of the coast such that an informed opinion could be assessed.

⁵ These issues have been well described by Berdie (1973), Yu and Copper (1983) and Creative Research Systems (2001).

8.4.2.3 Beach User Perception Questionnaire Survey Method.

The final questionnaire survey forms, are presented in Appendix 8.1, together with the appropriate pre-survey design considerations. Permission was sought, and received from the CZMU, to use their staff members in questionnaire administration. This demonstrated the Government's interest in, approval of, and support for the research. Guidance was provided to the interviewers to ensure that the same level of accuracy and approach by each interviewee⁷. In addition, where an assessment of a multiple answer question was required, a contact sheet was developed, allowing the interviewee to view the appropriate selection of responses.

Surveying took place over the main summer tourist season (July – September 2002). This is the time of year when most nationals return to the island for vacation, thereby allowing for an increased presence of locals on the beach over the period of a day. This further increased the probability that the interviewees would have some level of familiarity with the beach, as most locals tend to frequent their own preferred beaches. The interviews were conducted on days of good weather. All persons on the beach were interviewed⁸, as few persons were generally found on the beach. Interviews were carried out between the hours of 10:30 and 14:00, when maximum numbers were expected - especially on beaches with associated refreshment and toilet facilities.

8.4.2.4 Questionnaire Description

The questionnaire had a brief introduction, explaining the survey's rationale. It was designed for rapid completion as a series of questions with associated tick boxes and broken down into five sections, summarised below.

⁷ See Appendix 8 for guidance notes.

⁸ The number of persons interviewed at each beach was highly dependent on the actual numbers present at the time of the survey. Unlike many of the beach user descriptions of recreational beaches found in Europe, recreationists generally do not densely populate Barbados' beaches - including the peak tourism seasons.

Part 1 Personal Details: This section sought personal information on the interviewee, (including their resident status). Information was also gathered on their normal length of stay at the beach and their selection criteria used in choosing a beach.

This first part provided some basic demographic information on the respondent. It also allowed the respondent to gain a level of comfort at the start of the survey and provide information on his/her familiarity with the beach, being surveyed.

Part 2 Preference of Beach Characteristics: This section allowed the interviewee to identify the features preferred at a beach location and some of the features currently experienced at the beach, being visited. This was useful for potential future work in the identification of beaches that might need to have facilities provided or upgraded. Within the LVA context, this information was useful for comparison with the variable scores beaches received as part of the BAI. This provided a link in comparative assessment of the government's and the public's perceptions of beach characteristics.

The beach characteristic preferences followed perception and priority studies found in the literature (Young *et al.* 1996, Morgan *et al.* 1993 & 1995, and Morgan 1999). The characteristics have been modified to reflect the Barbados experience, while being generic enough for application in other small island contexts. It had originally been considered that a ranking scale of 1 to 5 for each category be developed. However, after the initial piloting, it was deemed unnecessary as it could introduce unfavourable biases into the responses. This could have led to the respondents selecting the best, rather than their preferred options. This section was designed to reinforce further the respondents resolve to complete the questionnaire, as it was quick and easy.

Part 3 Beach Amenity and Beach Quality Preferences: This section included a selection of beach facility preferences and issues relating to water quality to gather information on public perception of the association between water clarity and water quality. As documented in the literature (e.g. West 1989, Nelson 1998, Nelson *et al.* 2000), clear water is normally perceived by the public to mean clean water and therefore, good for recreational use.

This section aimed to capture respondents' perceptions of beach safety issues – not only physical safety but also public health and recreational water quality. It also introduced the issue of a beach aesthetics rating system for the island, and the potential role this could play in influencing beach choice. This provides a link to the BAI, developed in the LVA process in Chapter Five. The suggestion of such a BAI rating system was to determine if beach users were satisfied with, or, whether there was need to improve the general standard of the beaches. In addition, some European tourists⁹ are accustomed to the concept of beach awards and the Blue Flag schemes¹⁰ as promotional tools in coastal tourism (Williams and Morgan 1995, Nelson *et al.* 2000). The public recognition and understanding of such schemes can be a prime motivator in the selection of recreational beaches not only by the public but also by developed resorts (Williams *et al.* 1992). This could, therefore, have implications for the island's tourism product in the event that the recreational littoral is considered unsuitable as a recreational zone based on any publicised rating scheme.

Part 4 Perception of beach vulnerability to wave attack: This section gathered information on issues relating to the available options for beach facilities or properties that might be damaged by storm waves. It allowed the interviewee to provide a personal judgement, given the visible characteristics of the beach being surveyed. Using a “layman's” interpretation of the issues it also gathered information on their knowledge and understanding of some of the critical decisions that can affect coastal development. As part of the LVA process, this approach provided the interviewee opportunity to assess the importance of placement of structures and buildings on the shoreline. It also allowed opportunity for considering the beach segment within the context of the determined WEI.

⁹ The main tourism market has been the U.K since the mid 1990's (Central Bank of Barbados 2002).

¹⁰ Attempts are currently under way to introduce the Blue Flag Programme to the Caribbean region, including Barbados. The Caribbean Tourism Organisation (CTO) and the Caribbean Alliance for Sustainable Tourism (CAST) are supporting this. The literature (e.g. Morgan *et al.* 1996 and Nelson *et al.* 2000) demonstrates that there is little evidence that the Blue Flag Programme attracts tourist to beaches with the Blue Flag designation, however it does provide a mechanism for information dissemination to the public on the health of the beaches. Given Barbados' high dependence on tourism, it is this author's opinion that it is ill advised to introduce the programme to the island, unless modifications are made to reflect the difference between temperate and tropical beaches, as the criteria and context used to describe the former cannot be effectively applied to the latter.

This section has focused on the perceived use of the IPCC adaptation to climate change recommendations and the combined requirement for facilities on the beach. The public perception of littoral vulnerability included issues related to climate change and beach erosion. The respondents had to also identify perceived problems for the surveyed beach. In this way, they were providing input to the coastal management process, by identifying their issues of concern.

Part 5 Perception of beach aesthetic quality: This section allowed interviewees to provide their impression, and subjective rating of the general beach quality. It considered issues related to the types of public facilities expected at the beach. This was relevant to the LVA process allowing respondents to provide subjective assessments of beach aesthetic quality. This final section allowed the respondents to identify a combination of beach characteristics (Unal and Morgan 2000), frequently considered in beach selection.

8.4.3 Coastal Property Owner Survey

This questionnaire surveys were applied using a modified version of the Total Design Method (Dillman 1978) in which guidelines regarding the questionnaire cover letter design and follow-up have been identified. Due to budget constraints only one follow-up was performed (compared to the three as recommended by Dillman 1978). As part of this, a thank you letter was sent to all respondents and an additional questionnaire was sent out to households not responding within the first four weeks. After the expiration of the original response deadline, telephone contact was made with the commercial businesses. This acted as a final reminder, which it was hoped would contribute to an increased return response.

It was important to establish a representative opinion about coastal issues within the study areas and essential that these respondents were sufficiently familiar with coastal areas so informed property owners' opinions could be assessed.

- Allows for more critical responses to be provided where appropriate, as the interviewee feels separated from the “interview process” – a degree of anonymity.

8.4.3.2 Pilot Survey

A pilot survey questionnaire was designed and tested in September 2001. Six different types of properties¹², outside the study areas, were contacted for pre-testing. They were randomly selected on the basis that they represented the main respondent types to be surveyed. The respondents were asked to comment on:

- The ease of understanding and clarity of the questions;
- Whether any questions needed expansion or reduction;
- If there was sufficient emphasis on the primary aims of the survey;
- What modifications were needed to questionnaire design format (i.e. questionnaire flow);
- Inclusion of any other outstanding issues of importance from a property owner perspective;
- If the questionnaire would be a worthwhile activity to complete if they were to receive it in the post;
- The approximate time taken to complete the questionnaire.

The comments were evaluated in terms of their application to the questionnaire context and the research application process. Most responses considered the questionnaire information important and useful. However, it was felt that the questionnaire should be shortened and some terminologies should be generalised to increase survey completion time. There was general consensus that the questionnaire's flow and design allowed for its rapid completion. After suitable incorporation of the comments and relevant terminology modification, the final survey form was developed.

¹² Property types piloted were a residential property, a restaurant, a hotel, a guesthouse, a villa, and a commercial business.

8.4.3.3 Property Owner Perception Questionnaire Survey Method

A total of 216 questionnaires were sent to all coastal property owners within the study areas. Their addresses were verified from the Land Valuation Department database. Given the size of the areas, the hand delivery of each questionnaire pack was both time and cost efficient. For persons at home at the time of delivery, a brief rationale for the survey was provided to reiterate that it was in no way connected with a reassessment of their property values. In many instances the residents needed to be convinced about completing the questionnaire. However, upon explanation, it was well received, with residents proceeding into long conversations on their current problems and seeking contact information on appropriate government agencies. The final questionnaire survey form is presented in Appendix 8.2, together with the appropriate pre-survey design considerations. Permission was sought, and received from the CZMU to use their office as a mail return address. As with the beach user survey, this demonstrated Government's commitment and support to the research. This information was incorporated into the covering letter accompanying the questionnaire. The CZMU logo and the Cardiff University and departmental logos were displayed on the survey forms as an incentive. Fox *et al.* (1988) has demonstrated this as being an effective factor in the successful completion of postal responses.

Each property owner's questionnaire pack contained:

- a) A cover letter of introduction and an outline of the survey purpose with a closing date, and a contact telephone number at the CZMU office if assistance was required to complete the survey forms.
- b) A self-addressed and stamped return envelope (to encourage a high response rate¹³).
- c) A copy of the questionnaire form.

These packs were:

¹³ Demonstrated by McCrohan and Lowe (1981), and Armstrong and Lusk (1987).

1. Deposited in letterboxes to ensure their safety.
2. Delivered to reception desks of hotels and commercial businesses.
3. Directly received by owners who were at home at the time of delivery.
4. If none of the above, they were secured to sheltered entry points to the property in clear view of the owner on his/her return to the premises.

The respondents were given six weeks to respond to allow sufficient time:

- For the respondent not to feel pressured providing an immediate response (as this might cause a low response rate, if they did not consider the survey of relevance to them).
- To allow, where necessary, the property occupants to pass on the questionnaire to the owner or management agency for completion, and for the eventual return of the questionnaire to the CZMU office.

After this period, the response time was extended by 2 weeks to allow final reminders to be distributed and to allow for late returns. This was also publicised in the Advocate Newspaper. After that, all completed questionnaires were posted from the CZMU office to this researcher for data processing.

8.4.3.4 Questionnaire description

The postal questionnaire is divided into 3 sections:

Part 1 Personal Details of the Interviewee: This first section allowed the respondent to attain a level of comfort with the survey. It identified the personal details of property owners, the type of property, its ownership and the length of respondent's association with the property. These factors were considered important for determining familiarity of the owner with the property. If the respondent had no long-term familiarity, then some responses could reflect this. Additional information was also sought regarding the use of the coastal area associated with the property by the respondent. This helped determine the respondent's level of understanding of coastal processes affecting the

area. It also collected information regarding residents or persons employed at the property to provide a gauge on potential numbers living directly on the coast.

Part 2 Perception of Coastal Issues: This section allowed the respondents to identify their personal understanding of beach erosion issues. Within this section, respondents were required to identify their main sources of information for such issues. It sought their perception of government's role and their own role in the management of beach erosion. Given the location of the property, information was also gathered on property damage experienced. This included information on the frequency of such damage, and whether insurance claims were made in relation to storm wave damage. This information is useful in determining whether damage value was considered significant enough to make a claim or not. It also provided an indication of the level of insurance coverage received to effect repairs.

The respondents had to identify three main coastal issues related to their location and provide information on beach erosion and damage experienced annually to properties. To achieve this, the questions were designed to collect information on estimated property damage resulting from beach erosion and storm waves. Additionally, there was very little information regarding the level of coastal property insurance available locally in the public domain. The questionnaire was structured to collect information on the property, level of insurance coverage, the types of claims and total damage coverage received to assist in the repair of said damages. These results would provide an indication of the level of damage repair coverage experienced on the coast, providing an indication of the perceived vulnerability of the property by the respondent and, its need for financial protection coverage to restore the property or its surroundings.

Part 3 Perception of Risk to Coastal Property: This section allowed the respondents to select their personal understanding of certain coastal hazard issues. Respondents identified their main sources of information for such issues. Additionally, respondents were questioned on their knowledge of the island's CZMP and the type of coastal hazard information they considered relevant for inclusion in the plan. Also included here were statements to test the property owner's perception of effects relating to: 1) the use of coastal engineering structures and their contribution to the stability of beach

segments; and 2) the type of options that the owner would employ to protect the property against storm damage. Finally, it allowed the respondent to provide their perception of potential risk to the property.

This part of the questionnaire was directed at the level of knowledge of the respondent on the various vulnerability hazards, potentially affecting the coast. It also presented the IPCC recommendations for climate change adaptation to determine respondents' option preference for coastal buildings damaged by storm activity. Additionally, the respondents were asked to indicate the level of property protection that had been used at their site, and the source of advice received for the choice of protection option employed. This served two purposes 1) to determine if they were aware of the types of protective structures available and their use; and 2) to determine if they would use such in the event of storm damage experienced on site.

A results summary was offered to interested respondents. It was anticipated that this would help the survey return. Dommeyer (1985) and Diamantopoulos and Schlegelmilch (1996) have effectively demonstrated the use of this and its ability to generate interest in the research.

8.4.3.5 Methodology for Questionnaire Application

The surveys were administered in the main summer tourist season (July - September 2002). For all questions in the Beach User Survey, listed options were provided to the respondents who ranked responses in descending order of importance (from 1 to 8). For all questions in the Coastal Property Owner Postal Survey (with the exception of Question 8) listed options were provided to the respondents who ranked responses in descending order of importance (from 1 to 5). Both surveys provided respondents with options to indicate as many or as few response types as appropriately stipulated by the relevant question.

These choices were indicated in each question. The cumulative information of the study has been used to generally describe the perception of beach aesthetics and coastal issues

affecting the coastline. A category of “Other” was included to allow for the inclusion of options not provided. In the postal survey, a category of “Don’t know” was provided. Rigorous statistical analyses were not performed on the data sets as it was thought that descriptive statistics would be most effective and sufficient to reflect the personal views of the beach users and property owners.

8.4.3.6 Limitations to Applied Survey Techniques

The Beach User Survey has several limitations. Firstly, it was considered that the beach user being interviewed would consider the questionnaire an inconvenience. Therefore, those persons eating or sleeping on the beach or recreating in the sea were not interviewed. Secondly, the ability to randomly sample the beach in terms of age, sex, socio-economic group would be problematic given the busy mobile beach situation, as well as the available numbers on the visited beach, so a quota sample was utilized. It was, however, emphasised to the interviewer that in all instances, as many persons as possible should be sampled. These problems were beyond the control of this researcher and therefore, unavoidable.

Another basic limitation of the questionnaires was that a certain minimum level of coastal terminology had to be incorporated into the questions. This did not detract from the information being collected, but provided discussion points to keep the interview interesting and informal.

The Property Owner Survey also had several limitations. Consideration was given to the most appropriate time and efficient way to deliver the 216 postal surveys. It was determined that a weekend morning was the most suitable time to ensure a correct count of all the properties that received surveys¹⁴. Also, despite hand delivery, it was difficult to ensure that all properties were inhabited at the time of delivery¹⁵.

¹⁴ Some properties had derelict buildings on them although they were still listed on the land valuation department’s data set.

¹⁵ Some villas are only used annually during the winter months and for the rest of the year they remain closed.

8.4.4 Response Rates

Generally, the response rate and completion rates for the surveys were good (Table 8.2). The response percentages between sites ranged from 52.8% to 72.2% (Fig. 8.1). Of the 216 surveys posted, a total of 124 (57.4%) replied and completed the surveys.

Table 8.2 Total Postal Survey Response Rate

Responses	Number	Percentage (%)
Total Distributed	216	100
Total Responses	124	57.4
Total Non Responses	92	42.6
Total Invalid Responses	0	0
Total Valid Response	124	57.4

Table Note:

Where Total Invalid Response applies to respondent who when contacted declined to participate.

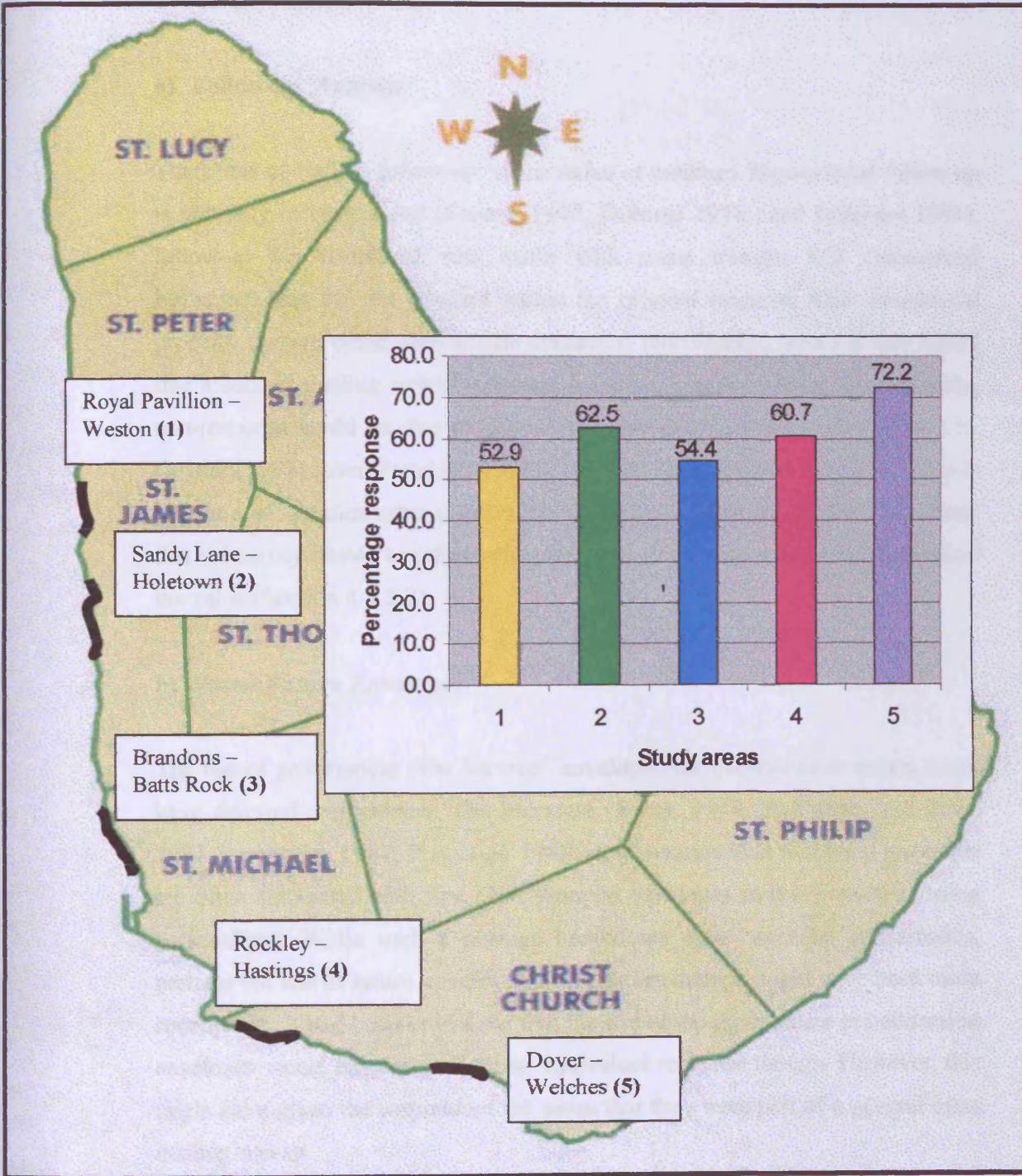
While it had been hoped for a higher property owner response rate, at least 50% of the respondents from each location contributed to the survey. This response is considered very satisfactory, as the literature points to response rates normally below 40% (Diamantopoulos & Schlegelmilch 1996, Jobber & Beasdale 1987, and May 1993). However, this level of response is difficult to interpret. It could be the result of the respondent's level of interest, in what happens to "their coastline". This would concur with Feitelson's (1991) findings.

As has been reported in the literature (Fox 1988), and applied successfully in other research areas (Potts 1999, Owen 2002, Ball 2003), the distribution of questionnaires on coloured paper has successfully boosted returns. This survey was, therefore, distributed on coloured paper to achieve a similar result.

Fig. 8.1 Postal Survey Response Rates from Case Study Area

18500mE
94200mN

47300mE
94200mN



18500mE
59800mN

47300mE
59800mN

Scale: 1 2 3 4
Kilometres

8.4.4.1 Limitations to Response Rates

The following provides an overview of some of the key limitations that might have contributed to the response levels:

a) Follow-up Mailings

There was no time to follow-up with a series of mailings. However, as follow-up is normally recommended (Roscoe 1975, Dillman 1978 cited Feitelson 1991), follow-up via telephone was made with some tourism and commercial businesses that did not respond within the original response time. Residential property owners could also not be contacted individually; hence it was hoped that a second mailing would stimulate a greater return response. Additionally, non-response could be due to perceived invasion of privacy as postulated by Goyder (1987) (cited Feitelson 1991). This may be a legitimate concern, since at the time of questionnaire distribution, property owners might have perceived that the survey related to information gathering in order to increase property land tax value (Section 8.4.3.3).

b) Postal Return Envelopes

The use of government "On Service" envelopes for questionnaire return could have deterred respondents. The literature (Brook 1978, McCrohan and Lowe 1981, Armstrong 1987, Fox *et al.* 1988) demonstrates that increased responses are often associated with first class stamped envelopes as it is viewed as being personalized. While such a postage breakdown does not exist in Barbados, perhaps the use of return envelopes with postage stamps might have been more appropriate. It had been envisaged that the use of the government pre-addressed envelopes would have stimulated an equivalent response though. However, this might have given the respondent the sense that they were part of a general mass mailing survey.

c) Respondent Diversity

While the issues raised in the survey are currently topical it is clear that the heterogeneous group approach used has not been effective in generating an increased response rate. From the literature (Frankfort-Nachmias & Nachmias 1992), it is noted that response rates from select groups are normally higher as members of such groups are able to relate to the study aims.

d) Increased Coastal Hazard Awareness

At the time of the survey issues relating to potential tsunami generation for the Kick 'em Jenny submarine volcano and concerns related to coastal flooding were being reported in the news. It had been hoped that the topicality of such news would have contributed to a higher response rate.

Despite these limitations, and with the completed return rate averaging more than 55%, the results are considered acceptable.

8.4.4.2 Data Storage and Processing

Questionnaire data entry for both surveys was performed using the Statistical package SPSS for Windows (Version 11) and Microsoft Excel. These provided the most comprehensive and accessible means of analysing this sort of data, both statistically and graphically.

8.5 QUESTIONNAIRE RESULTS.

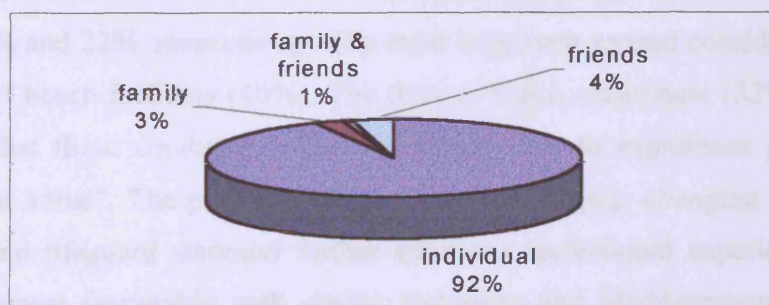
8.5.1 Public Beach User Questionnaire

This section presents the analysed results of the beach user survey and achieves research objective 7 (Section 1.3.1.2). The results interpretation follows the format of the developed questionnaire.

8.5.1.1 Part 1 Beach User Personal Details

Figures 8.2 – 8.4 summarise the respondents' characteristics relating to interviewee group type, employment level and age categories, respectively. Individuals represent the largest interviewed group type category (92%) (Fig. 8.2). Most respondents were local (82%), and working at the beach where the interview took place. Only 18% were visitors to the island. Most respondents (78%) were employed (Fig. 8.3). Although attempts were made to achieve a representative sample for each beach visit (in terms of age and sex of adult or near adult beach users and also the type of groups that could be represented), due to sampling constraints¹⁶ more than half of those interviewed were aged between 20 and 39 (53%) (Fig. 8.4).

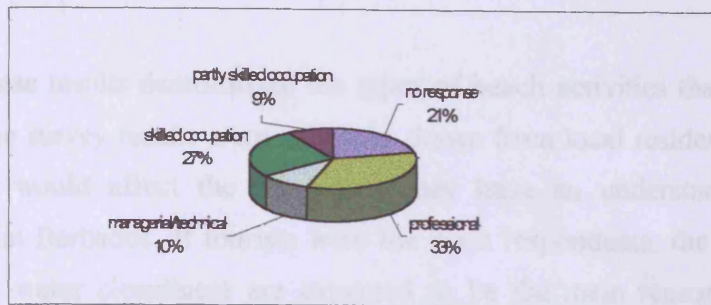
Fig. 8.2 Interviewee Group Type



N = 213 (s. e. 7%, p<0.05%)

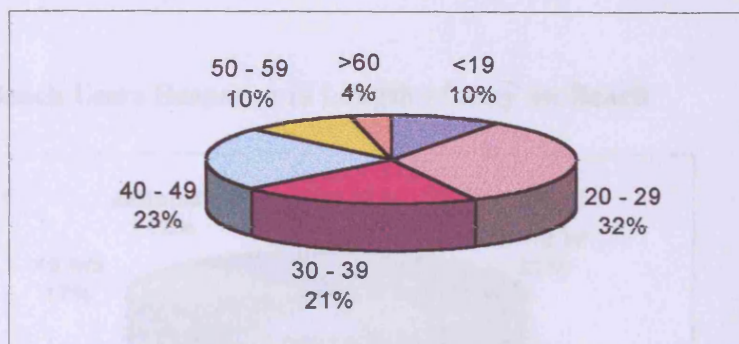
¹⁶ Few persons were present on the beach during the sample period, therefore, all beach users were surveyed.

Fig. 8.3 Type of Interviewee Employment Level



N = 213 (s. e. 7% (p<0.05%))

Fig. 8.4 Age of Beach Users Surveyed



N = 213 (s. e. 7%, p<0.05%)

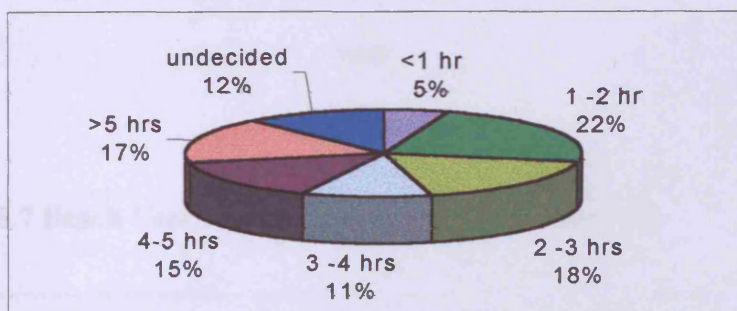
Most interviewees selected beach stay durations of 1-3 hours (41%), followed by longer than 5 hours (17%) (Fig. 8.5). Reasons for selecting beaches, (Fig. 8.6), demonstrate that most users (51%) select a beach first on the basis of cleanliness and safety, 29% and 22%, respectively. The most important second consideration is the presence of beach facilities (40%). The third is beach cleanliness (32%). It can be expected that these conditions allow the beach user to experience good “beach recreational value”. The presence of beach facilities¹⁷ (e.g. changing rooms, toilet facilities and lifeguard stations) further enhances recreational experience. These results compare favourably with similar European and Mediterranean beach user

¹⁷ It has to be noted here that beaches surveyed included beaches with and without facilities.

preference surveys in the literature (Morgan *et al.* 1995 and 1996, Williams *et al.* 2000, Nelson *et al.* 2003).

Finally, these results demonstrate the types of beach activities that determine user choice. The survey results were primarily drawn from local residents, whose beach familiarity would affect the results, as they have an understanding of “beach culture¹⁸” in Barbados. If tourists were the main respondents, the issues of safety, beach and water cleanliness are expected to be the main reason for selecting a particular beach. Thereafter, their preference might relate to water sports activities as well as the presence of facilities, bearing in mind that most tourists seldom move far away from the beaches near their accommodation.

Fig. 8.5 Beach Users Response to Length of Stay on Beach



N = 213 (s. e. 7%, $p < 0.05\%$)

From Fig. 8.7, the beach activity results demonstrate that most individual users participate in swimming (40%) watersports activities (37%) and beach related activities (23%). A similar pattern was shown for group activities.

¹⁸ Beach culture reflects a local understanding beach use patterns and what to expect and experience while there.

Fig. 8.6 Beach Users Preferred Reasons for Choosing the Beach

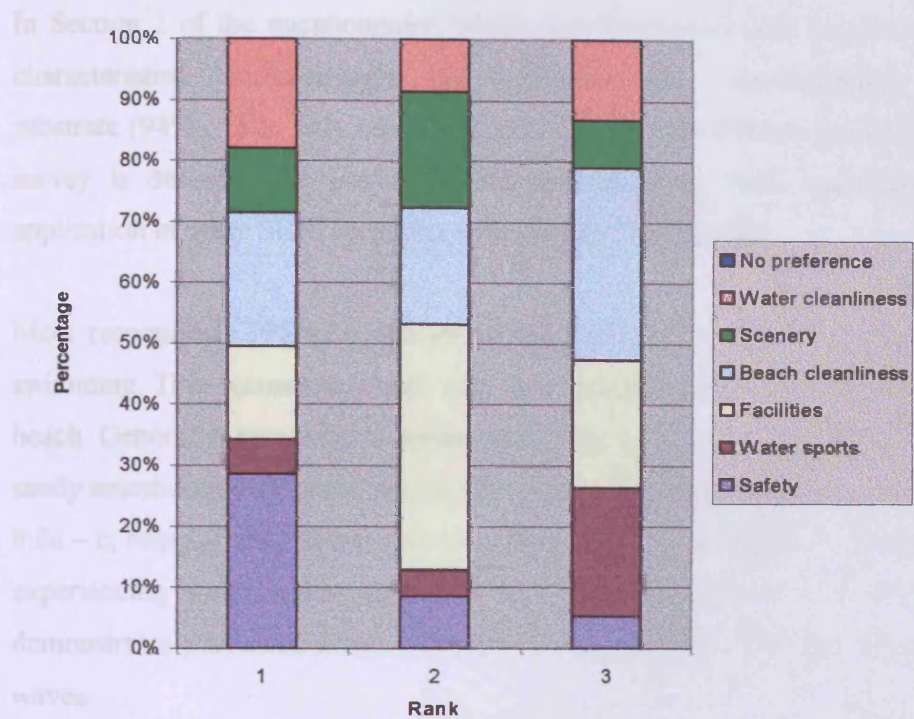
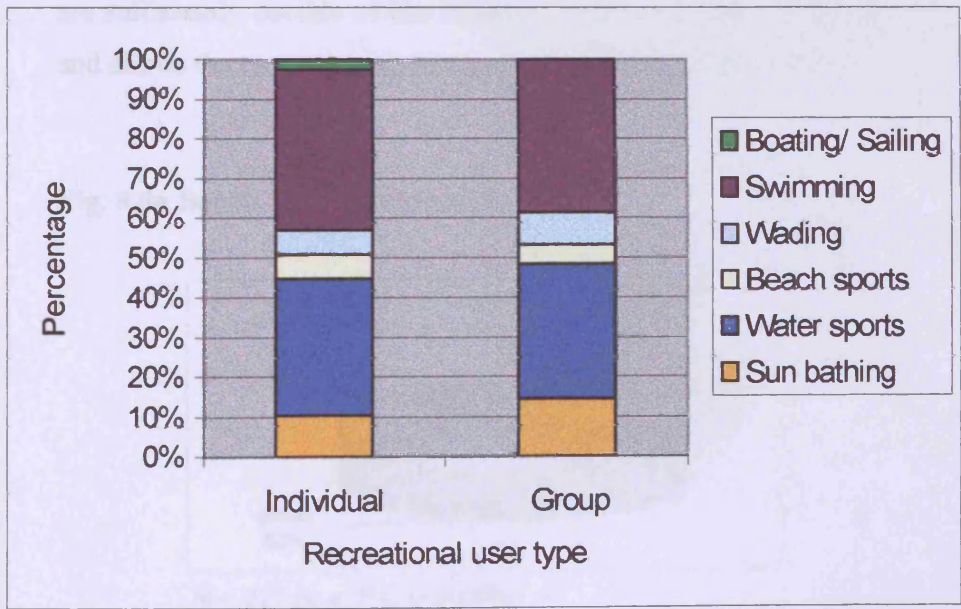


Fig. 8.7 Beach User Preferred Recreational Activities



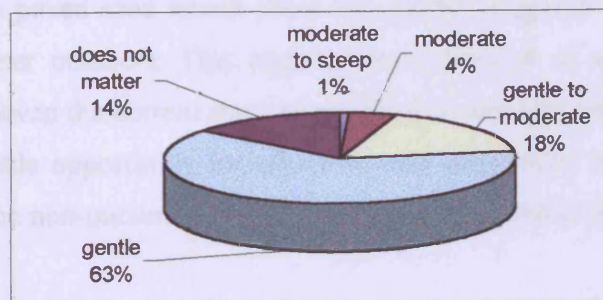
8.5.1.2 Part 2 Beach Characteristics Preferences

In Section 2 of the questionnaire, beach user preference was sought on 15 beach characteristics. Unsurprisingly, the preference was overwhelmingly for sandy substrate (94%). The only other selection was for gravel beaches (4%). While this survey is designed for Barbados, the classifications have been developed for application in other SIDS locations with varying beach types.

Most respondents (95%) preferred beach types to be “good” to “excellent” for swimming. This corresponds well with the identified reason for the user visiting the beach. Generally, respondents preferred to visit gently sloping beaches (63%), with sandy nearshore bottoms (85%), or with gently sloping nearshore areas (61%) (Figs. 8.8a – c, respectively). It was also preferred that these locations be sheltered (60%), experiencing small waves (59%). The ability to recreate at sheltered beaches demonstrates perceived levels of safety in the absence of strong currents or large waves.

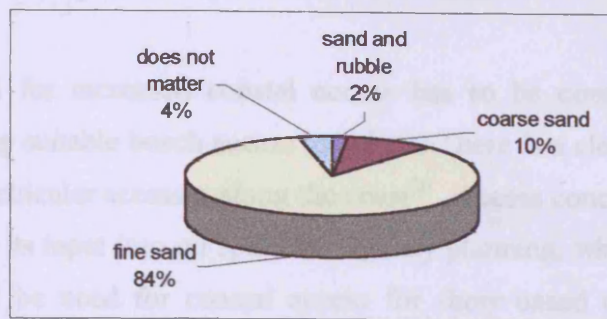
The most frequently chosen water depths 10m from the shoreline were waist depth (56%), followed by chest depth (18%). Most recreationists consider this distance as safe for “comfortable” nearshore recreation. With the former depth, it ensures they are sufficiently outside of the breaker zone not to feel the effects of the backwash and allows the recreationists to regain footing after a swell has passed.

Fig. 8.8a Beach Slope Preference



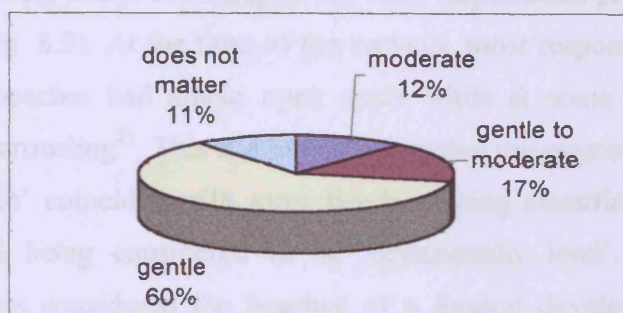
N = 213 (s. e. 7%, $p < 0.05\%$)

Fig. 8.8b Nearshore Bottom Condition Preference



N = 213 (s. e. 7%, $p < 0.05\%$)

Fig. 8.8c Nearshore Seabed Slope Preference



N = 213 (s. e. 7%, $p < 0.05\%$)

The results indicate a preference for more durable accesses with pedestrian access being the preferred option (paved footpaths (46%) and paved roads (41%)). This reflects the user's interest in having increased coastal access:

- A paved road would allow for greater vehicular access encouraging greater user numbers. This requires the provision of adequate parking facilities. Given the current state of coastal development within the study area, there is little opportunity for effective land acquisition by government, resulting in the non-pursuit of parking provision requirements¹⁹.

¹⁹ To address this concern requires the commitment of the government to acquire suitable land parcels on the coast. This is an activity that is neither routinely nor periodically performed.

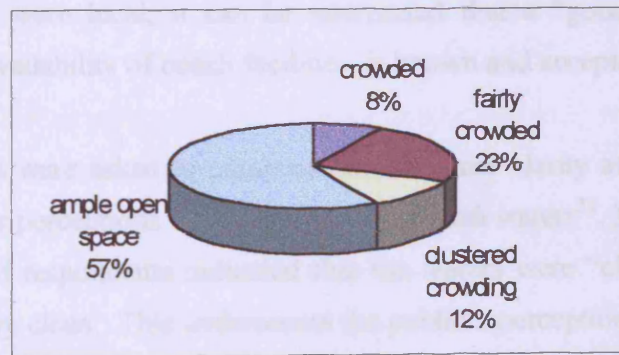
- The paved footpath recognises the need for clear access to the beach primarily for use by residents in the area.

The need for increased coastal access has to be considered by planners when identifying suitable beach access locations. There is a clear indication that there are too few vehicular accesses along the coast²⁰. Access concerns have direct relation to LVA and its input into oil spill contingency planning, where, in the event of a spill, there will be need for coastal access for shore-based deployment of equipment. Given the limited number of vehicular access coastal points, the government must consider appropriate land acquisition to provide more accesses.

In considering beach crowding levels, most respondents preferred ample open space (58%) (Fig. 8.9). At the time of the surveys, most respondents (>75%) considered that the beaches had ample open space while at some locations they identified clustered crowding²¹. This is a highly subjective interpretation. However, the 'ample open space' coincided with most beaches being classified as 'quiet' (73%), with only 26% being considered to be 'occasionally loud'. More than half of the respondents considered the beaches of a limited development level (51%) (Fig. 8.10).

8.5.2.3 Part 3 Perception of Beach Amenities and Beach Quality

Fig. 8.9 Perception of Recreational Use of Beach at Time of Survey

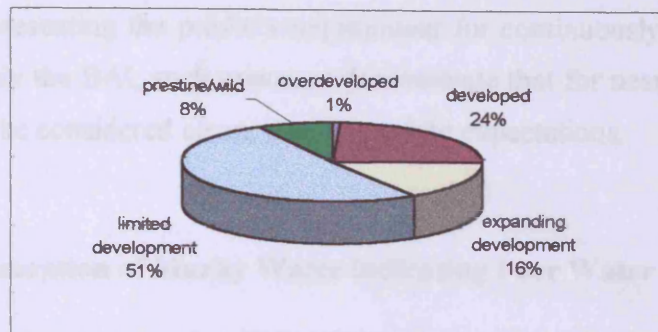


N = 213 (s. e. 7%, p<0.05%)

²⁰ Along the west and south coasts of the island there are less than ten actual vehicular beach access points, with associated parking areas (K. Neblett *pers. comm.* 2001).

²¹ Represented as clusters of individuals or groups in locations along the beach.

Fig. 8.10 Perception of Beach Development Level



N = 213 (s. e. 7%, $p < 0.05\%$)

Having developed the BAI for beaches (Section 5.4.4), the public perceptions of the crowding also provided input into the LVA process, helping to identify where potential overcrowding could occur. Generally, most crowding occurs on locations with facilities. In order to reduce crowding this sort of information can assist in identifying other beaches worthy of upgrading. These approaches support recommendations proposed in the Barbados ICZMP (Halcrow 1999).

8.5.1.3 Part 3 Preference of Beach Amenities and Beach Quality

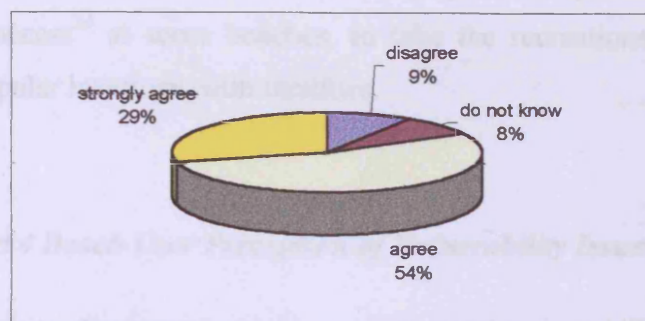
Most respondents (52%) consider that the beach facilities are adequate. As most respondents were local, it can be interpreted that a “good will” understanding, relative to availability of beach facilities, is known and accepted.

Respondents were asked to comment on the water clarity at the beaches and then provide their perceptions of the cleanliness of such waters²². In both instances, more than 90% of respondents indicated that the waters were “clear to very clear” and ‘clean to very clean’. This underscores the public’s perceptions that clear waters can be considered clean waters. A subsequent statement was provided for the

²² Water clarity is based on perceptions of light penetration and the lack of suspended particulate matter in the water column; while water cleanliness is linked to the turbidity perception associated with water pollution.

respondents to decide “if murky waters reflect poor water quality?” In general, most (88%) agreed with the statement (Fig. 8.11). This response relates well to the LVA process by presenting the public’s requirement for continuously clean, recreational waters. Within the BAI, such concerns demonstrate that for nearly all locations, the beaches can be considered clean, meeting public expectations.

Fig. 8.11 Perception of Murky Water indicating Poor Water Quality



N = 213 (s. e. 7%, $p < 0.05\%$)

Most respondents (53%) indicated that a beach rating system²³ was required for the island. Reasons for such a system focused mainly around information dissemination (e.g. the identification of good beaches, and information on the beach and coastal water cleanliness). The majority (59%) felt that having such a rating system would have a very important influence on their beach selection. A sizeable minority (45%) did not consider such a scheme necessary. Reasons included:

- The identification of good beaches would lead to overcrowding;
- Individual beach differences are important; and
- All the beaches on the island are of high quality and it should be the personal choice of a beach user to discover beaches.

²³ It should be noted here that no indication as to what type of rating to be developed was provided to the respondent. The only descriptor was that the beach aesthetics include physical, environmental and social use qualities, found at the location.

In general, most beach users accept the beach standard and its perceived quality. However, in the last five years, there has been increased pressure through expanding coastal development, and the continued threat of loss of available access to the coast. The public has become increasingly aware of these concerns and their effects on the beach quality. Thus, as part of the LVA process, a beach rating system would encourage the maintenance and enhancement of beaches and their public access. It would also put pressure on the government to maintain a “quality standard” at beach locations. Moreover, it provides the government with opportunities to acquire coastal property/space to provide basic facilities or improved access²⁴ at some beaches, to take the recreational load away from the existing popular locations, with facilities.

8.5.1.4 Part 4 Beach User Perception of Vulnerability Issues Affecting the Coast

In this section, the interviewee’s perception of vulnerability was explored. The questions determined if the respondent understood the developmental considerations applied to coastal locations. The respondents were asked to indicate the most appropriate option for beach facilities damaged by storm waves. The majority (87%) indicated that properties should be replaced if they were damaged by storm waves, while only 8% recommended relocation. This illustrates the beach user’s preference for facilities to remain on the beaches; they are seen as necessary to the beach experience.

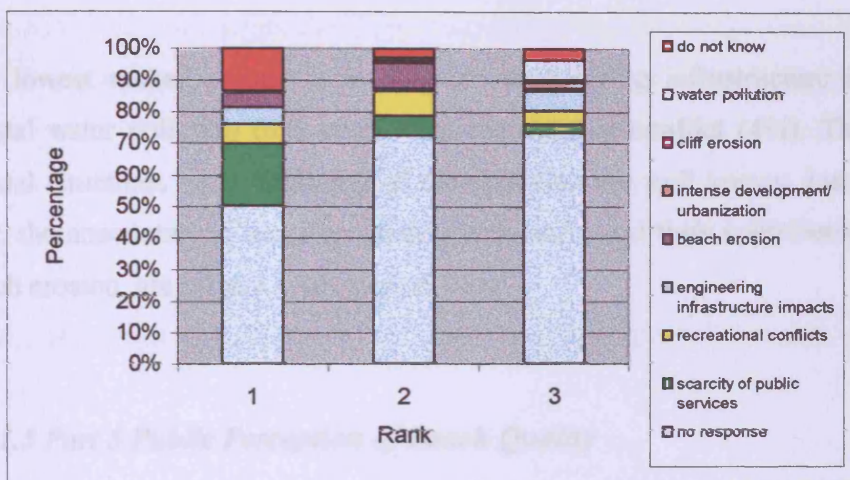
Most respondents (67%) indicated that if a coastal property was damaged by storm waves, it should be setback further from the sea. In contrast, some respondents (28%) indicated that they would rebuild on the same location, or rebuild and use a sea defence structure, in order to protect the property from future damage.

When asked to rank the main perceived coastal problems for the area, it was noted that there was a high proportion of non-responses for each ranking (Fig 8.12). This

²⁴For example shower stalls, limited parking, widened pedestrian access (rather than a small footpath between properties) with benches or picnic tables.

reflects the respondents' indecision. This might be as a result of (1) never having considered these problems before or (2) having general knowledge of the standard beach condition. The latter may be the reason for beach preference (e.g. the lack of facilities, the knowledge of the best time to visit and avoid crowds, the location of the beach and the fact that it may never be crowded).

Fig. 8.12 Beach User Priority Ranking of Problems Affecting the Beach



Despite this, the results show the main perceived coastal problem was the scarcity of public services (20%). Recreational conflicts (16%), and engineering infrastructural impacts (5%) were chosen as second and third. The concerns over public services have been addressed previously. The results also demonstrate the public's need for recreational conflicts to be addressed. Such conflicts normally relate to the use of powered or motorised craft in proximity to swimming and other nearshore recreationists²⁵. This has been a constant source of concern for many recreational beaches (Richard Alleyne, *pers. comm.* 2001). A recreational zoning system, initiated during the 1980's, has been successful at eliminating some conflicts

²⁵ Over the last decade, there has been an increase in the variety of recreational crafts especially shallow hull catamarans, which are able to "beach" to allow their passengers to disembark directly onto beaches.

experienced. However, the indiscriminate actions of some watersports operators are still a major concern for enforcement²⁶.

The second ranked priority problems are the issues of beach erosion and recreational conflict (8% each) followed by the lack of public services (6%). As a secondary priority, beach erosion has a direct impact on the effective use of the beach area. This is of relevance to hotel locations that install beach volleyball nets and beach tennis areas (normally flagged out on the beach). This allows guests to use the area but then prevents the use of the beach area by others.

The lowest ranked priority concerns are engineering infrastructure impacts and coastal water pollution (6% each), and recreational conflict (4%). The effects of coastal structures on the stability of the shoreline are well known, but for a beach user, the anecdotal evidence associated with such, and their contributory effects to beach erosion, are often a source of concern.

8.5.1.5 Part 5 Public Perception of Beach Quality

In this section, a perception of the beach aesthetic quality was sought. Three areas were identified (1) issues of beach cleanliness, (2) presence of beach facilities and (3) issues of beach safety. In all instances, more than 95% of respondents considered these aspects in determining beach choice.

The results relating to beach cleanliness (Fig. 8.13a) indicate that the priority concerns (86%) specifically relate to garbage/litter presence, water colour and clarity and sand quality and water quality. In the second ranking, emphasis (78%) focused on water colour and clarity and the number of persons present as an influence on beach litter.

²⁶ The Barbados Port Authority has responsibility for the licensing of water sports operators and the designation of watersports areas along the coast. They are also responsible for the enforcement of the water sports regulations, which they pursue in association with the Barbados Coast Guard. Within the Barbados Marine Reserve, the NCC is responsible for the regulation and enforcement of the watersports activities.

The results relating to beach facilities (Fig. 8.13b) identify the most important priorities as almost of equal importance (lifeguard stations (22%), and the need for access and parking (21%)). There is user preference for fully equipped facilities²⁷. Not all beaches have facilities; however, given the logistics involved, it seems highly unlikely that all beaches will ever be fully equipped. Recommendations for consideration include (1) the installation of shower stalls at the more frequently used beaches; and (2) the establishment of more lifeguard stations, along the coast.

The beach safety results (Fig. 8.13c) reveal that the highest priority concerns are swimming and water safety issues, followed by crime and harassment. In the second priority ranking crime and harassment was the main issue (47%). From a beach safety perspective, the beach users ability to use the nearshore for recreational purposes safely is important. The concern with substrate conditions focuses on the beach user not being affected by, or experiencing any discomfort²⁸; for example:

- Rubble in the nearshore and the possibility of black spiny sea urchins (*Diadema sp.*).
- The presence of accumulated seagrass frond beds²⁹ found in the nearshore – usually after rough seas³⁰ - and the perception of not knowing what may be lurking within the mass of fronds.

Most respondents (68%) indicated that they considered the surveyed beach to be ‘above average’, demonstrating the public’s perception that the islands’ beaches are above average for recreational purposes (Fig. 8.14) This perception shows that beaches are important to the regular beach user and therefore, their condition should be maintained.

²⁷ Locations with facilitated parking access to the beach, proper facilities for use by the public and supervised water safety control.

²⁸ This has previously resulted in the removal of coral rubble from the nearshore, contributing to the exacerbation of beach erosion problems in the area.

²⁹ Seagrass frond beds are the result of detached seagrass blades being aggregated together in the nearshore due to the nearshore current patterns and wave action.

³⁰ Storm wave action breaks the fronds off of the seagrass beds and transports them to the shoreline where they are deposited either on the beach, or in the nearshore before being transported along the coast when normal sea conditions return. Seagrass fronds deposited on the beach are cleaned away by NCC on a daily basis.

Fig. 8.13a Beach Cleanliness Issues considered in Beach Selection

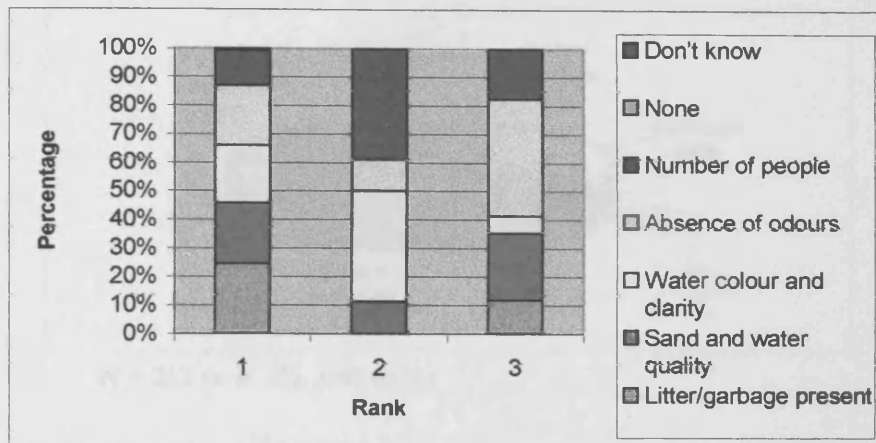


Fig. 8.13b Beach Facilities Issues considered in Beach Selection

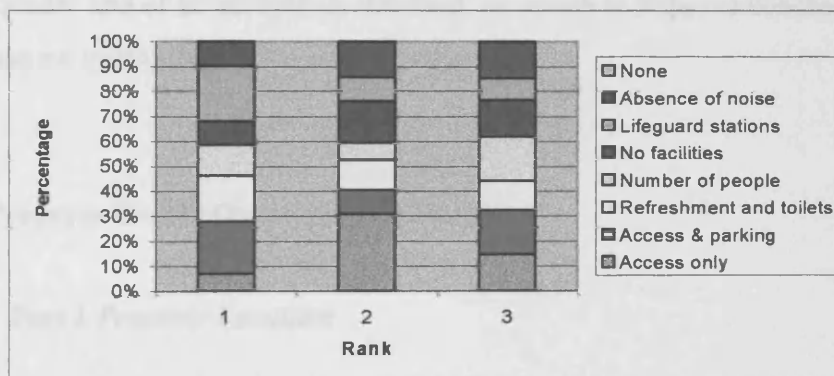


Fig. 8.13c Beach Safety Issues considered in Beach Selection

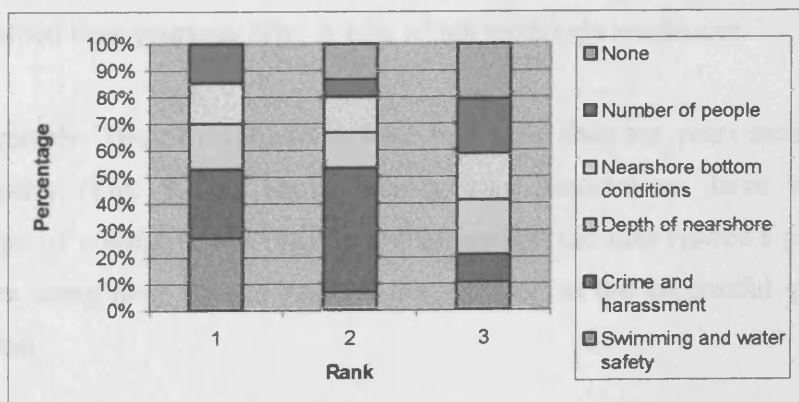
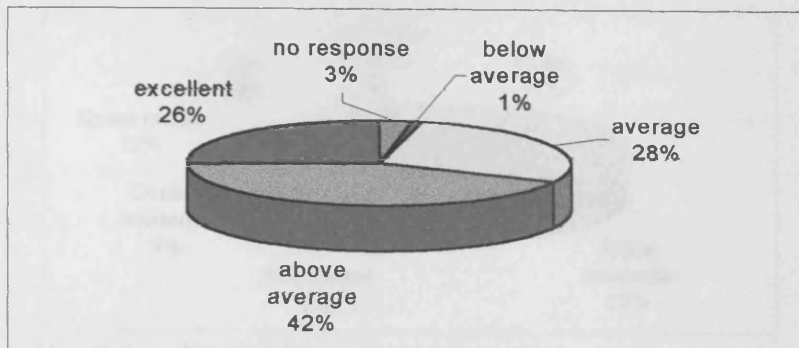


Fig. 8.14 Public Perception of Beach Quality



N = 213 (s. e. 7%, $p < 0.05\%$)

The 'above average' public perception of beach quality (68%), supports the BAI results where 50% of the beaches were considered to be of 'good quality or better' (Tables 5.12c and 5.13c). The BAI results are, therefore, useful as a benchmark for beach quality and of an acceptable standard, on which to improve beaches identified as 'moderate quality'.

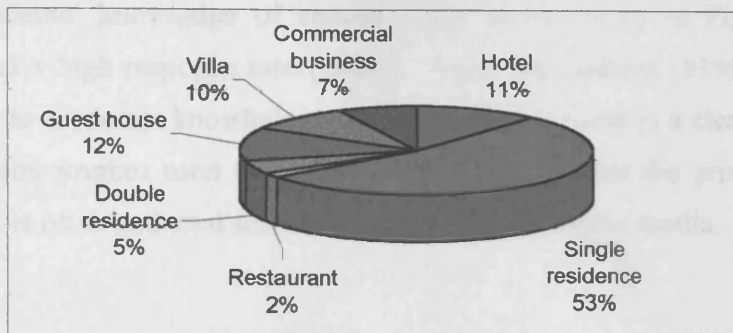
8.5.2 Property Owner Questionnaire Results.

8.5.2.1 Part 1 Property Location

The first section of the questionnaire was designed to collect personal details on the respondent as well as on the property's location. The property types for all study areas are presented in Fig. 8.15. These results demonstrate that most properties (91%) are residential and tourism accommodation. Additionally, most respondents (58%) owned their property (Fig. 8.16), which are single residences.

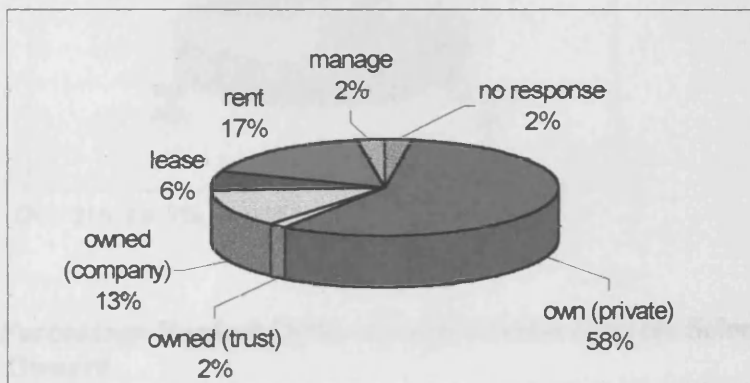
Approximately 70% of respondents have had more than ten years association with the property (Fig. 8.17). Those having long associations have an excellent knowledge of coastal issues. This helps strengthen the interviewee's perception of the issues along their coastal section, contributing to the successful questionnaire completion.

Fig. 8.15 Proportion of Property Types Found in the Combined Study Areas



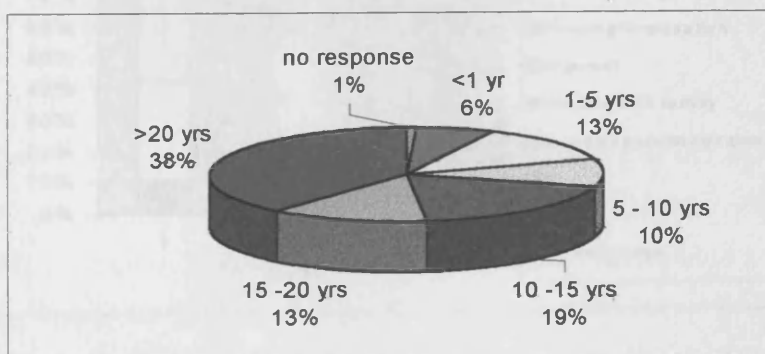
(N = 216; s.e. 7%, p<0.05)

Fig. 8.16 Property Owner's Association to the Property.



(N = 216; s.e. 7%, p<0.05)

Fig. 8.17 Length of Property Owner's Association with the Property.

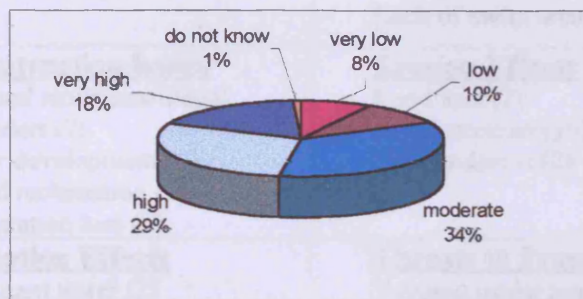


(N = 216; s.e. 7%, p<0.05)

8.5.2.2 Part 2 Property Owner Perception of Coastal Issues

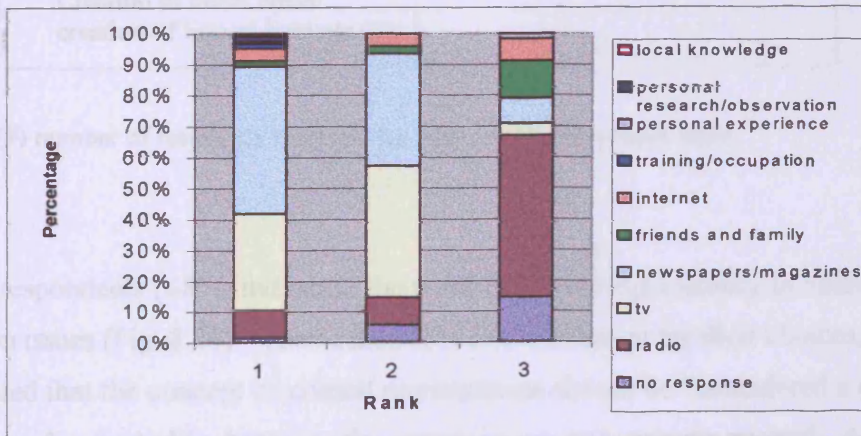
The respondents' knowledge of coastal issues is presented in Fig. 8.18. This question had a high response rate (100%). Most respondents (81%) thought they had a 'high to moderate knowledge' of coastal issues. There is a clear prioritisation of information sources used (Fig. 8.19), demonstrating that the primary source of information is often gathered from the print and/or electronic media.

Fig. 8.18 Property Owner Perception of their Coastal Issues Awareness



(N = 216; s.e. 7%, p<0.05)

Fig. 8.19 Percentage Ranked Order of Information Sources Selected by Property Owners



Respondents identified 26 coastal issues of which the most frequently identified were beach erosion (20%) and pollution (15%). These issues could be classified into

the seven categories indicated in Box 8.3. Pollution effects are considered to be the greatest issue (28%), followed by the effects of erosion (26%) and finally, coastal construction (15%).

Box 8.3 Table of Classified Coastal Issues Identified by Respondents

<p><u>Natural Events</u> Hurricanes/Storms (3) Sea level rise (1) Storm waves/storm surge (6) Wave action (1)</p>	<p><u>Human Use Issues</u> Conflicting recreation use (3) Crime (1) Irresponsible building/lack of management (2) Lack of swim areas (1)</p>
<p><u>Construction Issues</u> Coastal structures/illegal boulders (7) Over development (1) Land reclamation (2) Vegetation loss (3)</p>	<p><u>Erosion Effects</u> Land loss (2) Beach erosion (19) Cliff undercut (2)</p>
<p><u>Pollution Effects</u> Stagnant water (2) Pollution (land, marine, general) (14) Coliform levels (1) Land run off (1) Reef damage/reef erosion (4) Beach pollution (2)</p>	<p><u>Threats to Property</u> Volcano under sea (1) Lack of structures (2) Building undermined (1) Flooding from sea (3)</p>
<p><u>Improvement Requirements</u> Creation of swim areas/ creation of littoral habitats (2)</p>	

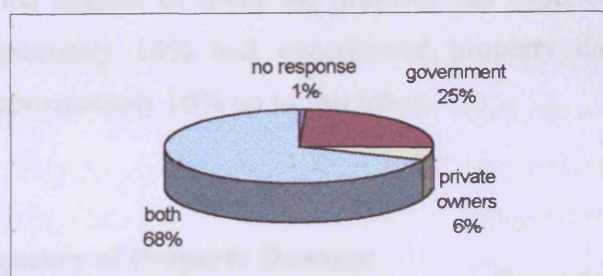
Note: (#) number of responses received for each identified coastal issue.

Most respondents (68%) indicated the need for joint responsibility in addressing beach erosion issues (Fig. 8.20). When asked to provide a reason for their choices, most (25%) indicated that the concept of coastal management should be “considered a co-ordinated effort and partnership between the government and private sector”. Another 19% considered that “it is in the best interest of the property owner and the coastline”. Only 6% of the respondents considered that it is “highly cost dependent”. This suggested that if the work to correct the erosion issues could be afforded by individual property

owners, then they would perform the work themselves. However, if the cost appeared to be prohibitive, the government should accept the responsibility for beach erosion control. The latter response supports the underlying principle often put forward by property owners (i.e. in the event of any storm wave damage to their property, they have to protect it as quickly as possible to avoid a reoccurrence of similar damage events). This, therefore, presents recognition that their coastal location, while not always subject to wave damage, can be vulnerable to such events. In addition, if a coastal segment does suffer damage, the government should implement the necessary protection works as a priority, for the preservation of the infrastructural investment, for the island's benefit.

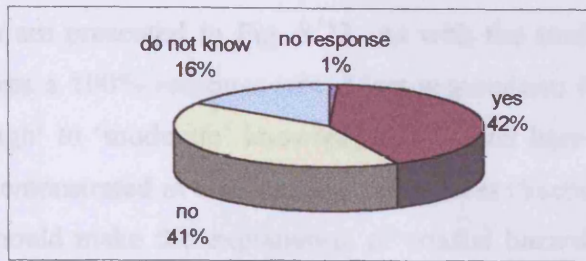
The respondents were almost evenly split regarding whether their property had suffered storm wave damage (41.9% yes and 41.1% no) (Fig. 8.21). The remainder indicated that they did not have any knowledge of damage to the property. This lack of knowledge may be a result of the seasonal use of some properties under lease or rent. In other instances, the respondent might have recently acquired the property and thus, have very little knowledge about the property.

Fig 8.20 Property Owner Perception of Responsibility for Correcting Beach Erosion.



(N = 216; s.e. 7%, $p < 0.05$)

Fig. 8.21 Property Damage Suffered as a Result of Storm Wave Action

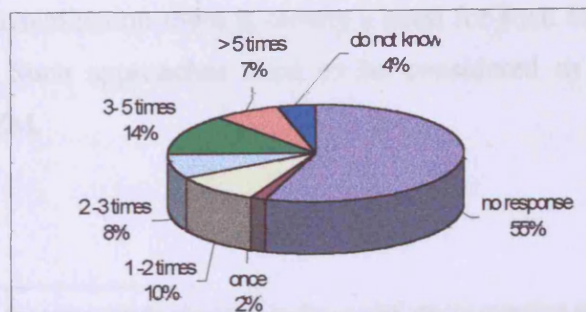


(N = 216; s.e. 7%, $p < 0.05$)

While it is anticipated that respondents would be “honest” in their responses, this question provided for the omission of the subsequent questions, if no property damage had been experienced on site. As the subsequent questions related to estimated property damage values and insurance related issues (i.e. if the property was insured, if claims were made and the percentage coverage by the insurance company), it is quite likely that this option might have been followed in order not to provide that information. While this cannot be verified, it may be a possible reason for the very low response (14%) to the insurance questions. Given the extremely low response, no further analysis has been performed.

Results from the number of times the property has experienced damage (Fig. 8.22), showed approximately 14% had experienced property damage up to five times, followed by approximately 10% up to two times.

Fig. 8.22 Frequency of Property Damage



(N = 216; s.e. 7%, $p < 0.05$)

8.5.2.3 Part 3 Property Owner Perception of Hazard Risk to Coastal Property

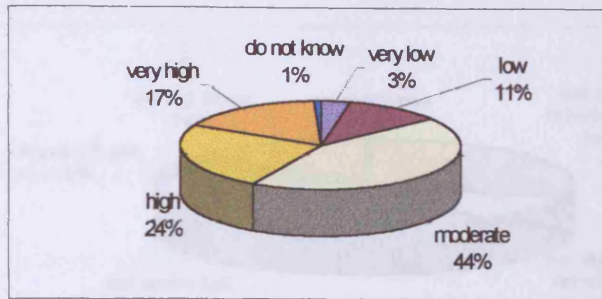
The responses are presented in Fig. 8.23. As with the similar question on the coastal issues, there was a 100% response rate. Most respondents (84.5%) indicated that they had a 'very high' to 'moderate' knowledge of coastal hazards. This showed a similar trend to that demonstrated in coastal issues awareness (Section 8.5.2.2). This perception information should make the explanation of coastal hazard issues to property owners easier when integrated in the ICZM process. As this is only a subset of the total coastal population, it would be difficult to draw major inferences from this, since different coastal segments within the study area might have different levels of awareness. It should, however, be expected that most respondents generally would have a moderate level of awareness of coastal hazards, which can be used as a baseline for public education within the ICZM process.

Figure 8.24 shows that within the first ranked choice, newspapers and magazines (61%) are the preferred source of information on coastal hazards. New categories provided by some respondents included training and occupation, personal research and observation and local knowledge. The identification of these responses shows that persons living or working on the coast have some level of understanding about coastal hazards, and the potential risk to which they are exposed.

For the second and third rank choices, an equal number of respondents identified that their coastal hazard information came from the television and radio³¹ (56% and 55% respectively). These results concur with what are generally considered the most appropriate media formats for public information dissemination in the LVA process. While various media formats (electronic and print) have been used for public information dissemination there is clearly a need for such information dissemination to be sustained. Such approaches need to be considered as part of the island's LVA process in ICZM.

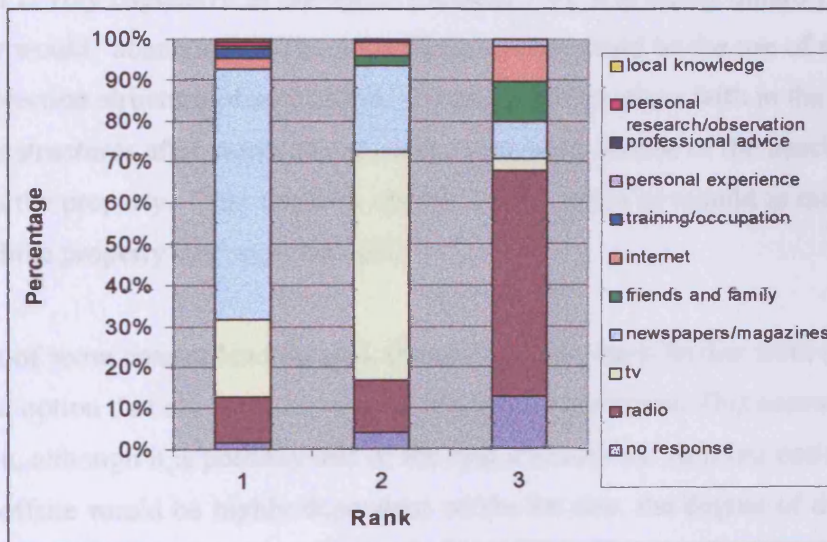
³¹ It is noted that the same trends observed in the coastal issues question are carried on in this coastal hazards information source question. As with the coastal issue section, the third ranked coastal hazard section also had the second largest response as "no response" (13%).

Fig. 8.23 Property Owner Awareness of Coastal Hazards



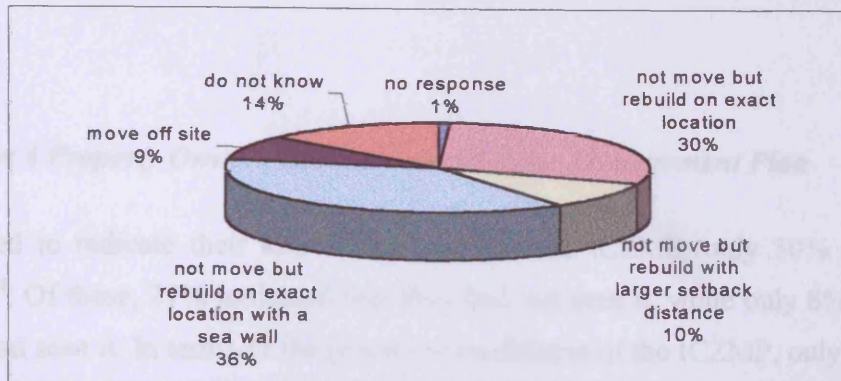
(N = 216; s.e. 7%, p<0.05)

Fig. 8.24 Percentage Ranked Order of Information Sources Selected by Property Owner



Respondents also had to identify what they thought the best option would be in the event that their coastal property received storm wave damage. Most (66%) indicated that they would choose to rebuild with a coastal protection structure and rebuild on the same location (Fig. 8.25).

Fig. 8.25 Property Owner Selection of Best Options in the Event of Property Damage due to a Storm Event



(N = 216; s.e. 7%, p<0.05)

As coastal land is very expensive in Barbados (Section 7.4), it is highly unlikely that a property owner would “abandon it”. The most likely option would be the use of a shore or property protection structure of some kind. Property owners place faith in the use of such protection structures after storm events, at the long-term demise of the beach land, associated with the property. This similarly applies to the option to rebuild in the same location even if the property has been damaged³².

Given the sizes of some coastal land parcels, the ability to set back further from the sea is not always an option that can be easily pursued by property owners. This accounts for its low selection, although it is possibly one of the best alternatives. As a last option, the need to move offsite would be highly dependent on the lot size, the degree of damage that the property experienced, and/or the cost of constructing any shore protection works for the property. The very low response rate for this option suggests that it might only be considered by those property owners who can least afford to perform the above-mentioned options. As such, this option would be tied to the actual sale of the property and not just abandonment as might be implicated, if the IPCC (1992) definition³³ is adhered to. Within a small island of limited land resources, moving off site is not an

³² Such situations would normally arise once the section of coast and beach has recovered after the storm event and the normal planning approvals have been sought.

³³ This recommendation is to allow nature to take its course on the coastline.

effective option for efficient land use, especially when tourism is the main foreign exchange earner. In effect there is always a high demand for coastal land, as it is prime real estate.

8.5.2.4 Part 4 Property Owners and the Coastal Zone Management Plan

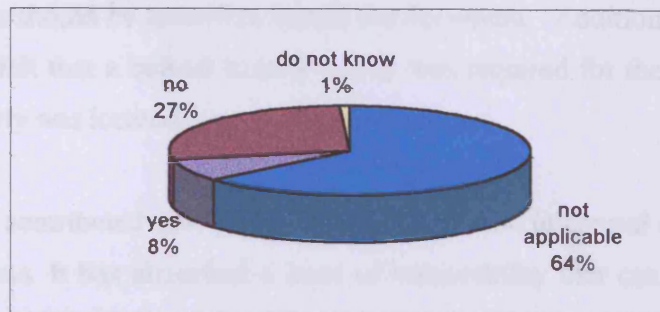
When asked to indicate their knowledge of Barbados ICZMP, only 30% responded positively³⁴. Of these, 27% indicated that they had not seen it, while only 8% indicated that they had seen it. In terms of the perceived usefulness of the ICZMP, only 8% of the respondents found it useful (Fig. 8.26). This has significant implications for public awareness of coastal issues and information dissemination to the public by the CZMU. As part of the ICZMP development process, it was made available for public comment and feedback (Jonathan McCue and Susan Gubbay, *pers. comm.* 2001). Information on issues affecting coastal areas was sought through a process of roundtable discussions with coastal users and stakeholder representatives³⁵.

While such a process resulted in the involvement of key stakeholders, and allowed for information dissemination to the relevant members of stakeholder organisations, the information might not have reached the general public. In addition, this sort of information dissemination has to be an ongoing process. The public will only become directly involved in an issue if they feel their rights are being threatened, or if they have to “pay more” e.g. increased taxes for the coastal lands.

³⁴ For those former respondents, they were not required to answer the subsequent questions. The category “not applicable” under both questions relating to the Plan being seen (64%) (Fig. 8.26) and its usefulness (88%) (Fig. 8.27).

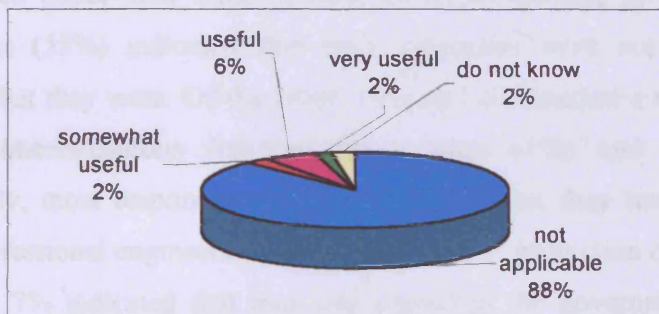
³⁵ Information on the process used in the development of the CZMP was obtained from discussions held with the following person who have each worked on various aspects of the development of the CZMP: John Willms, *pers. comm.* 2002, Jonathan McCue, *pers. comm.* 2001, Susan Gubbay, *pers. comm.* 2001, Janice Cumberbatch, *pers. comm.* 2001, Peter Barter, *pers. comm.* 2001.

Fig. 8.26 Property Owners that have seen the ICZMP



(N = 216; s.e. 7%, p<0.05)

Fig. 8.27 Property Owner Perception of Usefulness of ICZMP



(N = 216; s.e. 7%, p<0.05)

With respect to the ICZMP, the public's lack of knowledge about the Plan also reflects:

- (1) A general lack of knowledge on the existence of the document;
- (2) A lack of consistent information dissemination to the public on the ICZMP and its role in coastal planning by the CZMU;
- (3) A lack of concern over the issues that can affect their coastal location. It appears that their primary concern is their ability to develop the property or enhance the existing property, through the development process, as defined within the Town and Country Planning Act (Cap 18 and 20) for the island.

These issues are relevant since 66% of the respondents felt that there was a need for the development of an ICZMP. There was, however, 100% agreement that areas threatened by coastal hazards should be identified within the document. Additionally, 96% of the respondents also felt that a coastal hazard survey was required for the coastal section, where their property was located.

This research has contributed new information for inclusion in coastal surveys as a part of the LVA process. It has identified a level of vulnerability that can be attributed to potential oil spill effects, beach erosion and potential flooding in each of the study areas (Sections 5.3.3, 6.4.4, 6.4.5 and 7.4.2). This, therefore, provides useful information, which can be incorporated into the island's ICZMP.

When asked about their existing level of storm damage property protection, most respondents (55%) indicated that their properties were not protected while 40% indicated that they were. Of the latter, 18% had constructed a sea wall while 11% had used revetments/gabions followed by groynes (4%) and retaining walls (3%). Additionally, most respondents (29%) indicated that they had sought the advice of private professional engineers in the selection of the protection option for their property, while only 7% indicated that they had consulted the government for advice. This is expected, as the development application process requires the submission of detailed diagrams for all coastal works. Even if property owners had consulted the CZMU, it would still be necessary to go to a registered engineer (Antonio Rowe *pers. comm.* 2001).

For those respondents indicating no property protection, 52% identified that they would protect their property, while only 19% were satisfied that there was no need for property protection. For those willing to use protection measures, 19% opted for seawalls and 16% preferred revetments/gabions. These results are consistent with field observations where the main shoreline protective structures fall into these categories. These results further reflect the concerns presented earlier on the cost implications associated with installing shoreline protective structures. While most (35%) prefer the use of the harder option (seawalls and revetments), the choice of the less expensive options is also presented. However, it would also be expected that in this latter situation these

structures would be considered expendable, as they would not be built to the same reinforced engineering standard as seawalls and revetments. Thus, there would be a recurring replacement cost for these structures.

When asked to identify their selected options for advice on property protection, respondents were almost balanced in response between the use of the private sector (43%) and the government (40%). A minority (7%) indicated that they would use alternate approaches (i.e. do the protection works themselves (3%) or seek advice from another coastal property owner (4%)).

When respondents were asked to prioritise the coastal hazards (Fig. 8.28), most identified only beach erosion (54%) and tropical storms (27%) as the principle hazards. These results confirm the fact that the greatest perceived risk by the respondents is beach erosion. This is not surprising given the high value placed on coastal property and its associated physical amenities. Any threat to the beach poses an immediate threat to property value. The tropical storm hazard is also recognised, as it is an annual unavoidable event³⁶. The implications from this include the possibility of beach erosion and property damage from storm waves³⁷.

Within the second and third rankings, respondents identified tropical storms as the hazard of concern (34% and 20% respectively). The results also identify pollution issues of concern since they cause both short and long term negative effect on the shoreline.

In the fourth ranking, coastal flooding from the sea (20%) was identified, demonstrating the impact concerns frequently associated with storm wave damage. In addition, it is possible that the identification of the tsunami threat as a priority concern has arisen because of the recent publicity related to the underwater volcano Kick 'em Jenny, located near Grenada³⁸. The recent Asian Tsunami (December 26, 2004) and its associated effects has also re-emphasised and demonstrated natural hazard and

³⁶ While the island has not suffered a direct hit from a hurricane since 1955, it does experience the effects of storm waves from passing tropical storms and tropical depressions annually.

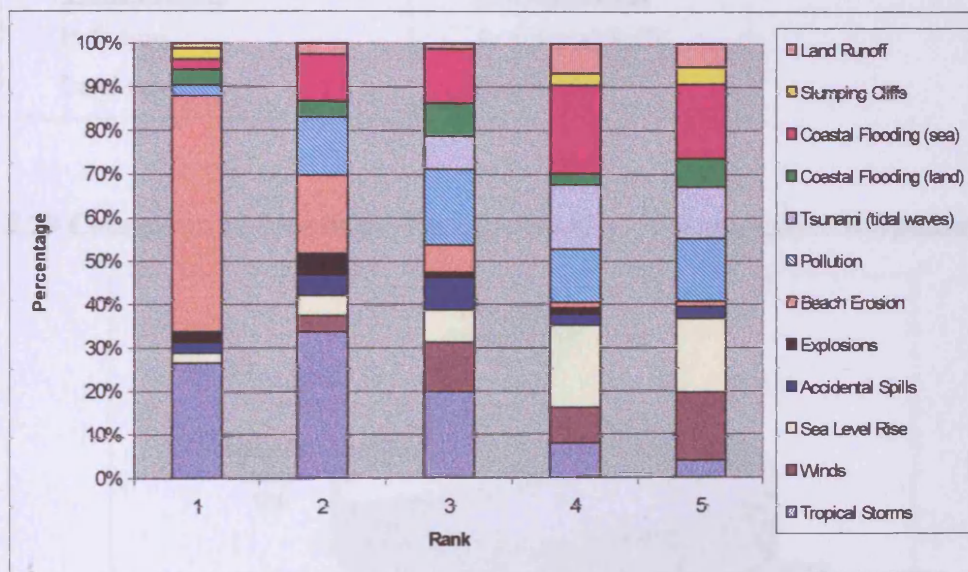
³⁷ Depending on the proximity of the building to the high water mark.

³⁸ For information on Kick 'em Jenny refer to: <http://www.cdera.org/Archive/2001/isa.htm>, http://www.spiceisle.com/nero/kick_em_jenny.htm and http://www.onecaribbean.com/regional_news.htm

vulnerability issues in SIDS, resulting in new efforts to install tsunami early warning systems.

In the fifth ranking, the main concerns are sea level rise and coastal flooding (from the sea) (17% respectively), followed by winds (16%). This demonstrates the low concern of property owners of sea level rise

Fig. 8.28 Ranked Priority Coastal Hazards of Concern to Property Owners



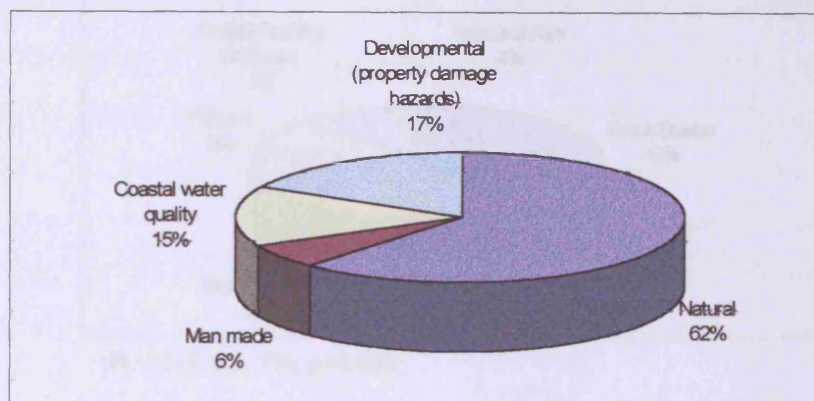
The choice of hazard types can be classified into natural hazards, development threats, anthropogenic hazards and coastal water quality threats (Box 8.4 and Fig. 8.29). The results for the man-made threats were derived primarily from the coastal segment that had coastal industry associated with it and are, therefore, very site specific. The overall results demonstrate that the following hazards are the most frequently identified: beach erosion, tropical storms, pollution, coastal flooding (from the sea), and sea level rise (Table 8.3).

Box 8.4 Classification of Coastal Hazard Types.

<p><u>Natural Hazards (62%)</u></p> <p>Tropical Storms</p> <p>Sea Level Rise</p> <p>Wind</p> <p>Tsunami</p> <p>Slumping Cliffs</p> <p>Beach erosion</p>	<p><u>Developmental Threats (17%)</u></p> <p>Coastal flooding (from land)</p> <p>Coastal flooding (from sea)</p>
<p><u>Coastal Water Quality Threat (15%)</u></p> <p>Pollution</p> <p>Land run off</p>	<p><u>Anthropogenic Hazards (6%)</u></p> <p>Accidental Spill</p> <p>Explosion</p>

Fig. 8.29 Most Frequently Cited Coastal Hazards based on the First and Second

Fig. 8.29 Categories of Identified Threats based on Questionnaire Responses



(N = 216; s.e. 7%, p<0.05)

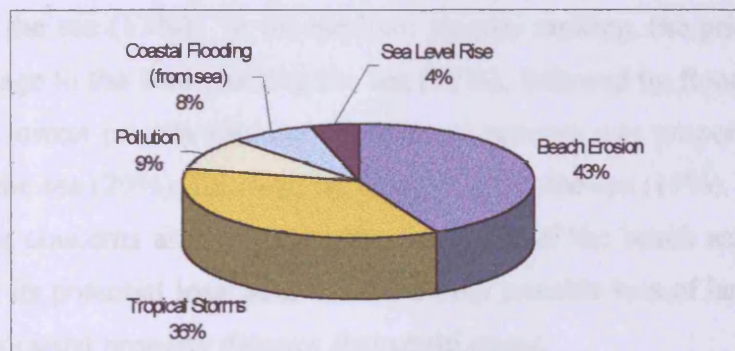
Table 8.3: Most Frequently Identified Hazards for the First 3 Rankings

Hazard type	Percentage Totals	
	Ranks 1 + 2	Ranks 1 + 2 + 3
Beach Erosion	42.8	34.0
Tropical Storms	35.7	34.6
Pollution	9.3	14.1
Coastal Flooding (from sea)	7.9	11.0
Sea Level Rise	4.3	6.3
Total	100.0	100.0

When the first and second ranked choices for these hazard types are combined it is observed (Fig. 8.30) that beach erosion is the primary hazard of concern, followed by tropical storms and pollution. However, with the inclusion of the third ranked values for the same hazards (Fig. 8.31), it is noted that tropical storms and beach erosion are of a similar value (35% and 34% respectively). This further strengthens the realisation that these hazards are of greatest importance to a property owner's perception.

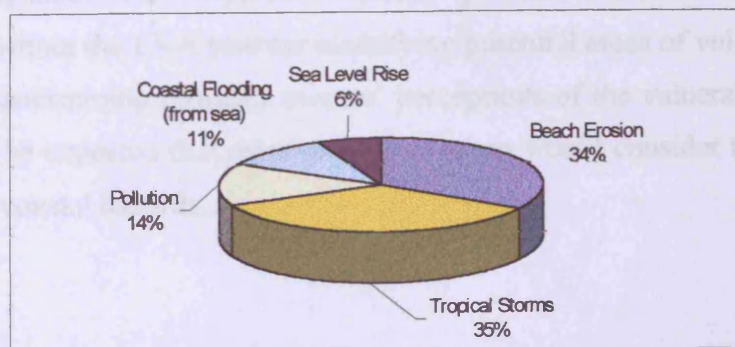
When the total responses from respondents for each of the hazards are analysed (Fig. 8.32), it is noted that tropical storms are considered to be the greatest cause for concern, (27%), followed by beach erosion hazards (24%), and coastal flooding (from the sea) (18%).

Fig. 8.30 Most Frequently Chosen Coastal Hazards based on the First and Second Ranked Priority Options



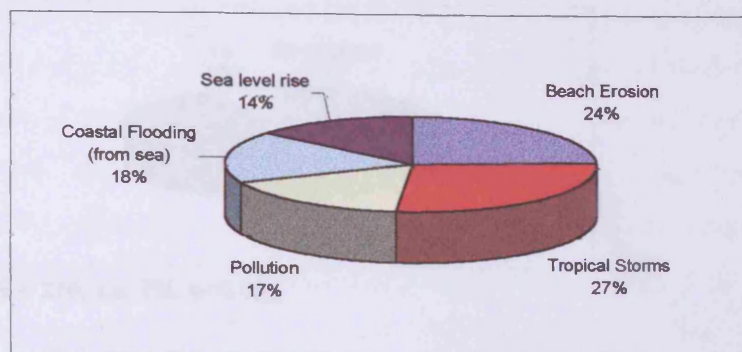
(N = 216; s.e. 7%, p<0.05)

Fig. 8.31 Most Frequently Identified Coastal Hazards based on the First and Second Ranked Priority Option (and the Third Ranked Priority Equivalent)



(N = 216; s.e. 7%, p<0.05)

Fig. 8.32 Total Responses for Most Frequently Selected Coastal Hazards in the First Three Rankings



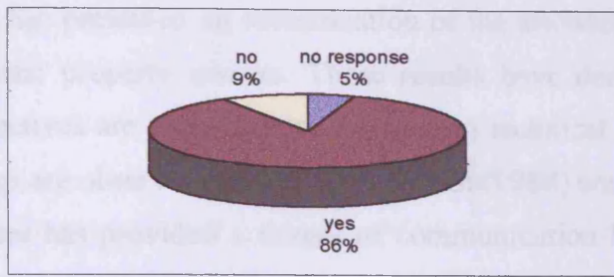
(N = 216; s.e. 7%, $p < 0.05$)

Fig. 8.34 Property Owner Identification of Priority Problems Experienced at Their Location

Most respondents (86%) consider their property at risk from coastal hazards (Fig. 8.33). This is consistent with the ranked results identifying the main problem experienced at the particular location (Fig. 8.34). The greatest priority was beach loss (69%) followed by flooding from the sea (13%). In the medium priority ranking, the priority concern was property damage to the land fronting the sea (31%), followed by flooding from the sea (25%). In the lowest priority ranking the greatest concern was property damage to the land fronting the sea (29%), followed by flooding from the sea (17%). These results demonstrate prime concerns are related to the condition of the beach associated with their property and its potential loss, and, thereafter, the possible loss of land behind the beach and any associated property damage that could ensue.

Finally, when asked to provide an overall perception of the level of risk to their property, most (86%) indicated that their property location had a moderate to very high degree of risk (Fig.8.35). This “layman’s concern” provides additional support to the results generated within the LVA process identifying potential areas of vulnerability. As a first attempt at determining property owners’ perceptions of the vulnerability of their property, it could be expected that most property owners would consider their property at some risk from coastal hazards.

Fig. 8.33 Property Owner Perception of Property Risk from Coastal Hazards



(N = 216; s.e. 7%, p<0.05)

Fig. 8.34 Property Owner Identification of Priority Problems Experienced at Their Location

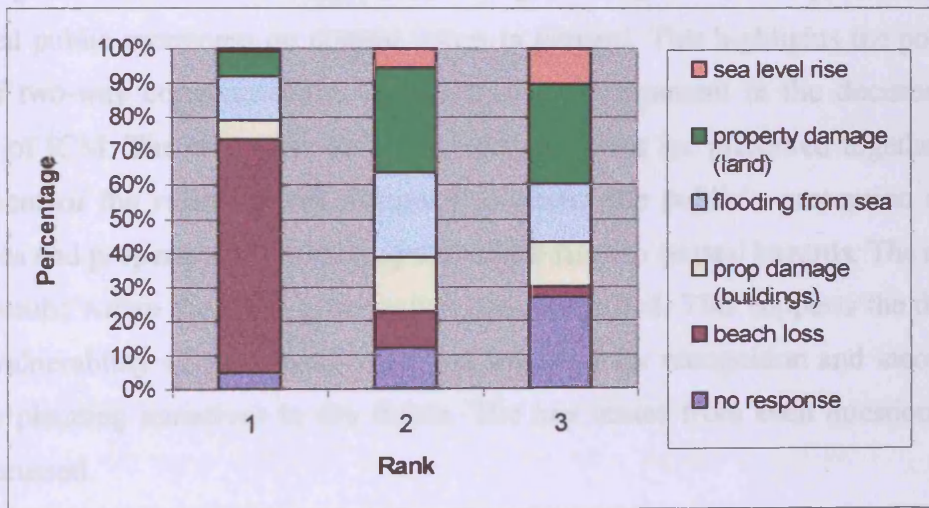
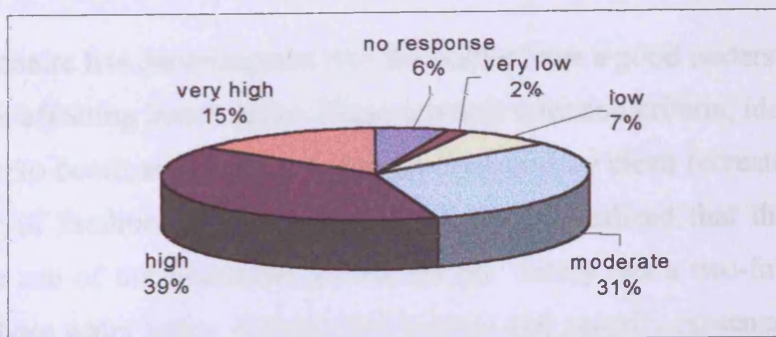


Fig 8.35 Property Owner Assignment of Risk to Their Property



(N = 216; s.e. 7%, p<0.05)

8.6 DISCUSSION

Chapter Eight has presented an identification of the knowledge and concerns of beach users and coastal property owners. These results have demonstrated that social and cultural perspectives are an important addition to technical and scientific information. Similar findings are observed in Ives and Furuseth (1988) and Gough (2000). The use of these techniques has provided a means of communication between the general public and the relevant government authority to assist in the cross transfer of information on perceived coastal hazards, and the need for priority attention. This is an important component of the ICM process.

The respondents have demonstrated a willingness to participate in this research, indicating that such continued approaches can generate goodwill and provide a basis for enhanced public awareness on coastal issues in general. This highlights the point that a level of two-way communication is an important component in the decision-making process of ICM. The responses and their interpretations are presented together, as this component of the research was designed to obtain the public's perception on beach aesthetics and property owners' perception of the risks to coastal hazards. The relevance of the results within the LVA process has been identified. This supports the discussion of the vulnerability of Barbados' coast and the need for recognition and incorporation into the planning initiatives in the future. The key issues from each questionnaire are now discussed.

8.6.1 Beach User Perception Survey

This questionnaire has demonstrated that the public have a good understanding of many coastal issues affecting beach areas. Priority beach selection criteria, identified from the results, relate to beach safety and cleanliness followed by clean recreational waters and the presence of facilities. From a beach visit, it was realized that the public do not always make use of the nearshore for recreation. Safety has a two-fold interpretation here – nearshore water safety (lifeguard presence) and security presence (NCC Rangers

and Police patrols) to reduce harassment and possible crimes. These concerns are important to ensure the full enjoyment of the beach experience.

While there is an expressed need for beach facilities, the results demonstrate that the current number of facilities needs to be increased marginally. This can be achieved with the installation of shower stalls/cubicles at some beaches. As some respondents indicated, the presence of “full facilities” could change beach character and the type of users. This suggests that the public’s preference for discovering different beaches is an important component of the beach user experience, and, furthermore, that users frequent beaches with a certain “character”, comfortable to them. The installation of such facilities has to be incorporated into the beach environment and be located in such a manner that, while accessible, they are not located on threatened or vulnerable beaches. As part of the LVA for different coastal segments, the issue of facilities is one of the characteristics of the BAI. This facilities requirement suggests that a selective beach enhancement approach (including the facilities installation) might aid the relief of crowd loading on well-established beaches.

The lack of beach access is of paramount concern. While this situation might be alleviated through proper signage³⁹, there is still a need for government to acquire coastal strips to allow pedestrian access from the road to the beach. This will be an expensive undertaking, given the limited free coastal space and its land value (as exemplified in Sections 7.4.2.4.1 and 7.4.2.4.2). An alternative approach to achieving this pedestrian access requirement is to recommend its incorporation into development application, submitted for assessment approval to the Town and Country Planning Office. This approach has been periodically used (Lionel Nurse, *pers comm.* 2001); however, it has never been rigorously applied as it is left to the discretion and goodwill of the property owner to forgo the strip of land on his property, for public use. Most cases have resulted in favourable consideration, through negotiated goodwill between the property owner and the planning department. However, the issues of access control still remain, as the access is normally no more than a small footpath that:

³⁹ Currently being implemented by the NCC as an island wide project (Keith Neblett Deputy General Manager NCC, *pers. comm.* 2001).

-
- Seldom has a clear signpost for public information.
 - The property of the landowner who can “gate it”⁴⁰ and therefore, control access to the beaches.
 - Is not always properly maintained in order to deter its use⁴¹ - an informal means of access control.

The implications of these are that the public still has to rely on using the better-known beach locations, putting these under significant stress in peak seasons. Currently, such issues are unavoidable, but with periodic inspection of accesses, a reported account can be kept on the quality of the accesses and their current status⁴² and the necessary action required.

In addition, as the government owns little coastal land, open space along the coast has been lost, and the concept of “open windows to the sea”⁴³ has been also slowly and systematically lost. This consideration requires priority attention by the government as part of its long-term coastal management planning policy. It will be especially applicable for the undeveloped east coast, where the high energy shoreline is not conducive to the concentrated development levels found elsewhere along coasts. Such acquisitions also have to take place within the LVA process, to ensure suitable vehicular access points along the coast, in case of major emergencies.

Finally, respondents generally consider the beaches to be of high quality. This standard has to be maintained wherever possible to ensure long-term sustainable beach use. The use of this beach rating approach has been instructive, allowing the public an opportunity to provide their own assessment of the beaches they frequent. It would also be useful to compare beach user responses for intra-beach comparative purposes in the future, to assist in the priority setting for selected beach improvements. The results

⁴⁰ Install a gate at the entry and egress points and there by restrict free open access to the beach.

⁴¹ Poorly maintained accesses can depict an isolated unsafe area for pedestrian passage and therefore, deters the public from its actual use.

⁴² Status here includes active or lost due to development, quality, maintenance easily accessible and need for upgrading and signage. This has been periodically performed by CZMU; however, it needs to be regularized in its application.

⁴³ This is an open unobstructed view of the beach and sea from the main coastal road.

demonstrated that the public perceptions for the surveyed beaches do relate with the calculated BAI for the locations.

8.6.2 Property Owner Perception Survey

These results demonstrated that generally the majority of coastal property owners have a moderate to high perception of the potential risks they face living in the coastal hazard zone. They are willing to live with these risks provided that they are able to protect their properties if the need arises, and if it is economically feasible to do so. The results clearly documented the limited public knowledge of the existence of the current ICZMP. Notwithstanding this, respondents fully supported the need for such a planning instrument.

Not all responses to all questions were presented here. Only those aspects of greatest relevance to the property owners' understanding of the issues faced on the coastline were discussed. It is noteworthy, however, that several respondents indicated that their property did not possess protective structures; yet field investigations (as part of the data collection for other aspects of this research), had previously demonstrated that many of these properties, did indeed have such structures.

From the general results, respondents still prefer hard protection. The reliance on these structures has to be taken within the island's context where the need for property protection has outweighed the need for shoreline stabilization – resulting in the inappropriate use of certain structure types in some coastal locations, contributing to long term shoreline instability. As part of the LVA for a coastal segment, consideration has to be given to the rationalization of coastal structures. In such situations, individual property owners protecting their separate properties and using different styled engineering works are avoided. The coastal segment should be viewed as a unit with the application of proper coastal defence planning procedures along its length. This perhaps could be a joint venture approach between the government and the property owners in

the area⁴⁴. This will require a radical shift in coastal planning policy for Barbados. However, if some of the concepts followed in the UK⁴⁵ shoreline management plans (DEFRA 2001) are applied, the coastal segments could be characterized and the most appropriate structures, best suited to the respective coastal lengths, could be identified and recommended as a subsection within the island's ICZMP. Such approaches fit well within the LVA process and would address an issue not currently presented within the ICZMP. This is an additional area for future research.

Generally the results have provided good insight into the property owner's perception on coastal vulnerability. The respondents identified beach erosion as the main coastal hazard concern and that (a) it is exacerbated by actions involving encroachment onto the active beach face and (b) effective management of such a hazard can be better controlled through joint action between themselves and the government. These results differ from reported results presented by Ives and Furuseth (1988), who noted that their coastal communities preferred non-structural approaches to control hazard risks and greater assistance from the government in the repair of erosion damage.

It was observed from the responses that very little information was received from the respondents regarding:

1. **The issues of insurance:** This resulted in an inability to actually determine some representative monetary value in terms of the level of insurance claims, made on property repairs. Such concerns have come to the fore within the last decade given global damage claims, made annually as a result of incurred shoreline property damage due to high intensity tropical storms and hurricanes (Vermeiren & Watson 1994, OAS 1996). The use of LVA and the representation of vulnerable coastal segments on maps could assist the industry in the development of insurance protocols for areas of varying risk level (OAS 1996, Risk Prediction Initiative 1997, OCIPEP 2001).

⁴⁴ Such an attempt is being initiated as part of the Coastal Conservation Phase II Programme with a hotel on the Southeast coast of the island.

⁴⁵ See <http://www.defra.gov.uk/environ/fcd/pubs/SMP's/Revised%20SMP%20Guidance%20Final.pdf>

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2. **The numbers of people living or working at the location:** It was hoped that this would have provided a useful representation of the residential and working population within the study areas. It was considered at the time of the questionnaire design to be an effective approach for gaining information on the coastal population. If a study of this type is to be performed again it would be necessary to implement a more effective approach – especially if this information is not directly available for the relevant government agencies. As part of the LVA process, this information would contribute to the socioeconomic considerations required for the development of mitigation plans for vulnerable coastal segments. This information would provide an estimation of the potential population that could be displaced due to storm damage.

It was hoped that the questionnaire would also act as an impetus for property owners to seek out information and education on some coastal issues. As identified by Smith (1994) *“Beach front residents find strong enjoyment in living on or near the beach, and as such the possibility of future unpleasant events is often rejected or kept out of mind. In this way they are accepting any potential risks to be experienced there, and they are willing to bear the cost of living on the coast.”* The postal survey has highlighted the need for improved public education and awareness mechanisms on coastal issues. Such education programmes have an important role in the LVA process, as well as the ICZM process. While public consultation and education is a mandatory requirement within the ICZM process, it is important to balance transparent information dissemination with prudent shoreline management. This will prevent liability claims being brought against the government for poor development planning permission decisions. It is, therefore, important to recognize that, with increased information incorporation in the ICZMP, there is increased responsibility placed on the relevant agencies to ensure that the necessary steps are taken to mitigate or minimize all threats of priority coastal hazards.

8.7 EVALUATION OF THE TECHNIQUE USED

This research has applied two questionnaire techniques – face-to-face interviews and postal questionnaires. For each of their designated purposes these have successfully met their required aims. As noted previously (Section 8.5.1) the face-to-face interview provided direct responses to the issues identified. A problem encountered with this method was the time spent with each respondent (Section 8.4.2.3). Generally, it had been estimated that a form should take no longer than 15 minutes per person. However, in some cases, this extended to up to 30 minutes, as the respondent sought out more information on the issues being discussed and presented their own considerations for addressing them.

The postal questionnaire survey was considered the most suitable approach for collecting the maximum level of information from the coastal property owners, in the minimum amount of time. As presented in Section 8.4.3.1, it was envisaged as the best way for allowing respondents to freely participate and give answers. This was to avoid the respondents feeling pressured into giving an “on the spot” response, as is the case with most face-to-face interviews. If this interview technique had been used to collect the information it might have been beneficial to the respondents and their better understanding of the issues and risk perceptions associated with their property. However, time constraints made this non viable. Furthermore, it would have possibly resulted in extended open discussion with the respondent on general coastal matters outside of the focus of the questionnaire.

The use of newspaper publicity made the respondents more aware of the survey; and some respondents even made reference to “having read about or heard about the survey that was to be applied to some coastal locations”. Its timing, however, was a little premature as the article was released in the first quarter of 2002, rather than closer to the date when the survey was carried out. If this approach were used again, it would be more appropriate to have the newspaper article released much closer to the date of survey dissemination.

A limitation to this approach, however, was that some respondents chose to be anonymous, not providing contact details on their property. This resulted in the inability to follow-up property owners on some responses. However, as most surveys of this nature are deemed to be a “one off”, it is highly unlikely that the respondents would have expected any subsequent follow-up.

Other limitations included the fact that some commercial businesses and industries did not complete the questionnaire, although reminders were sent by mail and telephone. In addition, upon receipt of the returned questionnaires, not all of them were fully completed. These problems need to be considered when reviewing the results, but they were beyond the control of this researcher and, therefore, unavoidable. Where possible, appropriate steps were taken to minimise these eventualities and ensure the integrity of the research process.

8.7.1 Questionnaire Styles and Administration used in the Barbados Experience and their Application in a Wider Context

Both questionnaire styles and their administration methods have been successfully demonstrated. They have allowed for the comprehensive collection of relevant public perceptions on coastal issues and concerns. The analysis formats used have provided for easy results' interpretation. This information actually provides a starting point for future research; however, greater attention has to be paid towards increasing the property owner response rate to 70% or higher. The administration of the beach user survey should perhaps be administered seasonally or annually. As with most questionnaires, care has to be taken to avoid “consultation burn out” for the respondents (Alleyne 1998).

8.7.2 Economic Cost

The economic cost associated with the application of this technique (GB £ 3459 (US \$ 5465)) includes the actual cost of producing the questionnaires, transportation to site

and man-hours for collecting the data and the associated postage costs for mailing out the postal surveys and their self-addressed envelopes (Table 8.4).

In the administration of the two surveys, the cost for beach user survey (£1000) was not an actual cost as the CZMU staff performed this work. The cost has been presented here as part of providing an indicative cost for performing such survey in SIDS, where it may be necessary to hire staff. For the property owner survey, costs associated with postage were not incurred as return envelopes were “On Service⁴⁶” and the cost was, therefore, absorbed by the CZMU. The postage options presented are for similar considerations as described above for the beach user survey. These approaches clearly demonstrate a level of inexpensiveness, if the administration is incorporated within the functional operation of the relevant department. The greatest costs associated with these procedures are the actual processing and interpretation of the collected data (GB£ 2102 (US \$ 3324)). In comparing the administration cost for the two survey types, the postal questionnaire cost is lower. The inherent cost in the beach user survey is the need to pay the person(s) administering the questionnaire. This also provides a good justification in support of postal questionnaire use.

⁴⁶ Postage paid by the Government.

Table 8.4 Cost Associated with the Administration of Questionnaire Surveys

Activity Administration of Questionnaire Surveys	Number of staff (weekly rate) and staff time (days) required to do survey	Cost GB £ (US\$)
<i>Beach User Survey</i>		
200 questionnaires produced at £0.04 per page (6 pages)		48 (76)
Cost of application of questionnaires per individual at £5* (Optional 1)		1000 (1578)
<i>Property Owner Survey</i>		
216 questionnaires produced at £0.04 per page (6 pages)		52 (82)
Hand delivery to property owners and return postage (£0.15) [^]		32 (51)
Postage to property owners and return postage (£0.15) (Optional 2)		65 (103)
Transportation cost		15 (23)
Man week cost (data acquisition)**	2 staff (week rate £121 (US\$ 199) per man); 5 days	1210 (1990)
Man week cost (data processing)	1 staff (week rate £ 168 (US\$ 277)); 60 days	2102 (3324)
Total Cost***		3459 (5465)
Total Cost (optional cost included)		4524 (7148)

Table Notes:

* Paid according to the number actually administered but ceiling limit set in regard to the total number to be applied. This cost would take effect if help were needed in the administration of questionnaires to the public. This cost is the current rate in Barbados.

[^] Postage rate in Barbados.

** Man week costs are salary rates based on current Government monthly salary scales for the positions of Chainman (for field data collection) and Clerical Officer (for data processing), as these are the level of staffing required to perform these works. These costs are not included since they have already been quoted and are weekly rates.

*** Cost presented here is only based on the use of CZMU staff. The optional costs as presented are based on the number of questionnaires administered and the postage costs that can normally be attributed to general mailings on the island.

8.7.3 Modifications to Questionnaires

The beach user questionnaire has met its required aim of providing the public with an opportunity to give a public rating to the beaches. There is little modification required to its style and structure. One modification, to shorten the content of the form, would be the removal of the section related to vulnerability perceptions. This does not have a direct bearing on the public's assessment of the beach amenity; however, it was necessary, as part of this research.

The property owner questionnaire has met its required aim of ascertaining the owner's perception on coastal vulnerability issues. It should be noted that some of the respondents indicated that they had not considered the issues identified in the questionnaire at the time of property purchase.

While a suitably high total questionnaire return response rate has been achieved (approximately 57%), if this had to be repeated, it would be important to try to attain a higher response rate. This could be achieved through the structure of the questionnaire being more effectively designed, especially with regard to the issues related to property protection and the choice of options (questions 26 to 31).

Given the low response with respect to information on the insurance aspects of the survey, there is a need for an improved process for collecting this information. This also applies to the issue of collecting information on the estimated value of damage done to property, after a storm event. Modifications here should include the regularity (time frame in years) with which the damage occurs. This researcher feels that the current phrasings of questions 12 to 16 are sufficiently general that they should have generated more favorable completion response. However, as stated earlier (Section 8.4.3.3), given the initial perception that this survey might have been related to increased land tax values on the coastal properties, a high response would still not be achieved by using the postal method for this aspect of data collection. It may be more appropriate for these and similar sorts of questions to be incorporated into a differently styled questionnaire, that is more directed at the insurance issues.

8.8 SUMMARY

8.8.1 Beach User Survey

The developed questionnaire has fulfilled research objectives 3 and 7(Section 1.3.1.2). This approach is important to the LVA process as it identified public concern on the quality of the coastal locations. The public's perception of coastal value has been collected in this survey. This is important in the identification of concerns pertinent to LVA.

As identified in Section 8.5.1.2, the preference of increased vehicular access points is important for LVA, as these provide emergency access to the coast in the event of shoreline hazard response. The current access points have direct vehicular access to the coast but seldom have associated parking (Tables 8.5a & b). Thus, the identified increased requirement of access points with associated parking facilities. At present, there are only 16 out of 32 vehicular access points with associated parking - the majority is formal access and the government owns these.

Table 8.5a Vehicular Access Points along the South Coast (Source: Town Planning Department 1988 and Brewster & Batson 2000)

Location	Access Type	Parking	Owner
Enterprise	F	Y	G
Oistins	F	Y	G
Dover	F	Y	G
Graeme Hall	F	Y	G
Sandy Beach/ Worthing	I	N	P
Rendezvous	I	N	P
Rockley	F	Y	G
Asta	I	N	P
Drill Hall	F	Y	G
Pebbles	F	Y	G
Carlisle Bay	F	Y	G

Where: Formal (F); Informal (I); Yes (Y); No (N); Government (G); Private (P)

Table 8.5b Vehicular Access Points along the West Coast (Source: Town Planning Department 1988 and Brewster and Batson 2000)

Location	Access Type	Parking	Owner
Brandons	F	Y	G
Brighton	F	Y	G
Pile Bay	I	N	G
Batts Rock	F	Y	G
Prospect	F	N	G
Fitts Village	I	N	G
Paynes Bay Fish Market	I	N	G
Coach House	F	N	P
Sandy Lane	F	N	G
Holetown	F	Y	G
Folkstone	F	Y	G
Colony Club/ Heron Bay	F	Y	P
Weston	F	N	G
Lower Carlton	I	N	P
Goddings Bay	I	N	P
Fort Denmark	F	Y	G
Heywoods	I	N	G
Almond Beach Village	F	Y	G
Port St Charles	F	N	P
Six Men's	F	N	G
Shermans	I	N	P

Where: Formal (F); Informal (I); Yes (Y); No (N); Government (G); Private (P)

The public places a high perception value on beach amenity characteristics. The results demonstrate that they prefer sheltered coastal segments to exposed areas, since the former provide greater recreational potential for use. As demonstrated through the other indices developed (Chapters Five and Six), the LVA for such locations can contribute to the recreational designation of coastal areas. The beach user perception can provide a benchmark on which to judge the effectiveness of coastal recreational designation. In addition, they provide an independent contribution to some aspects of the BAI determination (e.g. beach and nearshore slope, number and size of waves, water colour & clarity, intensity of beach use, and competition for free beach space). The results from the BAI procedure compare favorably with those obtained from the public, indicating a level of interpretation similarity in the ability to use the semi-quantitative as well as qualitative approaches. However, given the subjective nature of the beach user survey, greater reliance has to still be placed on the BAI methodology.

The general perception that the beaches are 'above average' is also consistent with the main results for the BAI, which identified the majority of locations as having index value ranges of 'good' to 'very good' (index value III to IV respectively).

8.8.2 Property Owner's Survey

The questionnaire has fulfilled research objectives 3 and 7 (Section 1.3.1.2). Similar to the beach user questionnaire, the LVA process has been strengthened by this. Key results included the need for greater investigations into the extent of property damage and its potential cost implications, public awareness of the ICZMP and, the inclusion of coastal hazards and vulnerable coastal locations in the ICZMP.

This research has identified keen interest in having documented, and readily available, public information on the susceptibility of coastal locations. The results of owners' perception of risks to their own property, identify an underlying concern that most properties are perceived to be at risk. This may have several interpretations including:

1. Their perceived importance of the coastal segment – because their property is on the coast, the government should be developing effective conservation strategies that should incorporate the entire coastline eventually. Their “informal justification” of the required need to install protection structures, even if there is no direct risk to the property (i.e. the prevention is better than cure concept).
2. To stimulate the release of available information that they now know exists so that they can seek relevant engineering advice, if they think further follow-up on the matter is required.

While this questionnaire has provided useful public consultation on property owners' concerns and, emphasised the relevance of its application to the developed LVAP methodology, it is not easily related to the other indices developed. While this was not the survey's intent, it would have been useful for broad inter-comparisons of the results.

In the penultimate chapters of this thesis, Chapter Nine, the relevance of the LVAP model (as applied in Chapters Five through Eight) is discussed within the context of the existing Barbados ICZM programme.

Chapter 9
Littoral Vulnerability Assessment Model
and its incorporation into
the Coastal Zone Management Process

Chapter 9

Littoral Vulnerability Assessment Model and its incorporation into the Coastal Zone Management Process

9.1 INTRODUCTION	388
9.2 EVALUATION OF THE LVA PROCESS	388
9.2.1 Discussion on the LVAP Model Developed	388
9.2.2 Model Structure Issues.....	393
9.2.3 Model Data Considerations.....	394
9.2.4 Selection Assessment of Methodologies and Variables	402
9.2.5 Costing Summary of Methodologies Used	408
9.3 INTEGRATED CZM IN BARBADOS.....	417
9.3.1 Phases of the ICZM Process.....	420
9.3.2 Functional ICZM in Barbados.....	426
9.4 INCORPORATION OF LVA INTO THE COASTAL MANAGEMENT PROCESS.....	442
9.4.1 Where Vulnerability Assessment fits in the ICZM Process.....	442
9.4.2 Incorporation of the Research Model into the ICZM Process of Barbados.....	446
9.5 CONCLUSION	451

9.1 INTRODUCTION

This chapter presents the Littoral Vulnerability Assessment Profile (LVAP) model, used to incorporate the processes described in this research into the Barbados ICZM process. The chapter draws together issues raised in the thesis and discusses them in a theoretical context, achieving research objectives 4 and 8 (Section 1.3.1.2). The chapter is structured into four sections:

- The first provides a description of the LVAP model developed from this research.
- The second presents a brief discussion of the current ICZM process in Barbados.
- The third illustrates the incorporation of vulnerability assessment into the ICZM process in Barbados. It also presents the issues associated with the cost for the incorporation of the LVA process into the current context.
- The fourth provides a conclusion relating to the general findings and interpretation of these parts of the research.

9.2 EVALUATION OF THE LVA PROCESS

This section, reviewing the LVA process, consists of three parts. The first provides a discussion of the research model and associated theoretical issues; the second presents an assessment of the criteria chosen to select the methodologies; and the third provides a review of the methods used.

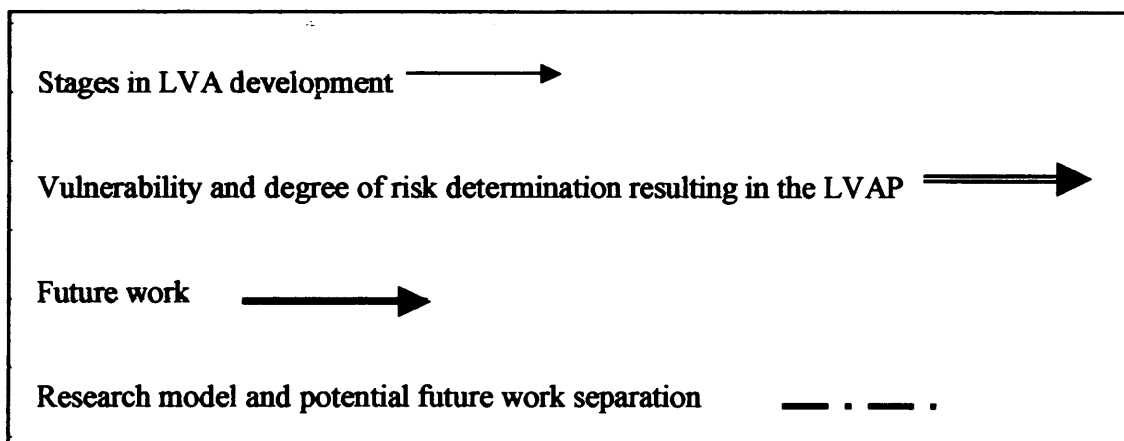
9.2.1 Discussion on the LVAP Model Developed

The LVAP model is designed to be a rapid approach for the comprehensive collection and interpretation of low cost data (Fig. 4.1). From the outset, time was spent developing the model structure and its component parts, taking into account the separate

methodologies (Section 4.2)¹. Given the need for applicability within other SIDS, the model has been kept simple to allow for refinement and wide application. It starts from the premise that, in the absence of easily available data, there is a need to collect a baseline data set. There are two main objectives: 1) to characterise the natural systems; and 2) to characterise the vulnerability of the littoral based on natural and socio-economic considerations. To achieve this, the model (Box 9.1 and Fig. 9.1) is organised around the following three themes: a) natural system characterisation; b) coastal vulnerability characterisation; and c) public risk perceptions (Fig. 4.1 and Section 4.2).

These characteristics contribute to the identification of the degree of risk along a coastal segment. The degree of risk quantifies the economic value of the coastal segment, potentially at risk in the absence of coastal hazard mitigation strategies. Perception studies, although not directly related to the determination of LVAP, are included as these demonstrate the role that public participation can play in the determination of perceived risks along coastal segments.

Box 9.1 Legend Components of the LVAP Research Model



¹ The model varies slightly from the conceptual model in Fig 4.1 with the separation of the public perception components out of the socio-economic characteristics for the sake of functional clarity.

The ESIs (WEI, CSI, and BAI) provide coastal representation of the natural systems (Sections 5.2, 5.3, 5.4) and have been used to develop an Environmental Sensitivity Profile (ESP) for coastal segments. The model places reliance on primary data collection, as part of the monitoring process, in the determination of shoreline classification. The specific data requirements of each subcomponent share some commonality and may, therefore, be considered interlinked. For example, the information collected on wave height has a direct bearing on the WEI, but also inputs to the BAI, and also has a bearing on the CSI of shorelines to the negative effects of oil spill contamination. The ability to use the data for determining the various multiple indices provides for the optimum use of the data without the need for individual index data gathering events.

It is important to note that the literature (Section 3.3.1.2) has identified that the local scale is the most suitable scale for application in small islands (coastal lengths of < 100 km, with an application scale of < 1:10000). Consequently, the indices have been developed and applied in this research, given the proximity of different beach locations, within adjacent bays, less than 2km apart.

The second theme determines the vulnerability of the coastal segment based on: 1) the physiographic and geomorphological data interpretation, (Sections 6.4.3 and 6.4.4); and 2) socio economic data interpretation (Section 7.3.2 and 7.4.2). In the former case, primary data collected are instrumental in the determination of coastal groupings reflecting similar coastal segment types (Chapter 6). In the latter case, the use of secondary data that were incorporated into a GIS proved useful, in determining the characteristics of the socio-economic systems at risk along the coast (Chapter 7). The ability to incorporate information on property sizes, their values and identification of land use classifications contributes to a quantification of the economic degree of risk (Section 7.3.2). The information is also useful for future coastal hazard mitigation planning. Such activities, still in their infancy in Barbados, will require a fully integrative approach, in their development. The results, however, can be used in communities for flood plain regulation and overall land use decision-making; additionally, it is a source of risk information for property owners and insurance agents, as demonstrated in the literature (Pasterick 1998, cited Esnard *et al.* 2001).

The degree of risk developed in the research is based on the representation of the coastal segment's percentage urbanisation versus the percentage vulnerability for each coastal segment (Section 6.4.5). Dal Cin and Simeoni (1987a & b, 1989a & b, 1991 & 1994), Amore and Randazzo (1994) and Simeoni *et al.* (1997) have successfully demonstrated the application of this approach. Application to the Barbados coast has now also been demonstrated; however, further refinement of the methodology is needed to improve the interpretation of the CVI results (by further prioritization according to their location within quartiles ranging from: low risk 0 – 25 %; moderate risk 25 – 50%; high risk 50 - 75 %; very high risk > 75%).

The third theme of the model is achieved by the integration of the findings of the questionnaire surveys (Sections 8.5.1 and 8.5.2). As the literature demonstrates (e.g. Mitchell 1974, Ives & Furuseth 1988, Ricketts 1989, Bird 1994, Smith 1994, Heinz 2000a & b, Gough 2002), a person's response to a hazard event is primarily based on their perception of the hazard, which is related to the length of time between hazard events.

The model identifies and presents the coastline LVAP systematically on maps. It also provides an effective starting point for the next stage of the process of vulnerability assessment – the development of specific response strategies to deal with the issues affecting the high-risk areas. The response strategies will have to be site-specific as each location has its own peculiarities/characteristics that need addressing. Due to time constraints, this could not be explored further here; however, the stages needed to extend the process into the ICZMP are presented in Fig. 9.1.

At this level, there is a need for model refinement and enhancement of the LVA component. Such approaches would contribute to the comprehensive nature of the model process. This can be achieved through the use of inundation modeling for the effects of sea level rise and storm surge as well as other detailed assessments of potential benefits as previously discussed (Section 7.4.3).

9.2.2 Model Structure Issues

The approach taken in model development is based on applied scientific assessments, grounded in the understanding of coastal hazard phenomena and a familiarity with local environmental processes. The review of relevant government agency documentation and available data has also provided a useful information base from which to commence the model development.

From its inception, the main issues in the model development, focused on the development of key components, their characterisation and representation. The model structure was developed through an iterative process to find the most appropriate and functional way to relate the number of indices derived from the interpreted data. Initially, it was believed that it should have been developed to present a single index value, an approach that has been used, with varying effect, in the literature (Section 3.9). However, this was rejected because it did not logistically reflect the level of importance that could be assigned to some coastal sections, either from a recreational or environmental perspective². Other approaches initially considered, included activity charts, and thematic models. The model finally chosen clearly presents all the prime components that have integrated linkages. In addition, the linkages show the systematic approach taken in the development of the LVAP.

There is now an established procedure for determining the vulnerability of the Barbados coastline. Although this model was designed specifically to suit the island's littoral, it is limited in that it has not been tested and revised leading to improvement and optimization. The model has been designed based on scientific reproducibility and testability (Sections 4.3 and 9.2.4). The methods used for the determination of the individual indices are reproducible, given the specific data collection procedures utilized and field equipment accuracy. The process is subject to the test of time as the data set can be considered a baseline on which to incorporate data from future monitoring events.

² The single index value would appear to be more applicable to indices where only specific characteristics are being considered for the determination of representative vulnerability. This is exemplified by the work of Gornitz and Kanciruk (1989), Gornitz and White (1992), Gornitz *et al.* (1994), O'Riain (1996), Klein and Nicholls (1999), Thieler and Hammar-Close (2000) and McLaughlin (2001).

9.2.2.1 Potential Model Modification

Within the broader functional context of the model, the current placement for incorporation of the public perception studies does not fit easily within the model development. This component, however, does provide for perception feedback from beach users and property owners. It would seem more suitably located within the coastal segment ranking stage under vulnerability characterisation. The choice of this position is proposed because:

- 1) The incorporation of the public's perception provides a feedback mechanism to the process for selecting priority areas for mitigation action.
- 2) The general development of the LVA process has to be viewed as a government-led initiative whereby the results must be formulated for presentation to the public, particularly the decision makers.
- 3) The property owner perception results indicate that coastal vulnerability assessments need to be documented and presented in the ICZMP (Section 8.5.2.4). As part of the ICZMP development process, a major public consultation is convened and this has to be followed. It is probably at this stage that the best level of feedback can be effectively achieved.

9.2.3 Model Data Considerations

The model has three main limitations specifically related to a) data sourcing and collection, b) data entry and c) data quality. As part of this discussion, the quality of the data used is also considered with regard to its suitability to meet application requirements set out by the assessment criteria for the applied methodologies.

9.2.3.1 Data Sourcing and Collection

The versatility of the procedures used for index development (WEI, CSI, & CVI), demonstrated reliance on one principle data set collected in the field. The checklist developed for BAI, while having applicable use of some measured field variables, relied

on the objective assessment of the person completing the form, using semi-quantitative and qualitative assessment techniques. The socio-economic coastal risk determination used the most recent land valuation and land use classification data. As a secondary data source requirement, a confidence level had to be assigned for data quality (Section 9.2.4). Based on the evaluation criteria (developed to assess the variables and the secondary data available) and the developed methodologies, an assessment has been made of their effectiveness.

The model is highly reliant on primary data collection. The research has demonstrated the ease with which 1) the applied field methodologies can be followed, and 2) the collected data can be recorded. As the CZMU is the repository for the majority of government's coastal information, the ability to source much of the coastal information from one location was commendable. However, in some instances where data needed to be sourced from other departments, it proved difficult. Another challenge related to finding the existing data and determining, if due to its age, it was relevant and recorded in a consistent manner. In some situations, consistent, large data gaps existed

9.2.3.2 Data Entry and Computer Generated Errors

Throughout the research, the raw data collected was entered manually. The errors related to transcription and transposition of data are a common concern. To minimize these, the data for each location were systematically checked at the end of each completed location's entry. Upon data entry, the original data sets were stored and backed up as master copies. Working data files were then created.

Computer-generated errors can be introduced when data are automatically rounded to the nearest whole number, or in some instances, where hyphenated data can be interpreted as a calendar date rather than an applied range. As part of this research, all data was entered in the Microsoft Excel software using two decimal places, to retain an acceptable level of accuracy.

As part of the coastal potential land loss valuation procedure, the conversion rates³ for Barbados Dollars into United Kingdom (GB) Pounds and United States (US) dollars were initially calculated to six decimal places, but presented as whole Pound or Dollar values for the ease of data presentation. This was decided, as the decimal information did not significantly prevent the interpretation of the land prices, for areas at risk.

9.2.3.3 LVAP Data Quality Requirements

Chapter 3 has identified that the application scales for most vulnerability indices. To provide useful indices for small island coastal planners, they must be at the local level with a more micro-scale application, in order to capture useful intra-beach and coastal segment differences, where they exist.

This research has made use of a varied variable data series to help establish such comparators. Where possible, the data has been at the highest available resolution⁴; however, given the variation in available scales, there is a need to integrate data to ensure resolution and accuracy are maintained. This has been achieved, through the applied use of GIS.

9.2.3.4 Index Development Considerations

The multiple application capability of the developed indices has been demonstrated previously (Sections 5.5, 6.4, 7.3.2). Consideration has to be given to the subjectivity associated with their development, which arises because of the need to combine quantitative data (primary and secondary data) with descriptive interpretations. This concern introduces the risk of selecting inappropriate variables. This is relevant, given the interrelated natures of many coastal process factors. The interactive nature of these factors has been described to various levels in the literature (Komar 1983, US ACE 1984, Pethick 1984, Carter 1989).

³ XE.Com the Universal Currency Converter - <http://www.xe.com/ucc/> between 24 - 28/5/03.

⁴ E.g. digital aerial photos scale 1:10000 with possible enhancement to 1:2500 without loss of detail; topographic maps – 1:10000; land valuation maps 1:5000.

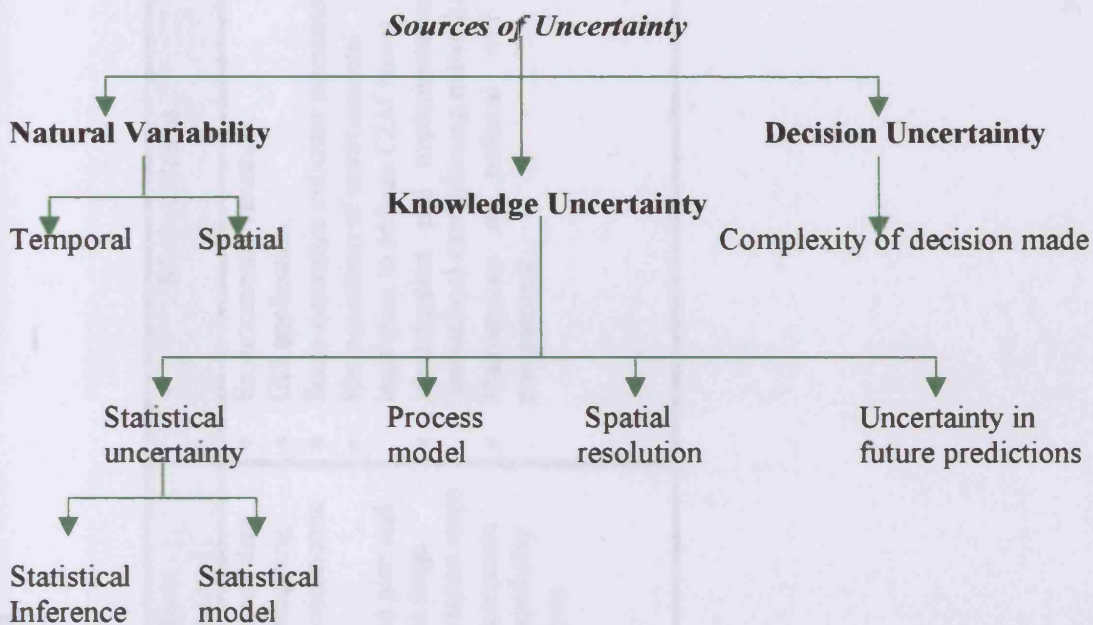
To reduce the level of subjectivity, the research has provided source information on:

- (1) The data sets and their origin - this allows for the evaluation of the quality and the level of reliability of the data set.
- (2) The procedures used in index development - this allows for the evaluation of the stages in the development of the index scores, to ensure the replicability of the process.
- (3) The criteria for variable selection and the effectiveness of the methodologies in achieving their objectives - this provides a defined confidence level to selected methods and selected variables.

9.2.3.5 *Uncertainty Issues*

Issues related to risk are implicit in the concepts of hazards and vulnerability (Canter and Sadler 1997, Uribe *et al.* 1999). Within CM there is no single measure of risk to meet all needs because different users have different objectives (Meadowcroft *et al.* 2002). However, the question of uncertainty, frequently associated with any hazard event, is part of the concept of risk. Understanding uncertainty is key in any decision-making process. It plays a major role in ICZM as it is linked to limited knowledge of the integrated functions of the CZ and the need for its proactive management (Otter and Capobianco 2000). Uncertainty can be broken down into three main categories (Fig 9.2).

Fig 9.2 Sources of Uncertainty (Sources: Ramsbottom *et al.* 2002 and Meadowcroft *et al.* 2002)



Several authors suggest that the incorporation of uncertainty issues as part of an integrated risk management framework can contribute to decision-making⁵. This author, however, considers that such incorporation is also equally applicable to an ICZM process, by determining the level of application appropriateness. Within this thesis, sources of uncertainty can be described on the basis of interpretation, using a technique similar to logframe analysis, applied in project management. This results in a proposed structure of strategic decision-making for the LVA components of ICZM applicable to Barbados (Table 9.1). This research has had to make decisions in the absence of complete information. Such limitations have been identified and accounted for as part of the interpretation of the results. Future improvements will contribute to reducing the identified limitations and making the procedures more robust.

⁵ Refer to Canter and Sadler (1997), MAFF (2000), DETR (2000), Otter and Capobianco (2000), Sayers *et al.* (2002), and Meadowcroft *et al.* (2002).

Table 9.1 Uncertainty Assessment of LVA in ICZM Strategic Planning for Barbados

(Source: Original)

Application Level	Decision Type	Decision to Inform	Data Sources	Methodologies
<p><i>High</i></p> <p>Strategic Decision Making</p>	<p>National Policy</p>	<p>National assessment of LV and CZM:</p> <ul style="list-style-type: none"> • Prioritization of expenditure for research and protective measures necessary for conservation of coastline (Screening of Priority areas) • Establishment of regional planning policies for coastal development • Development of specific hazard mitigation plans • Economic development plans and strategies • Integrated approach to CZM 	<ul style="list-style-type: none"> • Land use data and mapping • Socioeconomic data • Flood plan and storm surge inundation maps • Infrastructure susceptibility analysis 	<ul style="list-style-type: none"> • Environmental valuation. • GIS application. • Socio-economic indicator assessments. • Harmonisation of environmental legislation to address CZM issues. • Identification and implementation of institutional strengthening networks • Maintenance of political will and commitment.

Table 9.1 Uncertainty Assessment of LVA in ICZM Strategic Planning for Barbados (cont'd)

Application Level	Decision Type	Decision to Inform	Data Sources	Methodologies
<p><i>Intermediate</i></p> <p>Strategy formulation</p>	<p>Ministry/Department Application</p>	<ul style="list-style-type: none"> • Littoral strategy planning (CZMP and coastal vulnerability/hazard mitigation Schemes; Oil spill contingency plans) • Coastal development regulation • Coastal maintenance management and protection of sensitive areas • Assessment of littoral risk and valuation • Prioritisation of high risk areas • Identification of financial resource requirements • Development of institutional capacities 	<ul style="list-style-type: none"> • Land valuation data statistics • Detailed socio economic data statistics • Detailed topographic and land use information • Detailed marine ecosystem information 	<ul style="list-style-type: none"> • GIS application • Modelling of scenarios under different conditions • Hazard probability assessment and mitigation strategy development • Prediction of return levels and expected loss calculations • Identification and development of legal structures and instruments • Development of institutional framework for timely identification of potential hazards • Rehabilitation & reconstruction management • Promotion of sustainable management of coastal resources • Identification of integration requirements for effective ICZM

Table 9.1. Uncertainty Assessment of LVA in ICZM Strategic Planning for Barbados (cont'd)

Application Level	Decision Type	Decision to Inform	Data Sources	Methodologies
<p><i>Low</i></p> <p>Detailed data collection and analytical assessment</p>	<p>Department Implementation/ Hazard /Vulnerability Probability Identification and Assessment</p>	<ul style="list-style-type: none"> • Littoral segment issues identification • Coastal vulnerability assessment scheme and implementation • Development of prioritised list of risk areas • Identification of prioritized sources of risk • Development of coastal /littoral vulnerability assessment • Development of stakeholder representation 	<ul style="list-style-type: none"> • Variables to describe littoral⁶ • Predictive modelling to establish time series 	<ul style="list-style-type: none"> • Identification of GIS requirements • Stakeholder participation • Numerical modelling of coastal variation • Trends analysis for erosion and general shoreline change • Simulation of inundation level from storm surge and sea level rise • Identification of institutional capacity (man power) requirements • Identification of training needs • Public consultation and use of bottom up and empowerment consultations

⁶ Variables are systematically expanded as data and technology becomes available.

The use of the above approach supports the integration of LVA within an ICZM context (Section 9.4). Meadowcroft *et al.* (2002) suggested six principles to improve management response within a risk-based decision-making framework. They proposed that these principles supported a more integrated risk management process involving the identification and exploitation of synergies between organizations and available management responses. These principles have been adapted to incorporate the LVA concept for Barbados and have wider application for other SIDS:

- 1 Establishing broad definitions of the littoral vulnerability system and the scope of the impacts (Data collection and analytical assessment).
- 2 Continuous management of performance to assess the institutional capacity requirements to achieve LVA and the wider development of ICZM (Data collection and analytical assessment).
- 3 Tiered analysis and decision making lead to effective policy formulation and implementation (Strategy formulation).
- 4 Consideration of the widest possible management actions (Strategy formulation).
- 5 Development of integrated strategies that combine LVA to the ICZM process in a programmed way to contribute to implementation (Strategic decision making).
- 6 Evolving with and influencing the future of policy development through the use of best available technology and management practices in ICZM (Strategic decision making).

9.2.4 Selection Assessment of Methodologies and Variables

This section describes the assessment criteria developed and applied in the justification of the research methodologies, and the variables selected. It presents the confidence scores methodology used to determine the general effectiveness of the methods and variables, based on their assessment criteria. This procedure contributes to the research, presenting an assessment of the methodologies and variables applied, to determine their level of applicability for the LVA process.

9.2.4.1 Assessment of Research Methodologies Selected

Section 4.3 identified ten criteria used in the evaluation of the methodologies developed. These criteria have been used to develop a confidence score system. In using this scoring system, an approach has been developed to determine an indicative assessment of the procedure used. A scale range of 1 - 5 has been applied to each procedure for each assessment criteria (1 being the best confidence level and 5 being worst confidence level).

Each criterion is scored from 1 - 5 and the totals calculated (Table 9.2). The maximum score is 50. The calculated confidence scores applied are presented in Box 9.2 (where the lower the score the better the confidence in the methodology used).

Box 9.2 Confidence Scores for Assessing Methodologies used in the Research Application.

Score	Confidence level
1- 10	Very good
11 - 20	Good
21 - 30	Average
31 - 40	Poor
41 - 50	Very poor

Table 9.2 Assessment of the Methodology Used (Source: Original)

Methodology Application	Assessment Criteria										
	a	b	c	d	e	f	g	h	i	j	Total
Wave Exposure	1	1	1	2	5	1	2	1	1	1	16
Coastal Sensitivity	2	3	1	1	1	1	3	1	3	1	17
Beach Aesthetics	2	3	1	1	1	1	1	1	3	1	15
Coastal Vulnerability	2	1	1	1	1	3	5	3	2	1	20
Land Valuation	2	1	1	2	1	1	1	3	2	1	15

Table Notes:

Where a = Technically sound approach; b = Reliable consistent data source; c = Procedure used is replicable in /transferable to other locations; d = Wide variety of criteria; e = Flexibility; f = Low cost; g = Easily understandable; h = Systematic and interdisciplinary; i = Sensitivity; j = Criteria specific for purpose of assessment

The confidence scores for the methodologies demonstrate that they are all good procedures for assessing the applications they describe. There is variation within the scores. Very poor scores were noted for (1) the flexibility of the wave exposure as the variables used cannot be easily interchanged with any others, and (2) the easily understood criteria for determination of the coastal vulnerability. This implies the need for a level of training in the application procedure and the interpretation of the results generated.

9.2.4.2 Assessment of Field Variables Selected

Several of the variables identified in the field data collection sheet (Table 4.4 and Section 4.4.6) had to be determined both quantitatively and qualitatively using field measurement and secondary data sources. Most data came from on-site measurements. The bathymetric information was gathered from electronic bathymetry charts developed in 2000. The nearshore habitat types were determined from available aerial

photographs, the 1983 Coastal Map Atlas⁷ and the 2000 hydrographic and geophysical surveys⁸. In order to assess these variables a confidence scoring system to ensure research credibility had to be developed. A similar scoring system to that used in the methodology assessment was applied to the variables used in field assessment. The following criteria⁹ have been used to develop the confidence score system:

1. Scientific credibility;
2. Age of data;
3. Data format;
4. Replicability;
5. Equipment cost effectiveness.

Each criterion is scored from 1 - 5 and the totals calculated (Table 9.3). The maximum score possible is 25. The calculated confidence scores applied are presented in Box 9.3 (where the lower the score the better the confidence in the methodology used). The quality of most of the data fell into the category ranges of very good to moderate. This indicated that the data sources themselves were acceptable for use in the research, as they were of generally good quality and could be considered to be current and, therefore, applicable for use.

Box 9.3 Confidence Scores for Assessing Field Variables used in the Research

Score	Confidence level
1- 5	Very good
6 – 10	Good
11 - 15	Average
16 - 20	Poor
21 - 25	Very poor

⁷The coastal map atlas was developed by Proctor and Redfern (1984) as part of the Diagnostic Study in Coastal Conservation for the West and South Coasts of Barbados.

⁸Hydrographic and geophysical surveys performed by Terra Remote Sensing Inc. (2000).

⁹See Appendix 9 for the explanatory criteria table.

Table 9.3 Applied Confidence Score System to Field Variables (Source: Original)

Variable	Data Assessment Criteria					Confidence Score
	Scientific Credibility	Age of Data	Data Validity/ Accuracy	Replicability	Equipment Cost Effectiveness	
Wind speed	1	1	1	1	1	5
Wind direction	1	1	1	1	1	5
Wave height	1	1	1	1	1	5
Wave period	1	1	1	1	1	5
Wave angle	1	1	1	1	1	5
Longshore current speed	1	1	1	1	1	5
Beach length	1	1	1	1	1	5
Beach orientation	1	1	1	1	1	5
Beach slope	1	1	1	1	1	5
Beach volume	2	2	2	2	1	9
Dry beach width	1	1	1	1	1	5
Beach elevation	1	1	1	1	1	5
Beach sediment grain size	1	1	1	1	1	5
Cliff location	1	1	1	1	1	5
Cliff height	2	4	1	1	2	10
Cliff scarp	1	1	1	1	1	5
Cliff slope	2	3	1	3	2	11
Cliff texture	2	4	1	3	2	12

Table 9.3 Applied Confidence Score System to Field Variables (cont'd)

Variable	Data Assessment Criteria					Confidence Score
	Scientific Credibility	Age of Data	Data Validity/ Accuracy	Replicability	Equipment Cost Effectiveness	
Low rocky shore	1	4	1	1	1	8
Sea floor slope	1	2	1	4	4	12
Sea floor sediment grain size	1	2	1	1	3	8
Distance off shore (0 - -3m)	2	2	1	3	3	11
Nearshore habitat types	1	2	2	2	2	9
Dunes Types	1	1	2	2	2	8
Tidal flats	1	1	2	1	2	7
Beach rock	1	1	2	1	2	7
Percentage urbanisation	1	2	2	3	5	13
Coastal engineering structures	1	2	1	1	2	7
Length of coast covered by structure	2	2	2	1	2	9
Mean shore accretion rate	2	4	2	1	5	14
Mean shore erosion rate	2	4	2	1	5	14

9.2.5 Costing Summary of Methodologies Used

A costing has been developed and presented for each component output of the LVAP model (Chapters Five through to Eight). This section presents a summary of the overall cost components, achieving research objective 5 (Section 1.3.1.2). Two approaches to the cost effectiveness of the LVA process are presented, which are designed to:

- (a) Provide an additional context for improved management and planning of the shoreline;
- (b) Establish a baseline from which vulnerability changes can be determined over time;
- (c) Plan improved monitoring strategies.

A land-based field survey assessment and a GIS-based approach using aerial photography and LIDAR surveys have been used. These are relatively easily accessible in terms of equipment requirements and their product outputs. Each approach has its own limitations, the most important of which can be narrowed down respectively to the following:

- The use of field surveys provided only site-specific information. Thus, the scale of the detailed information required a greater level of survey effort, for a specific coastal segment.
- On the other hand the data collected by aerial photography and LIDAR allow for a much greater level of detailed information to be collected. However, as the functional scale is increased, the resolution of detail diminishes.

This research has made practical use of the existing knowledge of data and technologies, previously used in Barbados, that have provided reliable sources of highly accurate data for Barbados¹⁰. These technologies demonstrate their adaptability to other SIDS (Leslie Walling, *pers. comm.* 2002). The integration of the collected data, as presented in this thesis, also demonstrates a mechanism so that coastal planning issues

¹⁰ Such secondary sources of data have been compiled from projects executed by consultants for the CZMU, projects implemented by the CZMU as part of their regulatory function as well as its routine work programmes.

can be incorporated early within islands' development planning strategies – especially those islands about to embark on major tourism development.

9.2.5.1 The Need for Methodology Cost Effectiveness

Any basic discussion of the overall cost and cost effectiveness of LVA, using data collection techniques, is limited by the large numbers of issues to be considered (Green *et al.* 1999) (Box 9.4). If the decision is made that the works need to be executed as a consultancy, quotations will be required from aerial survey companies and or consultants for obtaining airborne data for the selected study area. The cost considerations required for this aspect of the work are presented in Box 9.5.

Box 9.4 Cost Considerations Required In Determining Cost Effectiveness

- (a) Number and types of variables to be measured.
- (b) Type of hardware available (new or upgrade existing).
- (c) The size of the study area.
- (d) The technical expertise of staff.

Box 9. 5 Main Consultancy Cost Considerations in Project Preparation

(Terra Remote Sensing Inc. *pers. comm.* 2002.)

- (a) Set up and mobilization /demobilization costs¹¹.
- (b) Field survey costs¹².
- (c) Time required for image processing¹³ and data reduction.
- (d) Time required for determination of coastal type classification (including land use).
- (e) Cost of imagery preparation (data format presentation requirements)¹⁴.
- (f) Report preparation.

9.2.5.2 Cost Considerations Associated with the Research Methodologies

The research has presented costings for the manual methodologies (Sections 5.2.5.3, 5.3.5.3, 5.4.6.3 and 6.6.3), the use of secondary sourced data (Section 7.3.3.1) and their associated equipment listings. The individual phases have been costed separately to demonstrate the cost per methodology. These are summarised accordingly (Table 9.4a and b).

¹¹ These include the delivery/removal of appropriate equipment to/from the study location to successfully execute the project (e.g. mobilization charges, hardware and software requirements).

¹² Use of differential GPS ground truthing, fuel costs, crew costs, and hire of equipment, as well as down time due to bad weather.

¹³ Processing refers to the combined time of the operation and computer when manipulating the imagery. It is not the time taken by the computer to perform calculations.

¹⁴ This includes the post processing costs to generate final presentation format.

Table 9.4a Summary of Costings Associated with Methodologies¹⁵

(Source: Original)

Methodology Application	Cost GB £ (US \$)	
	Maximum	Minimum
Environmental Sensitivity Index		
• Wave Exposure Index	3688 (6040)	2363 (3870)
• Coastal Sensitivity Index	7359 (12052)	1512 (2477)
• Beach Aesthetics Index	2919 (4780)	1023 (1675)
Subtotal	13968[£] (22872)	4899 (8022)
Coastal Vulnerability Index		
• Coastal Vulnerability Index	3436 (5627)	3004 (4920)
Subtotal	17403[£] (28499)	7903 (12942)
GIS Coastal Risk Quantification*		
• Aerial photography & Hydrographic study	118628 (194276)	
Grand Total	136031[£] (222775)	7903 (12942)

Where

Risk Quantification* is subdivided into three options presented in Table 9.4b.

The converted subtotal US \$ price to GB £ is represented by [£].

¹⁵ Exchange rate using Internet Universal currency converter: <http://www.xe.com/ucc/> on 28/5/03. Exchange rate was 1 U.S. \$ = 0.610250 GB £. Costs are presented on US \$ exchange rates of original prices. Hence, the total GB £ figures may not total correctly.

Table 9.4b Summary of Costings Associated with Methodologies¹⁶
 (Source: Original)

Methodology Application	Cost GB £ (US \$)
GIS Coastal Risk Quantification (A) Aerial Photography With Options*	
• Mobilisation	31189 (50000)
• Data acquisition processing with selected options	40920 (65600)
• Down time	9357 (15000)
Total	79708[£] (130600)
GIS Coastal Risk Quantification (B) Aerial photography Without Options*	
• Mobilisation	31189 (50000)
• Data acquisition processing	23454 (37600)
• Down time	9357 (15000)
Total	62607[£] (102600)
GIS Coastal Risk Quantification (C) LIDAR Hydrographic survey*	
• Mobilisation	31189 (50000)
• Data acquisition	12476 (20000)
• Data processing	15595 (25000)
• Down time	9357 (15000)
Total	67133[£] (110000)

¹⁶ Exchange rate using Internet Universal currency converter: <http://www.xe.com/ucc/> on 28/5/03. Exchange rate was 1 U.S. \$ = 0.610250 GB£. Costs are presented on US \$ exchange rates of original prices. Hence, the total GB£ figures may not total correctly.

9.2.5.2a Environmental Sensitivity Index Costs

Cost variations reflect those in the actual total cost of the equipment purchased and the level of training required for gaining familiarity with the equipment and the analytical methodologies. When the total costs are compared, there is a cost difference of GB£ 9069.00. This is largely associated with the equipment costs for the Total Station and the Swiffer current meter equipment items. The levels of accuracy and field applicability (i.e. functional storage of multiple data sets and ease of use) are relevant. It is noteworthy that the indices can be developed individually or as a unit, depending on available finances. The results demonstrate that the ESI can be determined for a minimum investment of approximately GB£ 5000. It is, therefore, recommended that these indices be developed as a unique monitoring entity.

9.2.5.2b Coastal Vulnerability Index Costs

There is little variation between the estimated maximum and minimum costs. The difference is based primarily on the cost of data processing and the training associated with data analysis. No equipment items were identified for purchase. The cost presents a true reflection of training cost consideration as part of any project research.

Table 9.4a illustrates that an estimated minimum of GB£ 8000.00 is required to perform the total index development along the 35 km West and South coast. This calculates to approximately GB£ 230.00 per km. This low cost makes the approach highly justifiable. Comparatively, the estimated maximum cost to perform the research is GB£ 17,400.00 for the same area. This results in a cost of approximately GB£ 500.00 per km for the study area (slightly more than double the estimated minimum cost).

These figures are useful for application in situations where a phased approach can be used in index development and associated equipment acquisition in the event that funds are limited. The field equipment listing, (Appendix 6), provides a guide for available options to successfully determine the indices. However, the level of accuracy and scientific credibility is maintained by the scientific accuracy of the inexpensive equipment.

9.2.5.2c GIS Coastal Risk Quantification

Risk quantification related to GIS was not considered above, as it did not have comparative prices (for application). However, it presented in Table 9.4b:

- (1) Original costing;
- (2) Phased costings with and without available options.
- (3) LIDAR costing

The latter approaches separate the original costs into the independent components of aerial photography, with and without the data processing options presented in Chapter 7; and the independent costing for the LIDAR hydrographic survey. This helps present an estimated costing for each aspect of the method employed.

(1) Original Costings

As presented in Section 7.3.3.1b, the cost was based on the original contract cost for performing this work for the CZMU in 2000. At a cost of GB£ 120,000.00, the value of the combined information gained from the aerial photography and LIDAR surveys must be viewed with respect to the level of detailed accuracy achievable by the collected data. These conditions were established as part of the Terms of Reference for the consultancy and had direct bearing on the project's cost price (Rick Quinn and Lynn Armstrong, Terra Remote Sensing Inc. *pers. comm.* 2002). The additional issues for consideration included the following:

(a) Regularity of Survey Requirements

Depending on the scale of the project and the level of expertise required, it is frequently considered more cost effective to hire in the services. This is especially the case where the type of work to be performed is often a "one off" event or is performed only once every few years (minimum of a five year time frame). As it is financially unjustifiable to invest in the purchase of expensive

large scale equipment, that will be used very infrequently, the option of using a consulting firm is considered more cost effective.

(b) Equipment Purchase and Training for Technology Transfer

The purchase of equipment for continued data processing, after the consultancy has ended, and the cost for training and reference materials (if necessary) also need to be incorporated in the investment evaluation. This is significant, since the concept of technology transfer is an important consideration for the continued development of the human resource capacity within a small island context. This is also applicable to Barbados.

(c) Data Analysis and Image Processing

The costs associated with this are related to the level of expertise associated with the processing of the collected information, the quantity and quality of the data collected and the capability of the equipment to process the information rapidly. An operator, proficient in the interpretation of data, will spend considerably less time dealing with data processing and analysis than a freshly trained person.

The combined methodology, used as part of the original costing, accrued savings to the project, as only one mobilisation cost was associated with the work. This allowed the most effective use of the airplane (to undertake aerial photography and LIDAR) for its allotted time in Barbados. The estimated cost per km is GB£ 3400.00. This is good value for the level and quality of information. In addition, the combined ability to relate nearshore depths with features found in the aerial photos allows for effective interpretation of the data and the accurate positioning¹⁷ of the features.

¹⁷ Using differential Global Positioning System (GPS) coordinates and georeferencing of the aerial photographs – all within the data collection process.

(2) Phased Costings With and Without Available Options

The costing presented here illustrates the independent cost for the performance of the works. The options selected for inclusion represent a cost difference of approximately GB£ 17,000.00 and relate to the ortho-correction and mosaic compilation of the images. The cost saving between the two approaches depends on the future application of the aerial photography. Ortho-correction of the photographs allows for greater accuracy in the geo-referencing and positioning of features in the images. However, photo-mosaicing does not need to be performed at the time of photograph acquisition. Photo-mosaics provide a useful visualization of the study area without having to consider the effects of resolution loss and distortion at the edges of the aerial photos. They also allow continuity in photograph interpretation, by providing a complete view of the study segments. This is important when some topographic features that influence the coastline, extend over the photograph edges.

The quality of the aerial photographs, their ease of manipulation and the ability to accurately scale and measure from the images are important considerations in the application of the option. Hence, it is essential that they are flown in a digital format and georeferenced at the time of data capture.

(3) LIDAR Costing

The LIDAR survey cost is presented independently for completeness. The level of bathymetric detail, obtained in this process, provides a level of resolution accuracy unobtainable using traditional hydrographic survey techniques. The technology allows for depth measurements from virtually the shoreline to 50m depth in clear nearshore conditions. There are potential limitations, however, if there is too much turbidity, preventing radar penetration. For instance, water depths in highly active breaker zones may not be achieved. In addition, if the water surface is too still, this results in “reflective mirror” effects, reflecting the radar beam and preventing water penetration. Knowledge of atmospheric and meteorological seasonal variations and their effects on the coast is, therefore, important in determining the most appropriate time for the survey (Rick Quinn, *pers. comm.* 2001).

While the LIDAR Survey can be performed independently, it is still more cost effective to execute with aerial photography surveys to reduce the associated mobilisation costs. The application to SIDS depends on their proximity and sovereignty (e.g. Bahamian archipelago or the individual nations of the Lesser Antilles Island chain). Governments can consider entering into bilateral arrangements to share survey costs (for improved knowledge of their nearshore bathymetry). Thus, it can be envisaged that the value of the data gathered increases while the overall cost per unit km length reduces with increasing distance as the cost is shared between island nations.

9.3 INTEGRATED CZM IN BARBADOS

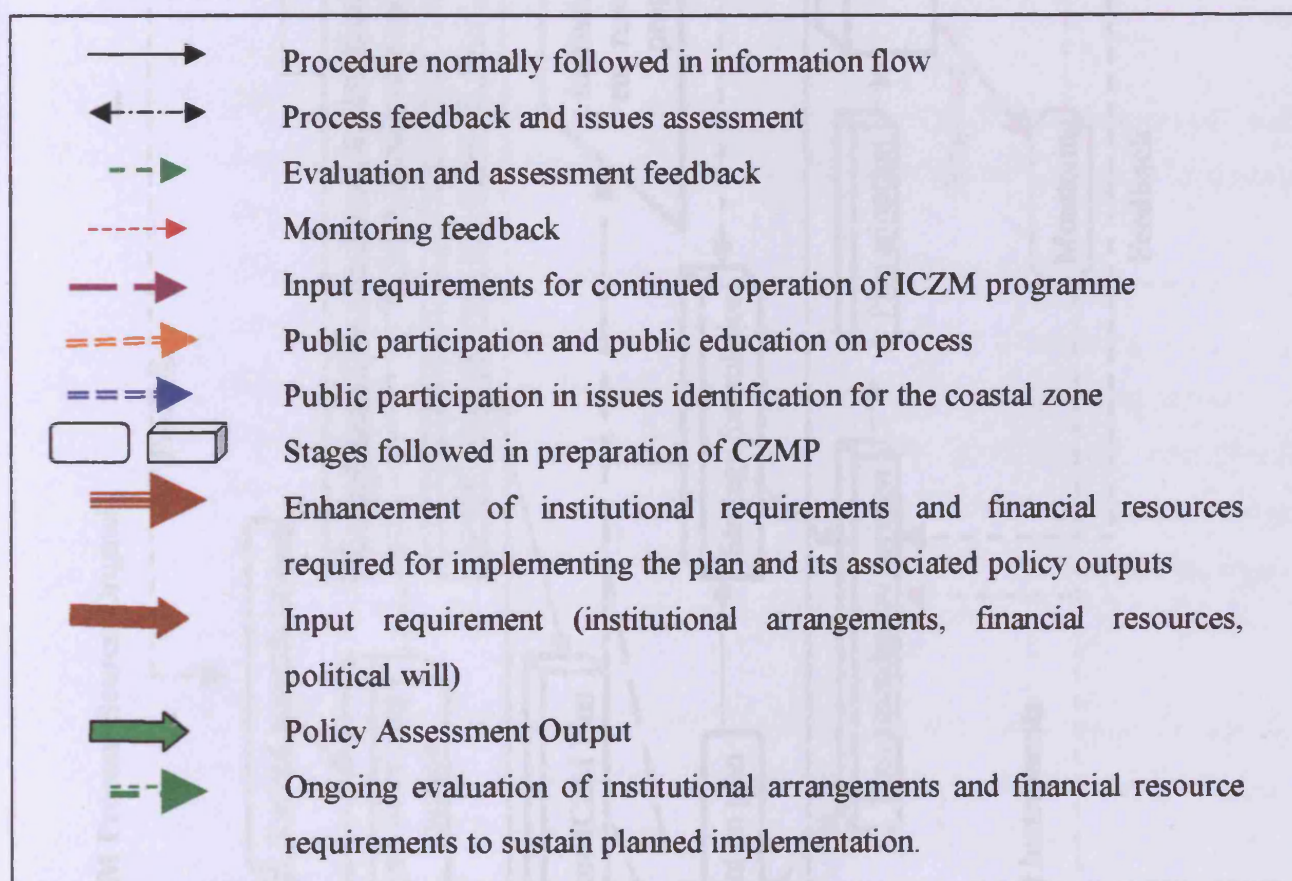
This section provides a brief review of the development of ICZM in Barbados. It presents the salient points used by the Barbados Government to execute its coastal conservation programme, systematically developed and expanded to ensure the coast retains its vital and pivotal role in the sustainable development of the island. This description has been placed here rather than earlier in the thesis to illustrate the clear linkages between how the model developed in Section 9.2 can be incorporated into the ICZM process (Section 9.4). It also provides a means to integrate all the methodologies demonstrated in the research into an applied practical process.

The description is based on primary research, including a series of in-house discussions with the CZMU staff, and with representatives from relevant government departments involved in the island's ICZM process; this author's own background experience¹⁸; and a review of available governmental documentation, developed as part of the island's phased, incremental approach to CM. The in-house and inter-departmental discussions followed a semi-structured interview format (Appendix 9) in which key issues on ICZM and the role played by the relevant departments in the process were explored. This enabled the exploration of the practices and experiences of the different departments within the ICZM process and allowed discussion of topical issues of concern to the particular individuals and organizations.

¹⁸ This author has worked for more than 12 years with the CZMU in Barbados.

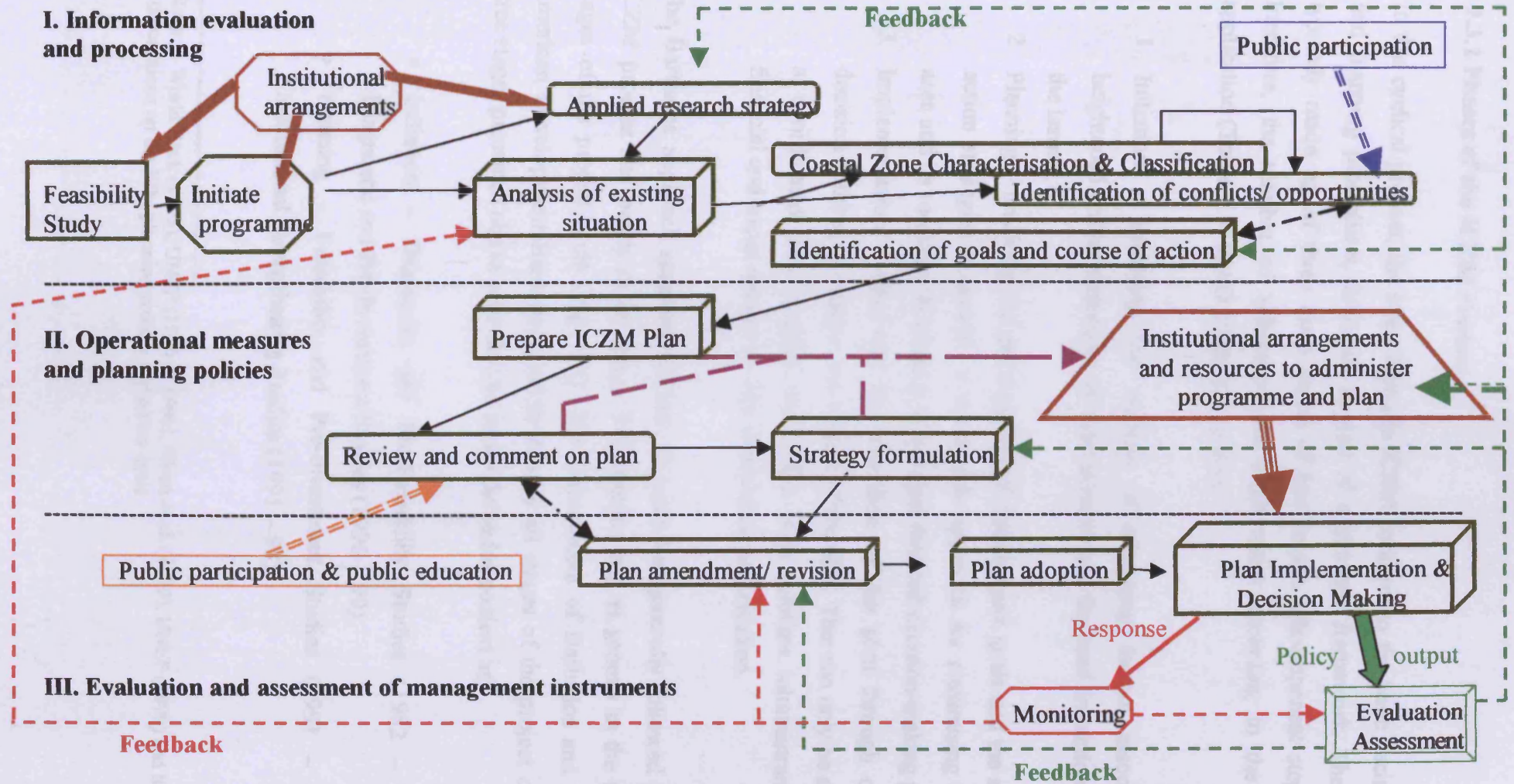
The general ICZM process has been well discussed in the literature¹⁹. The Barbados process comprises the critical steps normally followed in most coastal management cycles (Box 9.6 and Fig. 9.3).

Box 9.6 Legend to Basic Components of the CZM Process (Source: Original)



¹⁹Refer to Chua and Scura (1992), WCC (OC) (1993), World Bank (1993), Ballinger *et al.* (1994 and 1999) IPCC (1994), UNEP (1995), GESAMP (1996), Ballinger & Havard (1997), Olsen *et al.* (1998).

Fig 9.3 Basic Components of the Barbados CZM Process (Source: Original)



9.3.1 Phases of the ICZM Process

In this cyclical process, the steps found in ICZM conform to the basic decision-making and planning procedures, followed as part of a strategic framework. The process is typically made up of three main stages of five or six subcomponent steps²⁰. In the literature, the number of subcomponent steps varies according to the degree of application (Table 9.5) (FAO 1998, IOC 2001):

1. **Initiation** – involving the analysis of triggering factors associated with heightened public awareness of coastal issues and the need for action to address the issues.
2. **Planning** – involving the development of policies and goals and the selection of action strategies to provide a sustainable approach for maximising the coastal area and its resource. In essence, it is a goal directed decision-making process.
3. **Implementation** – involving the execution of the plan through operational decision making, to achieve the objects of the plan. This can only be achieved in a coordinated way through interaction with relevant administrative, legal, financial and social structures, and with public participation.

The Barbados approach spanning the last 20 years has generally followed the above ICZM process and policy cycle stages. The process has its genesis in the traditional stages of the project cycle (Fig. 9.4). The Government of Barbados and the Inter-American Development Bank have jointly funded all stages of the project cycle. The three stages presented above are reflected in the Barbados context as

- **Initiation** – Diagnostic and Pre-Feasibility Studies (1982 – 83) and Diagnostic and Pre-Investment Studies (1996 – 99).
- **Planning** – Feasibility and Pre-Investment Studies (1991 – 95) and Institutional Strengthening Studies (1991 – 93).

²⁰ Refer to World Bank (1993), UNEP (1995 & 1996), Olsen *et al.* (1999), UNEP (1999) and IOC (2001) for descriptions on the ICM planning process and policy cycle.

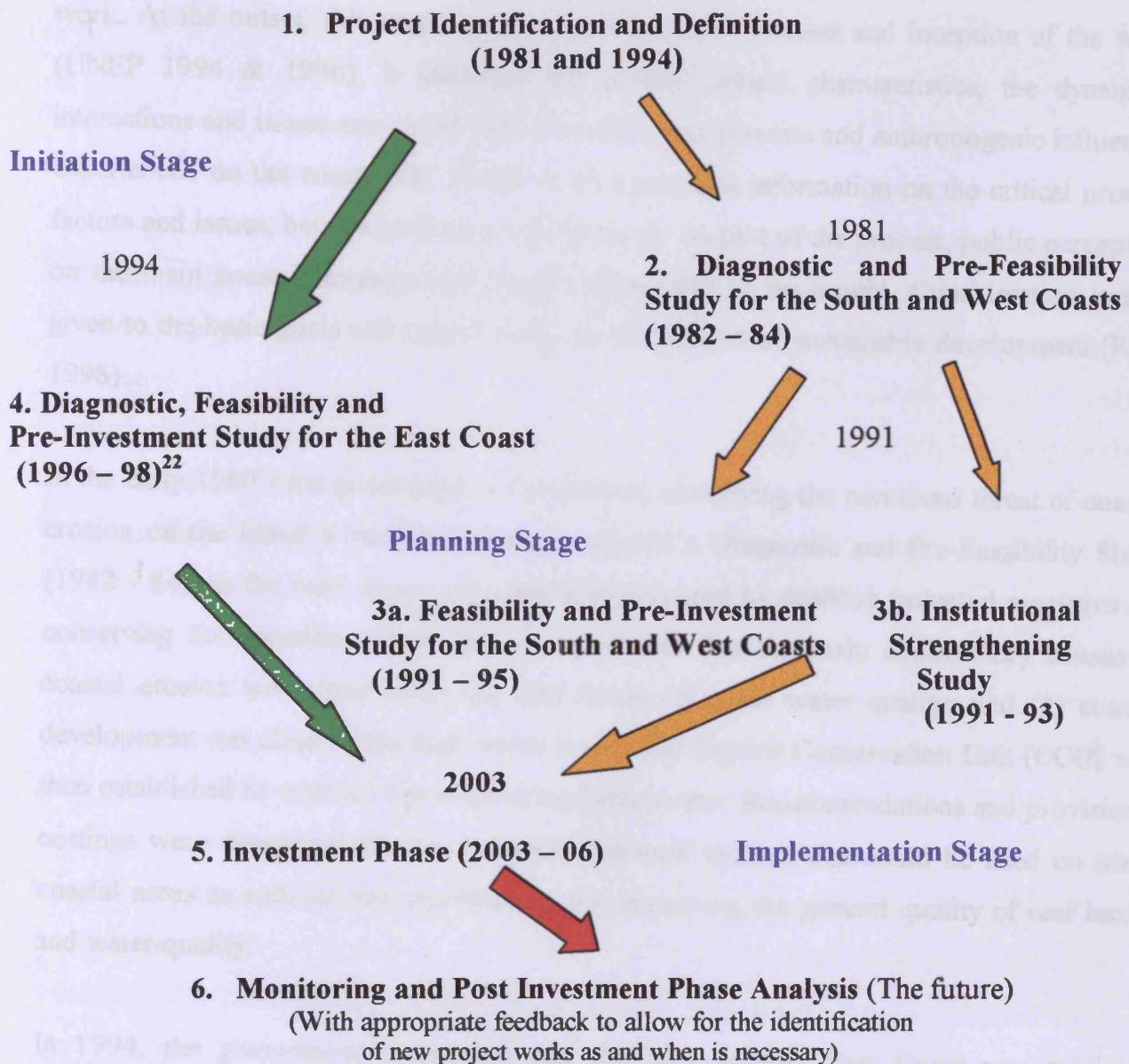
Table 9.5 Stages for Integrated CZM (Source: Original)

Process Stages for Integrated Coastal Zone Management	WCC (1993)	UNEP (1994)	UNEP (1996)	GESAMP (1996)	Olsen <i>et al.</i> (1998)	FAO (1998)	Kay & Alder (1999)	IOC (2001)
Inception/Initiation								
<i>1 Issue identification and assessment</i>	*	*	*	*	*	*	*	*
Planning								
Programme preparation	*	*		*	*		*	*
Performance review						*		
<i>2 Data collection and research</i>	*	*	*	*		*	*	*
<i>3 Analysis</i>	*	*	*			*	*	*
Strategy formulation	*	*	*			*		*
<i>4 Plan formulation</i>	*	*	*			*	*	*
Implementation								
<i>5 Plan implementation</i>	*	*	*	*	*	*	*	*
Formal adoption and funding	*			*	*			*
<i>6 Monitoring and evaluation</i>	*	*	*	*	*	*	*	*

Where # indicates the main subcomponent steps normally presented in the ICM process.

- Implementation – Systematic implementation of some aspects of the programme has occurred since inception; however, the largest component of implementation has recently commenced (2003) as part of the Investment Study Phase II²¹.

Fig. 9.4 Project Life Cycle Followed in the Development of the Barbados CZM Programme (Source Original)



²¹ This is referred to as the Coastal Infrastructure Programme

²² As no prior work had been performed in detail on the east coast, it was thought necessary to do so in order to standardise all the data, so that with the implementation of the investment phase, the complete data set for the island would be in a consistent format.

For the sake of functional application, the process (Fig. 9.3) may be better separated into the following three stages:

9.3.1a Stage I: Information Evaluation and Processing

This stage sets the context for the ICZM programme. It relies on available institutional arrangements, or the initial establishment of an agency that will be the focal point for the work. At the outset, this stage involves problem identification and inception of the work (UNEP 1994 & 1996). It identifies the general coastal characteristics, the dynamics, interactions and issues associated with the natural ecosystems and anthropogenic influences experienced on the coast (IOC 2001). It also provides information on the critical process factors and issues, being experienced on the coast. As part of the process, public perception on the main coastal stressors and conflict issues has to be sought. Consideration is also given to the basic goals and related issues in the context of sustainable development (FAO 1998).

In the early 1980's the government of Barbados, identifying the perceived threat of coastal erosion on the island's tourism industry, initiated a Diagnostic and Pre-Feasibility Study (1982 - 84) on the main causes of coastal erosion and to establish potential measures for conserving the coastline. From this, it was noted that the main contributory causes to coastal erosion were *inter alia*: (1) reef death; (2) poor water quality; and (3) coastal development too close to the high water mark. The Coastal Conservation Unit (CCU) was then established to continue the monitoring programme. Recommendations and provisional costings were developed for the potential structural options that could be used on some coastal areas as well as recommendations for improving the general quality of reef health and water quality.

In 1994, the government recognised that the little studied East Coast was receiving increased prospective interest by developers as they sought to provide an alternative form of tourism product investment. The Diagnostic, Feasibility and Pre-Investment Study of the East Coast (1996 - 1998) focused on the development of appropriate initiatives for

effective controlled development on the East Coast of the island. It involved *inter alia*: 1) the diagnostic assessment of the problems experienced along that coastal stretch; 2) the implementation of community based CM projects²³; 3) the pre-investment costing of mitigation options to address the coastal issues found within the study area; 4) legislative reform and 5) the identification of possible structural and non-structural options for improving the coastline. It culminated with the development of the island's ICZMP and provided comprehensive input into the appropriate strategies required as part of the investment phase works.

9.3.1b Stage II: Operational Measures and Planning Policies

This stage deals with the formulation of the ICZMP once the goals have been established. Wide consultation on the plan is required to ensure that all of its strategic objective can be met by all participating governmental and non-governmental agencies, inputting into the CM process. Additionally, the plan must be circulated to the wider public for general comment, feedback, amendment and clarification of potential new polices (World Bank 1993). With the plan review, a selection of priority issues are made within the context of public policy making, based on the strategies identified to transfer the management goals and objectives into targets and policy measures. To be effective within an institutional setting, the necessary commitment of financial and human resources are required, to ensure the continuity of the process. However, even with formulated strategies developed, there is still need for public consultation on the process to retain transparency (UNEP 1999, IOC 2001).

The Feasibility and Pre-Investment Study for the West and South Coasts (1991 – 1995) and the Institutional Strengthening Study (1991 – 1993) (Fig. 9.4), focused on the detailed technical, organizational and financial requirements to perform the shoreline stabilization

²³ Five coastal community demonstration projects were executed. The projects originated from within the community, based on different project concepts that were applicable to CM with public participation: Seamoss Cultivation, Dune Revegetation and Stabilisation, Sea egg Fishery Co-management, Coastal Watershed Public Awareness, and Coastal Trail Development.

works, identified as part of this study. They also reviewed the legal and institutional status of the Unit and recommended that it have its own enforceable legislation. Cost-recovery analyses were also performed on the projects identified for implementation. As part of the pre-investment works, specific technical analyses were undertaken in the form of pilot projects, precursors to the investment phase works. A draft ICZMP was also developed for the West and South coasts.

9.3.1c Stage III: Evaluation and Assessment of Management Instruments.

With the provision of the necessary amendments, the plan has to be formally adopted for actual implementation of the initiatives. Feedback is a continuous part of the implementation process (Thia-Eng & Scura 1992, UNEP 1996). This is achieved through the establishment of monitoring protocols and evaluation assessments regarding the fulfillment of targets, specified in the plan. Where appropriate, there is need for periodic reviews of the plan as targets are completed and implemented and new ones identified and incorporated. This is achieved through the development of periodic reviews of goals and course of actions and an applied research strategy (Kay and Alder 1999).

As part of the evaluation process, there is need for the progressive systematic upgrading of the institutional capacity of the responsible agency. This is especially important since once the ICZMP is implemented, the ongoing functions of the responsible agency are dictated by the demands set out in the ICZMP.

The Investment Phase (Coastal Infrastructure Programme) focuses on the construction of shoreline protection and stabilization structures and the provision of lateral access along beaches; based on the identified priority projects identified as outputs from previous projects spanning 1991 - 1998. It includes the review and updating of the existing CZM legislation through the development of regulations; and reviews the current implementation status of the ICZMP. This component of the project life cycle started in 2003 and has a four-year duration.

9.3.2 Functional ICZM in Barbados

The global pressure issues associated with the effects of coastal development have been described previously (Section 2.1.1). It is well documented that tourism pressure and general rapid coastal development has led to the development of “urban corridors” along the coastal fringe, where scenic vistas are frequently lost (Cencini *et al.* 1988, Van Herwerden and Baley 1989, Anderson 1980). Smith (1991) noted that this form of development often contributes to a decline in cultural heritage, the degradation and or destruction of natural resources, the exclusion of local residents, and changes in social values. For Barbados, Nurse (1988) and Atherley and Toppin (1993) observed similar trends. Their cumulative effects became noticeable in the early 1980's, and were contributory to the commencement of the island's coastal conservation programme. The coastal development condition at that time, is recognized as the baseline, with all future CM actions having tried to slowly correct this damage.

9.3.3.1 Existing Coastal Management System

The approach to ICZM in Barbados is based on a semi-dynamic system, which has been comparatively slow and well measured in its development and implementation. Within this, the core components are based on the work executed in the various stages of the coastal conservation programme²⁴. From discussions held with the CZMU staff, it is revealed, that there has been an increase in the Unit's overall coastal information and knowledge with each study. However, when a project terminates, there is seldom a continuation of the extended data collection programme, established as part of the project. Rather, the core variables originally monitored are reverted to²⁵. These variables are used to develop the

²⁴ It focuses primarily on the routine monitoring of variables used in coastal classification, which through the interpretation of the results aids in the determination of the active coastal response occurring at the monitored sites. This contributes to the annual update of the existing coastal classification, primarily in the form of if the coastline is eroding or accreting.

²⁵ These include the monitoring of some coastal oceanographic processes as part of a beach profiling regime performed on a quarterly basis, the determination of coastal responses in terms of accretion and erosion trends, and the general characterization of the coastline.

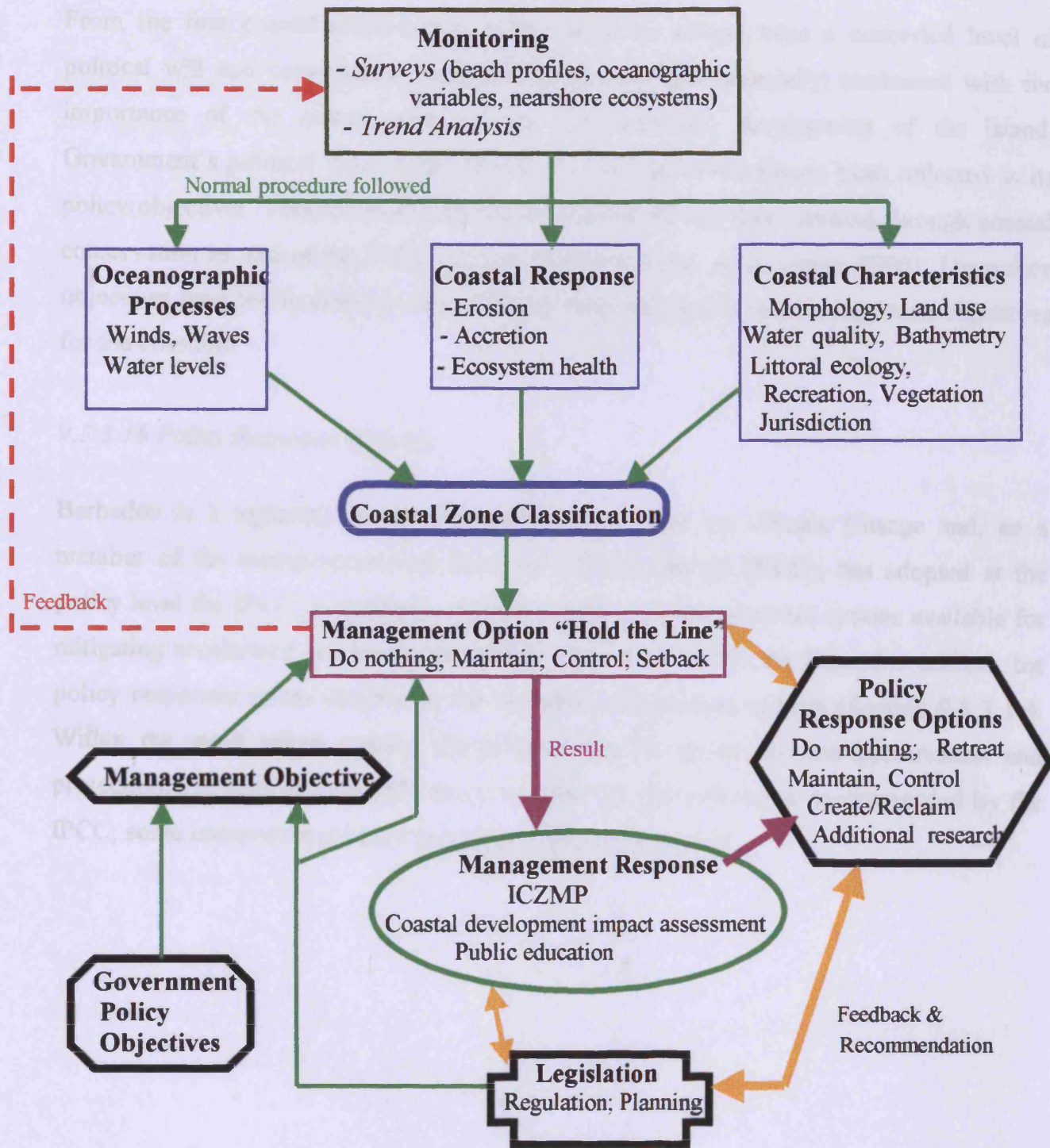
coastal classification. The results from the CC process have been instrumental in the development of management options.

The resulting CZ classification has had to conform to the land use zoning classification allocations developed and presented in the island's Physical Development Plan (PDP). The recent ICZMP for the West Coast (1999) has also had to maintain this policy given the level of coastal development. In effect, the general west coast land use policy recognizes that it cannot be retroactive in its application; however, it does allow for future development requirements to adhere to more stringent development guidelines for the coast²⁶.

On the other hand, the East Coast ICZMP (1998) has had greater opportunity to enhance actively the coastal planning options, given its low development density. The policies set out in the ICZMP ensure preservation of the scenic quality of the coastline through the use of enforceable setback requirements (Jonathan McCue *pers. comm.* 2001). While this is "stipulated on paper", the actual implementation of these setbacks is left up to the political will at the time of the application²⁷. However, both the CZMU and the Town and Country Planning Office (TCPO) attempt to ensure that the policies are enforced (Allison Wiggins and Patrick Bryant *pers. comm.* 2002).

²⁶ See Appendix 9 on the coastal application process.

Fig 9.5 The Present Coastal Management System in Barbados (Source: Original)



9.3.3.1a Government's Policy Objectives and Management Objectives

From the first coastal conservation study, there has always been a concerted level of political will and commitment (both administratively and financially) associated with the importance of the coastal zone to the socio-economic development of the island. Government's political view of the coastline's importance has always been reflected in its policy objectives. This has been consistently maintained and demonstrated through coastal conservation as part of the ICZM process (Leonard Nurse, *pers. comm.* 2000). The policy objectives have led to development of policy response options and management objectives for the coastline.

9.3.3.1b Policy Response Options

Barbados is a signatory to the Framework Convention on Climate Change and, as a member of the Intergovernmental Panel on Climate Change (IPCC), has adopted at the policy level the IPCC committee's recommendations on the potential options available for mitigating accelerated sea level rise (ASLR) (Box 9.6). Within the Barbados context, the policy responses relate directly to the shoreline management options (Section 9.3.3.1c). Within the small island context the prime policy has to be on land preservation and protection. As there is very little room to adhere to the policies as recommended by the IPCC; some interpretation has to be applied to these guidelines.

Box 9.6 IPCC Guidelines for Mitigating ASLR (Source: IPCC 1990)

- **Retreat/Abandon** – Abandon structures in developed areas, resettle inhabitants and redefine setback distances for threatened areas.
- **Advance/Reclaim** – Continue to occupy vulnerable areas either by building protective structures and perform land reclamation and in-filling to elevate the threatened area, or increase the size of beach areas by beach nourishment through the elevation of the beach profile to counter the effects of erosion. In some instances, there will be a need for the combined use of structures with the nourishment to “anchor” the sand in the nourished area.
- **Maintain/Protect** – Defend vulnerable areas, especially population centers and areas of economic activity through the use of appropriate coastal engineering structures.
- **Accommodate** – Continue to occupy vulnerable areas but make appropriate adjustments to building designs to deal with the increased chance of flooding, or consider conversion of land use classification of areas to better suit the changed condition.

The generic policies of ‘do nothing, maintain and control’ still apply; however, other options such as ‘retreat, creation (advance/reclamation) and the need for the identification of funding for project research’ are also considered. These latter three options can only be performed as a government initiative.

(A) Advance the Line

The private sector or property owners cannot perform this action, as the Government owns the seabed area under direct consideration. The creation option normally takes place as a government initiative through either:

- Land reclamation (as was done in Oistins in the 1980’s for the creation of a fish market complex and fishing boat haul out, storage and repair facility); or
- Beach nourishment (undertaken as a pilot project at Rockley Beach as part of the larger Coastal Conservation Feasibility and Pre Investment Study 1991- 1995).

It can also inadvertently occur when coastal structures are placed within poorly defined coastal sediment regimes. This can contribute to 1) the rapid accretion of some coastal segments, where beaches were previously non-existent or “seasonal²⁸”, or 2) erosion of coastal segments as waves adjust to the new coastline configuration. In other situations, the structure can also contribute to the gradual and imperceptible²⁹ development of beach areas resulting in the long-term development of a beach area. This, however, has land ownership implications for the accreted lands that are still to be determined within the current legal framework of Barbados (Robin Gittens, *pers. comm.* 2002).

(B) Retreat/Abandon/Relocation

In this situation, if the land parcel is large enough some property owners can relocate threatened infrastructure to other locations on the property. Generally, this is not the case and the main course of action normally taken is property protection, using hard coastal engineering structures.

Within the context of relocation, there have been situations where the government has had to relocate property owners from threatened locations e.g. Six Men’s, St. Peter, in the late 1980’s and early 1990’s, where the rates of erosion experienced on the site were so significant it was considered best to abandon the coastal area (Fisheries Division, Ministry of Agriculture; and Property Management Unit, Ministry of Housing and Lands *pers. comm.* 2001).

²⁸ Beaches found to occur annually only at certain times of the year possibly due to increased sediment volumes being transported longshore. Prior to 1996, this was a regular occurrence at St Lawrence Bay. Since 1996 the beach has become a more permanent amenity showing systematic accretion at the site – Lester Toppin *pers. comm.* 2002).

²⁹ Gradual and imperceptible relates to the rate at which a beach accretes (Willms and Shier 1994. See also www.utc.ac.za/depts/pbl/jgibson/iczm/notes for information on Common Law issues and the coastline.). It is not measured in geological time, but is related to the effect of a coastal structure (e.g. a groyne or jetty or the construction of a harbour breakwater), and the effect it might exert on the sediment dynamics of a shoreline. The resultant beach might develop over a period of three or more years as a result of the redirection of coastal currents and their associated sediment transport regimes.

(C) Funding Additional Project Research

This systematically carries forward the Barbados ICZM process. While international consultants perform the work, it allows the country to be kept up to date with the latest ICZM techniques and processes. The difficulty is that it only provides a snapshot of the current state of the coastal environment. While it would be hoped that the work would be continued after a project, it is logistically unrealistic given the CZMU's current manpower (Susan Gubbay, *pers. comm.* 2001). Over the years, government has sequentially expanded the Unit's staffing³⁰, but while its formal mandated roles have increased systematically, the informal roles of the Unit have expanded more rapidly. This has reduced its functional research and monitoring role, and, an expansion in the administrative management role of the coastline, without the appropriate increase in personnel.

9.3.3.1c Management Options "Hold the Line"

Given Barbados' small size and the level of development along its leeward coastline, the generic guiding management option has and continues to be to "Hold the Line". This concept³¹ has been in existence prior to the establishment of the CCU³² in 1983, when coastal development applications were assessed through the Town and Country Planning Office.

The other management options applied and available include:

³⁰ Each phase of the Barbados Coastal Conservation Programme has benefited from a cadre of personnel trained at postgraduate level as well as on the job training. In addition the sequential stages have all had components of institutional strengthening incorporated in them to systematically review the routine functions of the office at the time of the project and its projected work load expansion at the time of project completion.

³¹ It is this approach which in the past has contributed to some of the negative effects experienced on the coast as individual property owners have used their legal right to protect their property and associated beach areas against erosion. However, one of the principle policy objectives originally set out by the government at the time of the implementation of the 1983 Diagnostic Study was to ensure that the coastline was conserved through the most appropriate management mechanisms and strategies.

³² The former name of the CZMU prior to its establishment in 1994.

- **Do Nothing**

The “do nothing” concept is self explanatory; in essence it means to let nature take its course. This approach is currently used on the undeveloped East Coast locations, which are relatively natural and unspoiled. This concept allows for the natural buffer action of the backshore areas to absorb much of the high-energy waves experienced on open coastal sections. It also applies to other coastal locations that may be small open/vacant lots sandwiched in developed areas³³, where the land is considered undevelopable and, therefore, has to be left vacant.

- **Maintain (Hard Options)**

In order to maintain the coastline the use of hard engineering options is accepted (e.g. revetments, seawalls, groyne fields, gabions, piles, and breakwaters (surface piercing and submerged)). These structures have been used with varying degrees of success. Their advantages and disadvantages in shoreline and more importantly, property protection are well documented (US Army Corps of Engineers 1981 and 1984, CIRIA 1996).

- **Control (Soft Options)**

The soft options currently applied within the existing framework include: 1) the use of vegetation or revegetation of areas; 2) the use of sand fences on sand dunes; 3) the use of vegetative matting on bluff faces to aid in bluff face stabilization; and 4) the enforcement of coastal related legislation specifically for the protection of some vegetation species and the prevention beach sand mining. The first three have proven useful; however, they are plagued by vandalism (including the willful uprooting of plants by property owners), and poor maintenance. Control options, when applied within a community setting³⁴, get a more

³³ Due to their size these locations are too small for any sort of development, since the setbacks for construction and the road reserve requirements overlap.

³⁴ This has been demonstrated in the community projects performed as part of the Coastal Conservation Phase 1 Programme. Refer to reports on *The East Coast Revegetation* and *The Integration of Community Participation into CZM in Barbados* by People Dynamics Associates (1999).

favoured response as the community gleans a sense of ownership from their involvement – maintenance however, is still a problem.

- **Setback Control**

Setback control³⁵ is applied to all coastal development on the island. However, along developed coastlines where the 30m setback cannot be easily applied, the Chief Town Planner can use his/her discretion to provide a relaxation of the setback requirement. Under such circumstances, it is possible to allow the setback to be consistent with setbacks found on properties, immediately adjacent to the site, in order not to adversely affect the new development or its surroundings.

These management options have a direct feedback to the monitoring and research requirement of the coastal management system. Given that much of the Barbados' coastline is privately owned, the level of goodwill that exists between coastal property owners and the public has ensured that, over the years public lateral access along any beach is not usually inhibited. Unfortunately, the current levels of coastal development along much of the West and South coasts has cut off many of the public accesses leading from the coastal roads onto the beach.

9.3.3.1d Legislation

Legislation has also played a key role in the development of the island's CM system. The draft CZM Act (1993), it was the first time that legal aspects of CZM for the island were seriously considered (John Willms, *pers. comm.* 2000). Prior to that, the CCU had only an

³⁵ Minimum set back distances - (a) building construction as measured from high water mark - 30m; (b) fences walls and other enclosures as measured from high water mark - 10m. The individual property owner owns coastal land down to the high water mark on the beach. This is based on the Common Law. The Government owns seaward of the high water mark. Thus technically the private property owner owns the dry beach area generally used for public recreation. See Willms and Shier (1993) and Halcrow (1998).

³⁵See Willms and Shier (1993). See Appendix 9 for an overview of the current legislation issues in need of consideration.

advisory role to various government agencies with responsibility for different coastal-related matters.

The level of interdepartmental fragmentation between different government offices and the key issues to be considered in the establishment of an ICZM programme has been well documented (Fig. 9.6a and b and Table 9.1)³⁶. The most important was maintenance political will and dealing with inter-ministerial territorial issues as related to the legally mandated responsibility of the CZ (Willms and Shier 1993).

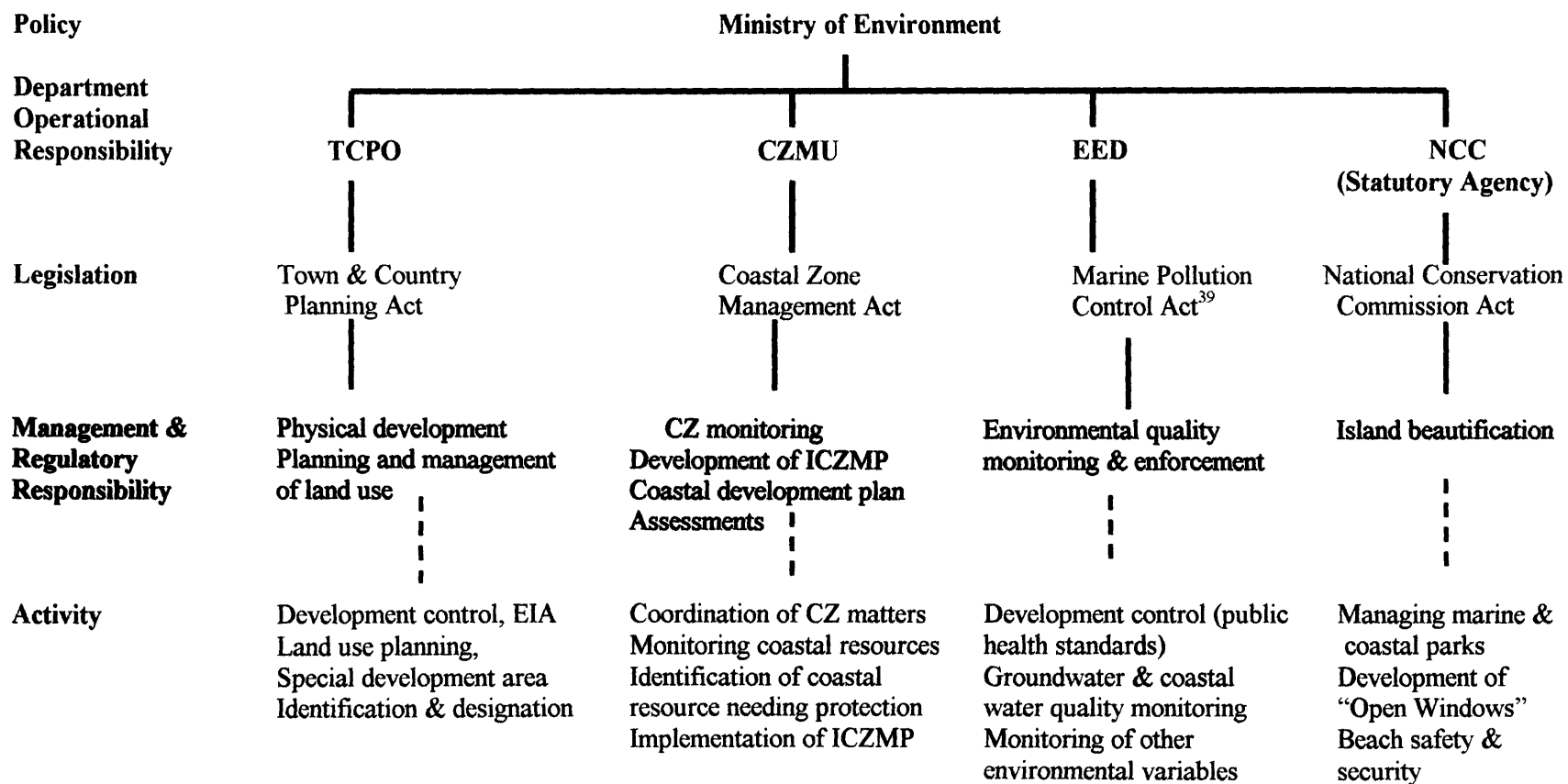
The CZM Act (1999) describes the broad requirements for the effective management of the CZ, through the use of regulatory and planning mechanisms. The legal mechanisms are closely aligned with the overall coastal management objectives and the associated existing management options. Based on the recommendations provided by the management options and, their input into the policy response options, and vice versa, there is often a need to consider the legal implications. This is to be periodically reviewed as the CM process develops.

Fig. 9.6a Main Legal and Institutional Framework and Management Instruments Applied to the Integrated Management of the Barbados Coastline³⁷ (Source: Original)



³⁷ This is only a representation of the primary legal and administrative frameworks associated with the management of the coastal zone.

Fig. 9.6b Structural and Administrative Framework for Primary ICZM Requirements in Barbados³⁸ (Source: Original)



³⁸ Other agencies involved in ICZM are listed in Table 9.1

³⁹ Also associated with this Act is the Health Services Act

Table 9.6 Current Government Agencies involved in Integrated CZM in Barbados (Source: Original)

Ministry	Organization	Main ICZM Function
Physical Development and the Environment ⁴⁰	CZM Unit	Coastal research, coastal ecosystem monitoring, beach monitoring, coastal engineering (design, construction and advice), coastal development control, oceanographic variable assessment, identification of protected areas, public education, community involvement in coastal related projects.
	Town and Country Development Planning Office	All development approvals, control and compliance in the coastal area. EIA application to coastal projects.
	National Conservation Commission	Operation of beach and park facilities, provision of life guard service, coastal area beautification and enhancement, coastal area maintenance, beach revegetation, maintenance of "open windows to the sea", management of marine reserve.
	Environmental Unit	Provide advice on national environmental policy and public education on environmental issues. Focal point for all environmental conventions (international and regional). Policy coordination of all main environmental matters.
	Environmental Special Projects Unit	Development of National Park initiatives and marine management agency for management of additional marine park/protected areas.
	Environmental Engineering Division	Development approval, marine pollution monitoring and enforcement, coastal water quality monitoring (public health), inspection of swimming pools and mini sewage treatment facilities.

⁴⁰ This ministerial arrangement has only been in effect since 2001. It had been recommended as part of the Institutional Strengthening Study 1991 – 1993.

Table 9.6 Current Government Agencies involved in Integrated CZM in Barbados (cont'd)

Ministry	Department	Main ICZM Function
Housing and Lands	Property Management Unit	Management of Crown Lands, identification of coastal lands for purchase by government, issuing licenses for property owner coastal protection structures.
	Lands and Surveys Department	Definition and determination of land boundaries, delimitation of High Water Mark, periodic updating of all land use maps.
Tourism and International Transport	Barbados Port Authority	Operation of harbour, harbour terminals and marinas, navigation safety, pollution in territorial waters, Registration of water sports operators; Marine affairs regulation and shipping, identification of all mooring locations.
	Tourism	Promotion of coastal resources as a tourism asset, identification of potential locations for tourism investment, identification of diversification options for the tourism product and infrastructure investment along the coast.
Health	Sewerage and Solid Waste Project Unit	Design and construction of public sewerage collection, treatment and sea outfall works; Solid waste recycling initiatives and public education.
	Sanitation Service Authority	Solid waste collection and disposal, Cleaning of illegal dump sites (in gullies and watercourses).
Public Works and Transport	Drainage Unit	Design and construction of coastal drainage points (culverts and drains, channelisation of watercourses). Cleaning and maintenance of coastal culverts, wells and drains.

Table 9.6 Current Government Agencies involved in Integrated CZM in Barbados (cont'd)

Ministry	Department	Main ICZM Function
Agriculture and Rural Development	Fisheries Division	Commercial fisheries regulation, fisheries research, maintenance of fish landing sites.
	Soil Conservation Unit	Soil conservation and slope stabilisation in the Scotland District St. Andrew, controlled channeling of water courses coastal revegetation and dune stabilisation.
	Analytical Services Laboratory	Laboratory analysis of coastal water samples and other analyses where appropriate
Prime Minister's Office	Defence and Security (Police Department (Marine Police) and Barbados Defence Force (Coast Guard))	Policing and enforcing regulations set out for use of the beach and sea (e.g. driving on the beach/sand dunes, illegal beach sand mining, water sports, illegal fishing, navigation, coastal cruiser mooring, anchoring), drug interdiction.

9.3.3.1e Management Responses

The management response developed for the island is based on the feedback and recommendations generated from the management and policy response options (Box 9.7). The response also links directly to the review and updating of current coastal management legislation. The legislation similarly has direct input into the existing management objectives and options, and policy response options.

Box 9.7 Management Responses arising from the Barbados CZM Process

(Source: Original)

- The development of the ICZMPs for the island (and the identification of appropriate planning response mechanisms and strategies for the management of the coastline).
- The use of coastal impact assessment procedures (for all coastal developments, above a specific size) as part of the development evaluation process.
- Greater emphasis on public education (on the role of the ICZMP within the overall CZM process and the role the public plays in the development of the plan as one of the key stakeholders).
- The better integration of the ICZMP into other existing plans (e.g. Physical Development Plan, National Park Plan, and Environmental Management Plan for the island⁴¹).
- The management response is directed through the ICZMP, which is to be reviewed, amended or updated as appropriate every five years. As part of this process, there may be instances when legislative review and appropriate amendments need to be made.

Having reviewed the existing ICZM process in Barbados, the following sections demonstrate how the LVA model can be incorporated into this.

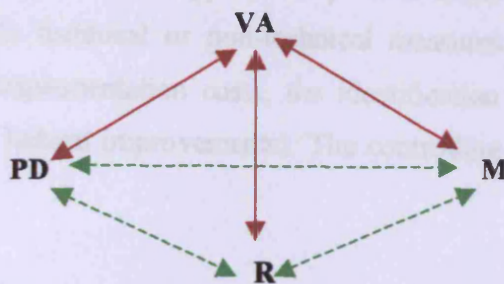
⁴¹ It was the first time that such a coordinated approach to development plan synchronization was achieved in Barbados. This was because all three of these projects came on stream within approximately one year of each other, so the policies developed were able to be simultaneously reviewed and adapted to show greater synergy (Peter Barter *pers. comm.*)

9.4 Incorporation of LVA into the Coastal Management Process

While the Barbados ICZM approach has been considered an effective model for adoption in other SIDS (Michelle Lamay, *pers. comm.* 2000), there are still some elements lacking. One such element is the consideration of vulnerability assessment to coastal hazards (Christopher Fleming and Peter Barter *pers. comm.* 2001).

The IPCC (1994) suggested CVA should initiate awareness of the problems associated with ASLR and climate change and stimulate ICZM efforts. It is, therefore, essential linking research and monitoring to decision-making (Fig.9.7).

Fig. 9.7 Vulnerability Assessment Linkage between Research, Monitoring and Policy Decision-Making Process (modified from IPCC 1994)



Where VA = Vulnerability Assessment, R = Research, M = Monitoring, PD = Policy and Decision Making process

9.4.1 Where Vulnerability Assessment fits in the ICZM Process

Townend (1990) and Capobianco *et al.* (1999) have demonstrated that impact and vulnerability assessments are integrally linked within the CM process. CVA can be highly specialized based on the types hazards they experience (Sections 3.3 and 3.4). Given its contribution to the coastal planning process, vulnerability assessment can be considered as a preparatory phase for the ICZM planning process (IPCC 1991 and Sterr

2000). ICZM and planning is a continuous process implemented by a nominated national agency. The integration of the process within a national context is intended to:

- Define the expected and desired development of the coastline;
- Provide an operational basis for the day to day management for institutional and organizational structures;
- Identify tasks and responsibilities, rules and regulation and specific measures and actions to be taken (IPCC 1991).

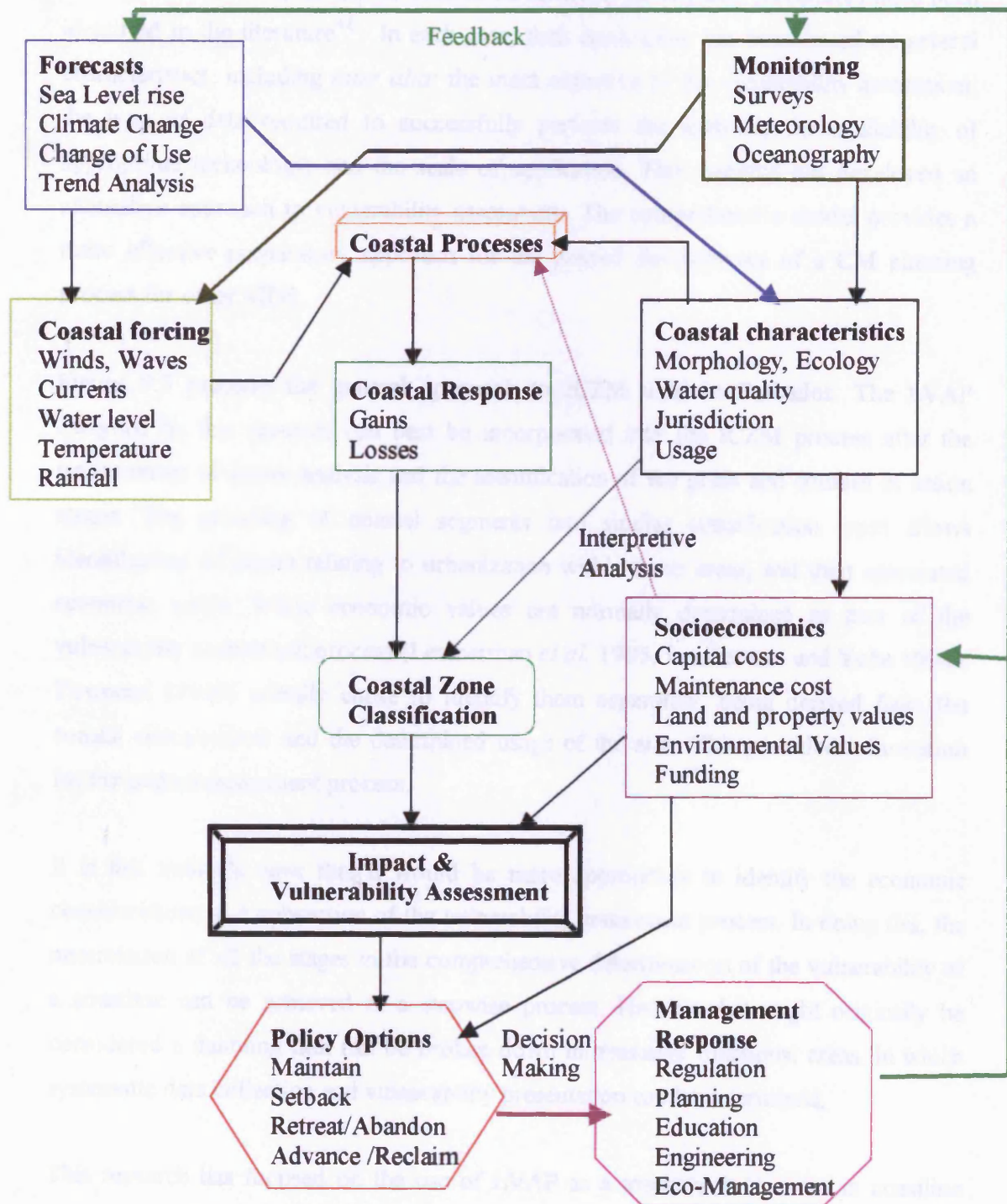
Generally, vulnerability assessment is strongly linked to socioeconomic values assigned to coastal segments (IPCC 1990 and 1992, Leatherman *et al.* 1995, Estnard *et al.* 2000, Carvalho 2002, and McLaughlin 2002). Capobianco *et al.* (1999) determined that changes in socioeconomic value along coastlines could assist in the identification of appropriate responses. They further determined that vulnerability profiles could actively drive the development of appropriate policies to ensure sustainable use. The policies can be either (1) technical or non-technical measures or (2) relative costs and benefits (including implementation costs, the identification of land area for different use and appropriate habitat improvements). The controlling determinant is the level of political will.

As described by Towrend (1990) and presented by Capobianco *et al.* (1999) (Fig. 9.8), the need for greater integrated management at the national level places reliance on the understanding of the physical processes affecting the coastline and the integrated use of GIS. The incorporation of economic aspects into the framework enables representation of the considerations needed to perform impact assessments. There is also a need for the inclusion of forecast data on the effects of ASLR and climate change and the potential requirements for change of use of coastal lands, under different climate change events. It is this forecast aspect, which also contributes to a better understanding of the potential impacts that can arise from oceanographic and coastal forcing variables and their impinging effects on coastal characteristics and the resulting coastal responses. Such an approach, allows for evaluation of a number of situations to see what the best available preparatory option. As such, the methodology would be a dynamic and evolving management tool that would meet the needs of the constantly changing coastal fringe

environment. Additionally, this approach would allow the implementation of a response strategy based on fully technical assessments. However, its integration into existing planning and regulatory frameworks might prove difficult.

The approach identified has appropriate application for Barbados. Although the CZMU has collected some of the data types identified, there remain considerable data gaps – mainly within the socio-economic context. Consideration must be given in the future to identifying appropriate strategies to address these issues.

Fig. 9.8 Framework for Integrated CZM with the Incorporation of Impact and Vulnerability Assessment (Source: Capobianco *et al.* 1999)



9.4.2 Incorporation of the Research Model into the ICZM Process of Barbados

As explained in Chapter Three, several vulnerability assessment procedures have been identified in the literature⁴². In each case, their application has been based on several characteristics, including *inter alia*: the main objective of the vulnerability assessment; the type of data required to successfully perform the analyses; the availability of appropriate technology; and the scale of application. This research has developed an alternative approach to vulnerability assessment. The comprehensive model provides a more effective preparatory approach for the phased development of a CM planning process for other SIDS.

Figure 9.3 presents the general approach to ICZM used in Barbados. The LVAP designed by this research can best be incorporated into the ICZM process after the performance of issues analysis and the identification of the goals and courses of action stages. The grouping of coastal segments into similar classification types allows identification of issues relating to urbanization within those areas, and their associated economic value. While economic values are normally determined as part of the vulnerability assessment process (Leatherman *et al.* 1995, Leatherman and Yohe 1996), Townend (1990) initially chose to identify them separately, being derived from the coastal characteristic and the determined usage of the area. This provided information for the impact assessment process.

It is this author's view that it would be more appropriate to identify the economic considerations as a subsection of the vulnerability assessment process. In doing this, the interrelation of all the stages in the comprehensive determination of the vulnerability of a coastline can be achieved in a stepwise process. Hence, what might originally be considered a daunting task can be broken down into smaller functional areas, in which systematic data collection and vulnerability presentation can be determined.

This research has focused on the use of LVAP as a mechanism to assist in coastline planning and development of Barbados and other SIDS. The procedures provide a

⁴² See IPCC (1992), Gornitz *et al.* (1994), Leatherman *et al.* (1996), Capobianco (1999), NOAA (1999), Thieler and Hammar-Klose (2000), McLaughlin (2001).

necessary intermediary stage between the identification of coastal management goals and the development of ICZMP (Fig. 9.9a). Its location also provides an additional input into the institutional requirements to achieve implementation of the ICZMP. It identifies the additional resource requirements necessary for successful integration into the strategy formulation for the long-term development of CM policies of the island. Such input will be represented within the ICZMP. Its contributory nature to the process of ICZM achieves similar effects to that presented by Capobianco *et al.* (1999), in terms of its location within the ICZM process cycle.

Box 9.8 Legend to the Expanded ICZM Process

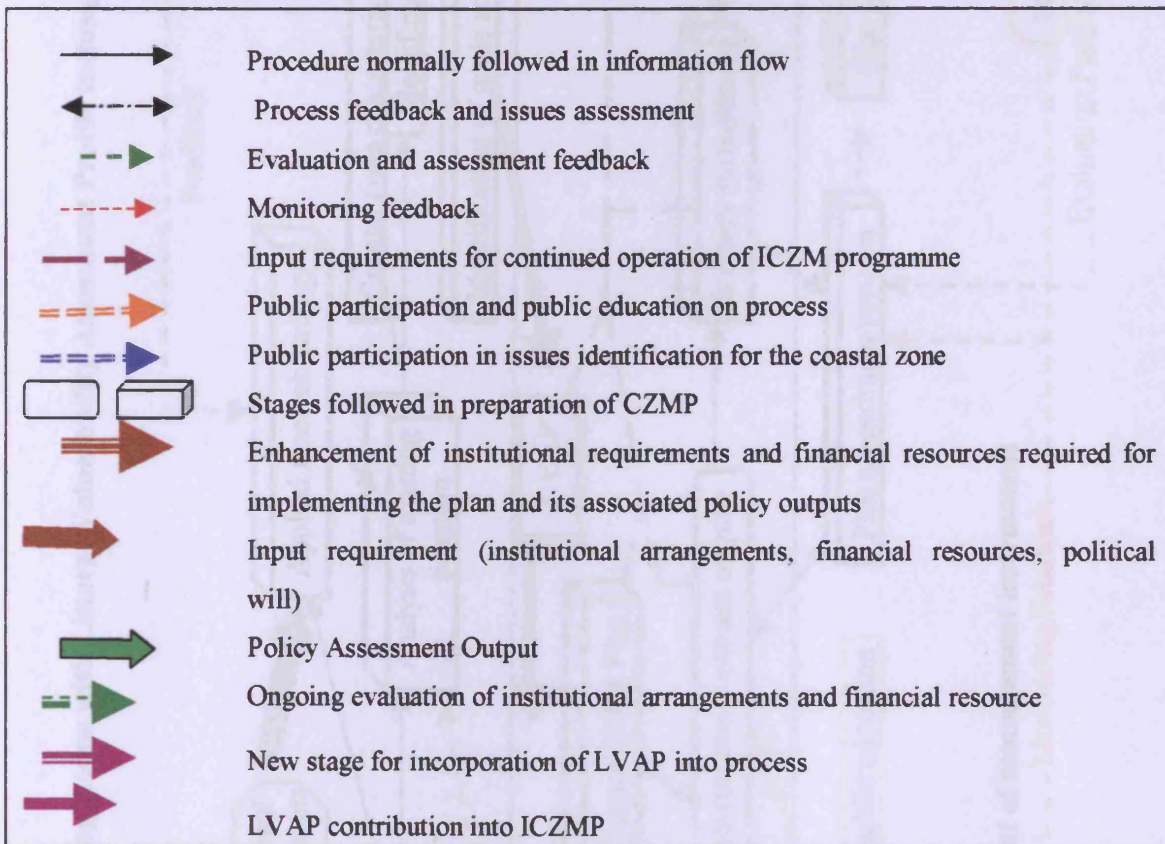


Fig. 9.9a Expanded CZM Programme with Littoral Vulnerability Assessment Profile inclusion

(Source: Original)

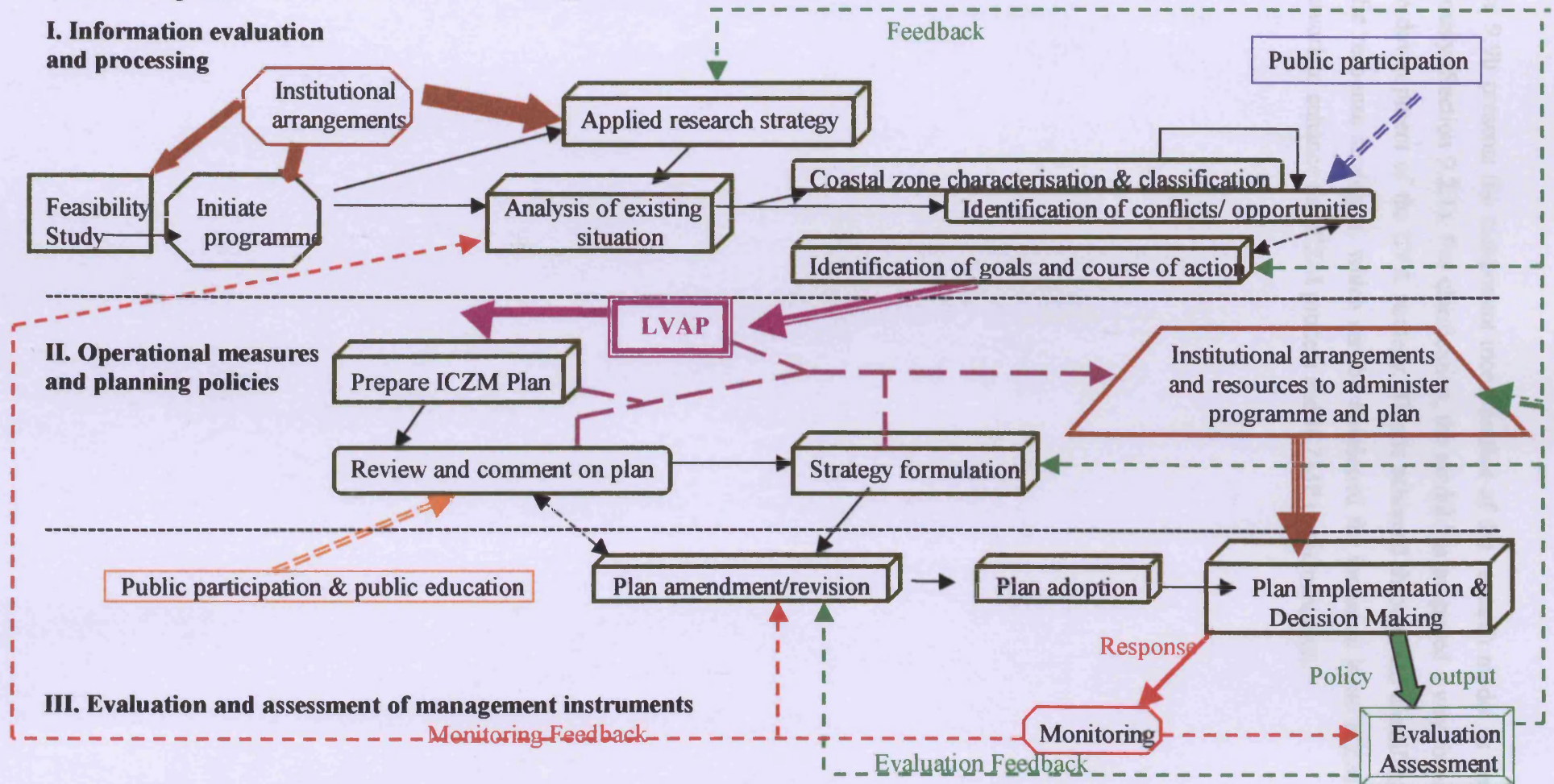
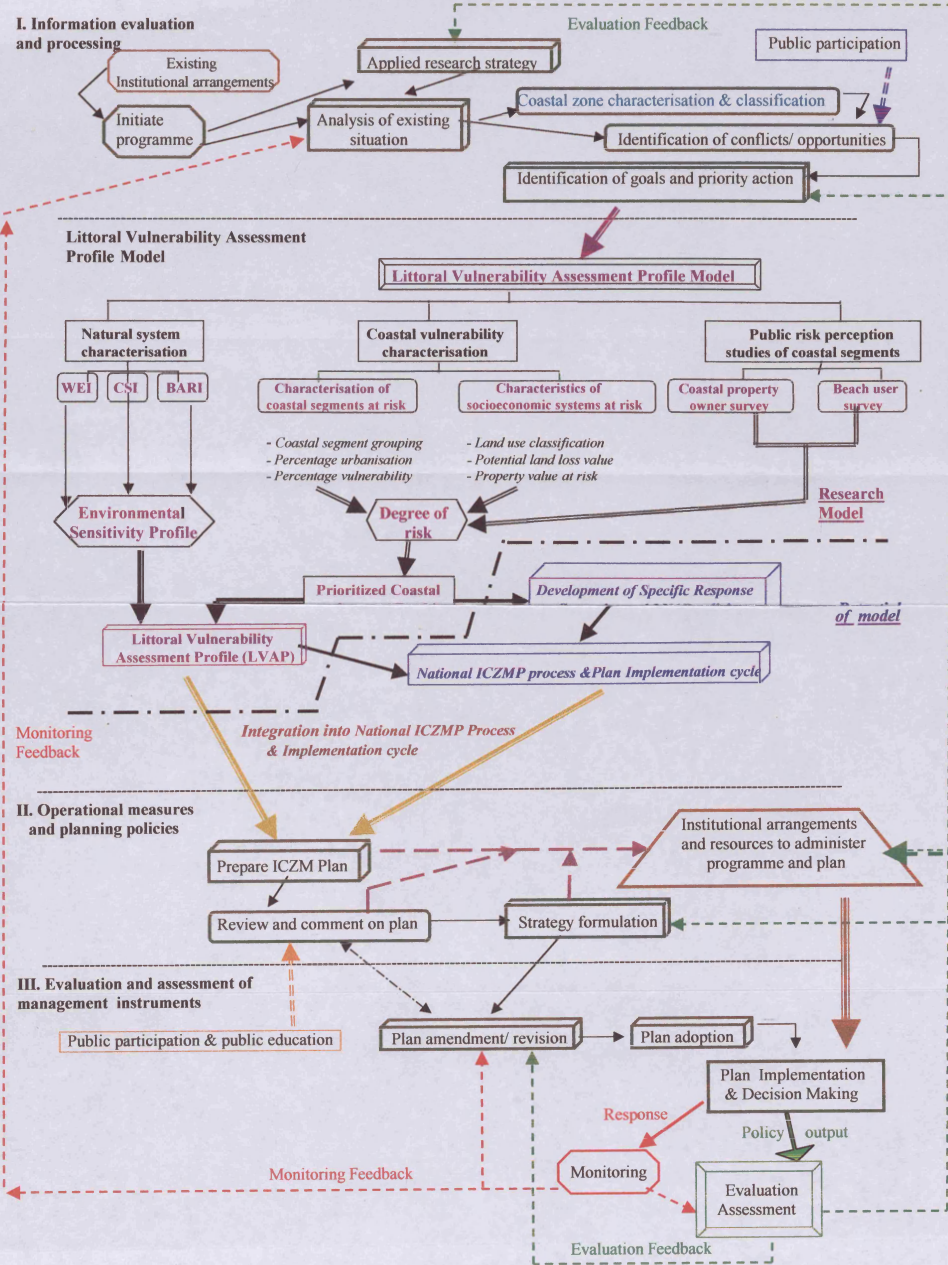


Figure 9.9b presents the component incorporation of the research model as described previously (Section 9.2.1). For clarification, the model has proposed a way forward for future development of the LVA strategy. This is achieved through the identification of specific response strategies, which can be developed for inclusion in an ICZM policy framework to enhance the ICZM process and ICZMP implementation.

Fig. 9.9b Expanded CZM Programme with Littoral Vulnerability Assessment Profile Model inclusion

(Source: Original)



9.5 Conclusion

At this point in Barbados' ICZM process, LVA needs to be implemented. The data set that has been compiled by the CZMU, over the last 20 or so years, allows it to be systematically performed and incorporated into the ICZM process within the data archiving and processing procedures used by the CZMU. At present the Unit is unable to effectively execute this aspect due to its limited human resources. However, the newly developed ICZMP and its association with the PDP allows for a transition into the planning assessment stage, perhaps by the next five years when the ICZMP is to be updated. LVA will identify priority areas in need of future detailed study so that more stringent planning guidelines can be developed for those areas under the greatest threat.

This chapter has reviewed the existing Barbados CM framework and presented the most appropriate location within the framework, where the LVA can be included. It should be remembered that the concept of vulnerability would feed into the overall management plans developed for the island's coastline. The use of primary data as the main data source for the ESP development has demonstrated the ease with which the procedure can be applied to a coast in the absence of accumulated or prolonged scientific data. The use of scientific literature has been instrumental in the identification of the principle variables to be used in the assessment of the littoral.

In addition, Barbados must begin considering other possible additional information requirements for determining coastal vulnerability i.e. the use of forecasting on the major issues of ASLR, climate change and change of use of the coastal fringe. As demonstrated in the literature (Townend 1990, IPCC 1994, Klein and Nicholls 1998, Sterr *et al.* 2000), the areas of forecasting have a direct input to the determination of coastal forcing processes, and the effects that they can exert on modified coastlines. It further highlights the need for better integration of meteorological data and modelling into the ICZM process. This has not been previously explored in Barbados. To be effective it will require the establishment of a series of coastal meteorological monitoring stations to monitor the microclimate conditions. There is also a need to consider the use of offshore weather monitoring stations to measure coastal forcing processes to determine possible coastal impacts, in longer term.

As part of the ICZM system the economic value associated with the coastal fringe there needs highlighting. Not all the requisite statistics may be available, but information on property values and the potential costs of capital works required for the protection of priority coast areas can be developed in the long term. Greater emphasis on the associated issues of the CZ and their overall value can also be explored. These (discussed previously in Section 7.4.3) include:

- The population being displaced due to inundation or sea level rise;
- Loss of employment in the sectors of tourism, commercial business and industry due to inundation or sea level rise;
- The levels of affected housing (in terms of number of houses per kilometer);
- Expected economic losses in land cover for coastal land and urban clusters in coastal areas;
- Economic evaluation for beach areas, urban clusters, industry and commercial areas, transportation services and utility services that would be lost (represented as percentage of total land area and the total value of the lost land.)

This approach somewhat follows the IPCC Common Methodology guidelines (IPCC 1991 and 1994) but also places considerable emphasis on the use of quantitative techniques and the manipulative use of GIS and modelling techniques, with their associated ground truthing surveys. This is highly dependent on availability of relevant information and provides opportunities for future research

Chapter 10

Thesis Summary and Recommendations

Chapter 10

Thesis Summary and Recommendations

10.1 INTRODUCTION.....	453
10.2 SUMMARY AND RECOMMENDATIONS	454
10.2.1 DEVELOPMENT OF INDICES.....	454
10.2.1.1 Recommendations.....	456
10.2.2 RISK QUANTIFICATION AND POTENTIAL ECONOMIC LOSS OF COASTAL PROPERTY	457
10.2.2.1 Recommendations.....	458
10.2.3 PUBLIC PERCEPTION CONSIDERATIONS.....	458
10.2.3.1 Recommendations.....	460
10.2.4 MODEL DEVELOPMENT	460
10.2.4.1 Recommendations.....	461
10.2.4.2 SIDS APPLICATION OF LVAP MODEL.....	461
10.3 RECOMMENDATIONS	462
10.3.1 A VIEW OF THE WAY AHEAD	464

10.1 INTRODUCTION

This thesis investigates the development and incorporation of low cost LVA into the ICZM process of Barbados. The first part of the thesis sets the research context, contributing to the rationalised selection of key variables applied to the LVA process developed within. The main objective has been to develop a flexible, rapid, risk assessment methodology, to assist in the identification and prioritisation of sensitive coastline segments for improved decision-making throughout the ICZM process (Chapter One). This has been achieved through an evaluation of a comprehensive literature review, and the identification of a minimum set of variables that can be used in the determination of littoral characterisation and vulnerability assessment (Chapter Three).

The second part presents the applied quantitative and qualitative methodologies developed to achieve the research aim and objectives. Due to the variety of research methodologies employed, a strategic overview of the procedures and their integration into the LVA profile model has been developed (Chapter Four). This has highlighted key elements in the planning and management of the coastline. Each methodology employed, and its associated findings have been co-presented as individual chapters to reduce repetition of some aspects of interpretation. The applied use of field and land valuation data, together with public perception surveys used in CC (Chapters Five to Eight), has proven useful for interpretation with emphasis on data, information and resource requirements.

The final part puts forward the LVAP model and subsequent conclusions. The model illustrates the most appropriate location for its integration within the island's existing ICZM framework. The model has developed recommendations to facilitate incorporation of the research approaches into the Barbados ICZM process (Chapter Nine). This is intended to assist in the formulation and implementation of future ICZM policy in areas related to LVA for Barbados.

10.2 SUMMARY AND RECOMMENDATIONS

The following provides a summary of the main conclusions arising from the research. Key observations are divided into three themes corresponding to the analytical procedures applied in the research. The literature has demonstrated that high-technology applications provide precise and accurate shoreline position information, but they also are expensive, often time consuming, and require a high level of expertise. Additionally, when applied to CVA, the approaches are frequently regional in scale and, therefore, not suited for short coastal segments, local or site specific coastal evaluations (Gornitz and Kanciruk 1989). While perhaps best suited within the developed world, such approaches are not always easily applicable within the context of SIDS, where there is frequently a paucity of available field data, and funds are limited for the purchase of necessary equipment to perform sophisticated quantitative determinations of shoreline change (Young *et al.* 1993 & 1996, Bush *et al.* 1999). The research has presented an inexpensive, rapid, practical, but scientifically robust technique that makes use of easily acquired semi-quantitative shoreline assessment information. It has, therefore, achieved its aim and objectives. As demonstrated by the research results, a coastal manager, planner or policy/decision-maker can make a sound assessment of the state of a particular coastline based on the immediate information and the form in which it is presented. The technique is therefore, applicable not only to the study area, but, with suitable modifications, is relevant to other SIDS.

10.2.1 Development of Indices

The development of the ESIs and ESP has ensured that the research objectives 1, 3, 4, and 5 (Section 1.3.1.2) have been achieved. Sections 5.2 through 5.4 presented the developed ESIs. These indices have characterised the coastline in terms of its wave climate, nearshore ecosystem sensitivity and general aesthetic quality. The development of a single index value was not pursued in this research, as this researcher found that the combination of indices, to present a single index value, was not best suited as a coastal descriptor for this application. The rationale for this was that individual indices have greater potential interpretive use for end users and, therefore, have greater multi-sectoral

application. Using a combined single index value, the effects of some parameters might be masked, and therefore reduce their ease of interpretation.

There is need for more work to be undertaken on the ESI classification scheme in order to contribute to the development of preliminary resource maps (Sections 5.2.6, 5.3.6 and 5.4.7) Such information sources will have wide application, not only for beach management perspectives, but also can contribute to the systematic monitoring of coastlines for improvement and degradation changes. This information, once integrated into a GIS, will allow for easy updating of the maps, provide a rapid means of identifying changes in the littoral, as well as an appropriate means of public education and information dissemination on coastal change.

Determination of ESIs has presented a flexible technique that is easily applied and adaptable to most coastal locations. This is a new contribution to the research on Barbados, and provides an information base with cross-sectoral application (e.g. recreational zoning of the nearshore, tourism applications, oil spill control, nearshore habitat protection and coastal development control). The ESIs also have application potential in other SIDS coastal environments.

Chapter Six presented the CVI for the West and South coasts using factor and cluster analyses and demonstrated that the research objectives 1, 2, 3, 4, and 5 (Section 1.3.1.2) have been achieved. The use of 19 variables for cluster analysis has presented an effective means of objectively grouping similar coast segments together, based on their physical characteristics (Sections 6.4.2 and 6.4.3). The ability to use this technique provides the basis for the effective management of the coast. It subdivides the coast into similar characteristic segments and groups the variables that best describes them.

The use of factor analysis (Section 6.4.4) has demonstrated that there is low variability between the coastal segments. Additionally, the factors of vulnerability correspond to coastal segment having the following characteristics: medium to narrow beaches with low beach volumes, low backshore elevations, few protective structures and moderately sloping nearshore areas. This result is similar to findings in the literature (Dal Cin and

Simeoni 1989, 1991 and 1994, Amore and Randazzo 1994). The use of this technique, therefore, compares favourably with those contained in the literature.

The degree of risk to flooding (Section 6.4.5) has proven useful in the identification of coastal segments, requiring priority attention. The procedure demonstrates the ability to combine coastal urbanisation information from aerial photography, with the factor analysis results to identify coastal segments, which are vulnerable to flooding in the backshore¹. It should be noted that the procedure does not predict ASLR. This research has only focused on the potential for flooding from storm waves and the identification of beaches, which may be prone to erosion. As an initial process, the technique is applicable for priority setting for the designation of coastal locations to vulnerable beach erosion and potential backshore flooding.

The research has presented an effective, low cost LVA technique (Section 9.2.5), through the use of objective approaches for data collection and assessment (Sections 4.3 and 9.2.4). In both chapters, the flexibility of the methodologies has been demonstrated. The results presented here, while applicable to Barbados, demonstrate that, with suitable variable modification, the methodologies could be applied to other SIDS, resulting in similar characterisations.

10.2.1.1 Recommendations

The main recommendation is the continuation of the monitoring protocol developed in this research, expanding it to the remainder of the island. This will require minor modifications to some variables identified in the CSI and BAI determination, as there are additional ecosystems that need to be included, which were not considered as part of this research. If applied, a decision needs to be made regarding the retention of the present approach to index development and ranking systems, or whether to apply a general ranking for the island. Due to the high variation in coastal types found around

¹ Vulnerability considered here in terms of potential economic loss from damage.

the island, and the reliability of the research procedure used, it is recommended to retain separate coastal segment rankings for each coastal boundary designation (Section 4.4.1).

10.2.2 Risk Quantification and Potential Economic Loss of Coastal Property

Chapter Seven presented the quantification of coastal risk and potential economic loss for the case study areas using GIS. The methodology ensured that the research objectives 1, 3, 4, and 6 (Section 1.3.1.2) were achieved. These techniques (Sections 7.3 and 7.4) used remotely sensed data and secondary data to determine the main coastal land use categories potentially at risk. The use of digitally georeferenced aerial photography at a 1:10,000 resolution scale allowed for identification and classification of coastal land uses and nearshore habitats. The high-resolution quality of the digital photographs also allowed for on-screen measurements of some coastal features, and the areal calculation of the land use classification types.

These procedures also generate high quality results that are important in several aspects of development planning. They demonstrated the acquisition and application of highly accurate data that can be incorporated easily in GIS. However, the cost may be considered prohibitive when compared to the other methods used to determine littoral vulnerability. They also provide a high degree of accuracy in the identification of features found in the photographs that can be groundtruthed. The ability to combine aerial photography with LIDAR surveys of the nearshore contributes to ICZM as the data provides readily suited information of relevance to multi-sectoral agencies, (e.g. CZMU, Fisheries Division, TCPO, Barbados Port Authority, and Lands and Surveys Department). In addition, the ability to correlate this information with land valuation data provides an additional asset to the coastal planning process. Furthermore, it correlates risk quantification assessments for land use easily.

The research technique has potential application to the remainder of the coasts (e.g. the determination of risk quantification for potential flood damage to adjacent coastal segments, allowing for prioritisation of coastal segments at risk, based on their contributory land values). The methodologies have also illustrated the use of GIS

technology in collaboration with public domain data to extract meaningful information on the vulnerability of coastal properties. The research has used this technique to present coastal property as a priority of potential economic loss. This is highly significant for Barbados as coastal properties are prime real estate, and all coastal property owners investing in such, at some point or the other, will try to protect their valuable asset at all costs.

10.2.2.1 Recommendations

The technique can be further developed with the incorporation of storm surge modelling to accurately identify flood inundation zones, together with information on coastal areas susceptible to terrestrial flooding, from torrential runoff. Additionally, flood line predictions under different scenarios, the identification of development exclusion zones, accurate information on coastal structures² and coastal population information should be considered for inclusion. These will contribute to an enhanced ICZMP, and the implementation of appropriate regulatory measures for the sustainable use of the littoral.

10.2.3 Public Perception Considerations

Chapter Eight presents the use of public participatory process in ICZM, ensuring that the research objectives 3, 4, 5 and 7 (Section 1.3.1.2) have been achieved. It was necessary to sample beach users and coastal property owners to obtain their perceptions on beach quality and coastal vulnerability issues, respectively (Section 8.3). The consensus of beach users (Section 8.5.1) is that the island's beaches are of high quality. They prefer beaches with high aesthetic characteristics (i.e. beach and coastal water cleanliness, recreational and beach use safety). Most users also recommended the retention of existing public facilities on beaches, in the event they become damaged by storm waves. Additionally, they recommend that private property, damaged by storms, should be required to setback further. The scarcity of public services and facilities on

² Including structural dimensions, maintenance status and GPS positioning information.

the beaches and the need for improvements to public access to beaches were also identified as a concern.

The public perception studies drew mainly on the knowledge of local residents familiar with the beaches and the cultural background to the problems experienced therein. They also proved to be familiar with the times when peak pressure is experienced at their favourite beach and gave possible suggestions for the improved management of the locations. The knowledge of such respondents has provided better feedback than if the respondents had been tourists. The rationale for this is that the tourist who lacks familiarity with the beaches would naturally find the beaches as “highly acceptable” – as part of their overall vacation experience³ - as they are unlikely to venture far from their accommodation. Thus, their knowledge is restricted to the beaches, associated with their accommodation, and any facilities provided by the hotel.

Property owners’ perceptions’ (Section 8.5.2) have presented a high level of knowledge and understanding of the potential issues and risks experienced on the coast. The results demonstrated the need for improved public education on different aspects of ICZM and the current status of ICZM, established by the government. The property owners have also indicated that a new level of management has to be established to identify coastal hazard and vulnerable areas, which have to be presented for public knowledge. The respondents also recommended that this be considered a priority. Additionally, while property owners understood the need for setbacks, they also indicated that if given a choice, they would defend their property with coastal structures, given the level of investment associated with the property.

Public participation should be regarded as both desirable and necessary for all level of ICZM. The application of future policies on ICZM in Barbados requires greater involvement of the public to better understand their interpretation of and concerns for the littoral (Bottom Up Approach). Such perception studies will contribute to the improved management of the coastline and improved feedback to the coastal managers who have to develop and implement policy. This also has cross-sectoral stakeholder

³ This is a trend normally reported as part of exit surveys performed by both Barbados Hotel and Tourism Association and the Board of Tourism (Ministry of Tourism pers. comm. 2002).

implications (e.g. fishing communities, diving sector, tourism sector and hotel related recreation activity, and development control and enforcement agencies) as common ground for avoiding user conflicts has to be found for the management of the multi-use coastline.

10.2.3.1 Recommendations

Systematic undertakings of property owner perception survey need to be continued. This will allow property owners concerns, along each segment, to be identified and where appropriate incorporated into the island's medium and long term ICZM strategic plan. As this would provide worthwhile research opportunities, the University of the West Indies campus based in Barbados could undertake this activity. It is recommended that such activities be repeated on a similar cycle as the development of the ICZMP. Consultation information gathered and concerns raised, should be allowing sufficient time to be addressed within the ICZMP. This process of consultation forms a primary component of ICZMP as stipulated in the Barbados Coastal Zone Management Act (1999).

10.2.4 Model Development

The development of the LVAP model is the culmination of the thesis, and successfully integrates all the research objectives though emphasis remains on research objectives 3, 4, 5 and 8 (Section 1.3.1.2). Additionally, the implementation costs of the methodologies presented in the research (Section 9.2.5) also have achieved research objectives 3 and 5 (Section 1.3.1.2) in demonstrating the general low cost application of each technique.

The proposed research model (Sections 4.2 and 9.2.1) has been demonstrated to integrate easily into the present Barbados ICZM framework (Section 9.4.2). The model has the potential to enhance existing ICZM procedures currently employed on the island. The CZMU has been successful in the initial steps at ICZM and will need to

carry the integration process onto the “next level” by creating and implementing the necessary linkages identified within the current LVAP model and its linkages to the ICZMP.

The model emphasises the need for greater interpretative use of the data sets currently acquired as part of the CZMU monitoring protocol. This is consistent with providing necessary input to the multiple use concept of ICZM that the Unit has been developing, since its establishment. This will be a necessary requirement as the understanding of the littoral zone continues to improve and the island's development goals change towards achieving optimum sustainable use of the littoral.

10.2.4.1 Recommendations

The main recommendation is for the incorporation of the model into the island’s current ICZM process. As has been demonstrated throughout the research, individual components can be systematically integrated as technology and equipment becomes available. Once prioritisation of coastal segments has been achieved, detailed vulnerability assessment studies need to be performed, and the appropriate mitigation strategies developed. Furthermore, there is need for more proactive interdisciplinary approaches used in the implementation of the ICZM process for the island. This is a priority recommendation within a developmental context, as the use of multi-sectoral disciplines, identified within the expanded ICZM process, will provide for greater developmental interpretation of the littoral and will contribute to improved planning strategies. This will require interdepartmental actions to make the most of limited manpower spread over fragmented departments.

10.2.4.2 SIDS Application of LVAP Model

It is proposed that the development of the LVAP model (Section 9.2.1) and its incorporation into the Barbados situation (Section 9.4.2) establish an appropriate iterative process for LVA integration into CZM process for a SIDS. The costings,

presented as part of the methodologies, (Section 9.2.5) have demonstrated that components can be systematically integrated into the procedure to present the comprehensive assessment of the littoral. The approach adopted recognises that not all SIDS possess levels of data in consistent formats, but presents a standard method of development for major indices that are easily understood and interpreted, which can prove useful in multiple sectors. Such information can be suitably incorporated into GIS as the ICZM programme develops.

The LVAP model as presented encompasses the complexities of the littoral in a user-friendly manner for easy determination and development of an ICZM process. It provides a framework for best management practice within a context of limited financial and human resources. To this end, the proposed model can be viewed as the transition point between the establishment of an ICZM programme and the integrative assessment of the applied ICZM process. Its ability to prioritise littoral areas in need of specific attention: 1) guides the more effective development of the ICZM process; and 2) identifies relatively low cost technology and modest man power efforts, while setting the context for a more coherent systematic approach of long term ICZM in SIDS.

10.3 RECOMMENDATIONS

As proposed by Ballinger (1997), the ultimate success of ICZM programmes is dependent on the implementation of coastal policies through a range of management techniques. Much still remains to be done in Barbados regarding LVA and ICZM. It is necessary to act quickly to prevent future damage to the coastline. Taking the necessary steps implies:

- i. Improved decision making for coastal developments⁴;
- ii. The improved preservation of the natural and cultural features on the coast;

⁴ Decision makers need an information system that is fully responsive to decision making informational needs, with information that is: a) timely, b) easily understandable, c) displayed clearly, d) of the right space and time scales, and e) adequate and in time for action. There is a need to keep all relevant information up to date in order to make real time decisions.

- iii. The adoption of appropriate habitat restoration initiatives; and
- iv. The continued maintenance of free access to the coast for public use and enjoyment, in order to achieve the rational and sustained use of the coastal resources.

The multiple use concept of ICZM is well established in Barbados, and needs to be maintained with the minimum conflict possible. This can be achieved through flexible ICZM policies, whereby new strategies can be introduced. Such upgrading is necessary as the dynamics of littoral system become better understood, and the island's development goals change.

This can be achieved through the following recommendations:

1. The precise demarcation⁵ of coastal public property, which remains in perpetuity and cannot be acquired by prescription and in which any kind of building is forbidden (i.e. public access points to the beach).
2. Elaboration of large scale maps showing coastal physiographic units and their vulnerability indices. The elaboration of coastal maps, showing the distribution of areas that may be affected by natural hazards: flooding (inland and storm surge), erosion, mass movements (as applicable to the East coast) as well as potential man-made hazards.
3. Continued capacity building within the CZMU, as its mandated role expands to incorporate LVA and the interdepartmental co-ordination responsibility to execute the ICZMP.
4. Conservation and acquisition of land and marine ecosystems of natural and cultural interest for the public use in perpetuity (i.e. marine park and protected area development).
5. Better application and enhancement of the Coastal Zone Management Act for the control of urban sprawl and protection of natural areas found along the littoral.

⁵ Application of clear geographic concepts and identifiable boundaries need to be applied here.

6. Improved public participation in ICZM processes to strengthen public awareness of coastal resource management policies and capabilities.
7. Implementation of public discussions programmes and public awareness campaigns aimed at incorporating the management and sustainable development ideas and procedures, for the conservation of the area and its natural resources.
8. Continued provision of technical solutions to conflicts in the use of coastal resources.
9. Development and application of ESI's to the remainder of the island.
10. GIS application regarding land valuation and potential property loss should be expanded to the remainder of the island.
11. Consideration of improved vulnerability assessment using accurate shoreline inundation modelling. This will require use of land laser data to generate accurate contours for areas from the shoreline to the 5m contour, along the coast. This should be incorporated into GIS.
12. The definition and instrumentation of programmes of inspection, monitoring and legal regulation should be reviewed. This will require the periodic review and assessment of the administrative and legal instruments for the environmental management of the littoral to further strengthen the integrated nature of the ICZMP and its proposed arrangements for sustainable ICZM.

10.3.1 A View of the Way Ahead

A number of challenges face policy and practical application of the ICZMP; however, its aims must run constant, through proactive rather than reactive management⁶. To achieve this it is recommended that:

- a) The CZMU's role must be expanded to incorporate a more integrated and co-ordinated link with other departments in the ICZM process.

⁶ Including site specific management.

- b) Existing CZMU monitoring programmes be refined to include new littoral issues, identified in this research, and their associated interactions of human influences.
- c) Greater interdepartmental collaboration on ICZM issues, especially for education and interpretation of ICZM policy initiatives, as part of the ICZMP.

While the future will be challenging, with significant improvements anticipated in the planning and management of the coastal zone for the island, the proposals presented here can assist by lending more strategic and co-ordinated approaches to the sustainable long-term management of the coastline. Invariably, the continued success will rest on the key pillars of ICZM⁷:

- Continued political will and commitment to the process, with a vision of long-term sustainable development. A vision and scope of a broader and long-term concept of development, including social and environmental vulnerability reduction, is one of the key elements in sustainable development. This includes the formulation of national vulnerability reduction plans for the coastline;
- Institutional capacity building is imperative and should be continued at the Ministry level, as well as the departmental level, for all agencies involved in the ICZM process, to further strengthen the integrated approach to vulnerability mitigation as part of the ICZM process;
- Feasible approach and regular process reviews for ICZMP development and adaptability;
- Continued recognition of the integrated nature of all parts of the littoral and its associated human activities; and
- Development and implementation of acceptable policy options that may afford added value to the end product for the full range of stakeholders, included in the planning and management of the coastline.

⁷ ICZM usually focuses on three goals: 1) overcoming the conflicts associated with sectoral management; 2) preserving the productivity and biodiversity of coastal ecosystems; and 3) promoting the equitable and sustainable allocation of coastal resources.

To conclude, it is recommended that the Barbados ICZMP continue to be grounded in a development strategy based on scientific knowledge, geared towards the solution of priority problems and on planning and development policies. This study and its results offer indications of the way in which the current application of ICZM in Barbados can be further improved. It has also demonstrated the wide-ranging nature of the process, and how, in the long term, it can assist multi-sectoral users ensure that the Barbados coast remains a coast to be proud of.

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GLOSSARY OF TERMS

Accretion - May be either natural or artificial. Natural accretion is the build up of land, solely by the action of the forces of nature, on a BEACH by deposition of water – or airborne material. Artificial accretion is a similar build-up of land by reason of an act of man, such as the accretion formed by a groyne, breakwater, or beach fill deposited by mechanical mean.

Backshore - That zone of the shore or beach lying between the foreshore and the coastline comprising the BERM or BERMS and acted upon by waves only during severe storms, especially when combined with exceptionally high water.

Beach - The zone of unconsolidated material that extends landward from the low water line to the place where there is marked change in material or physiographic form, or to the line of permanent vegetation (usually the effective limit of storm waves). The seaward limit of a beach - unless otherwise specified – is the mean low water line. A beach includes FORESHORE and BACKSHORE.

Beach berm - A nearly horizontal part of the beach or backshore formed by the deposit of material by wave action. Some beaches have no berms, others have one or several.

Beach erosion - The carrying away of beach materials by wave action, tidal currents, littoral currents, or wind.

Beach width - The horizontal dimension of the beach measured normal to the shoreline.

Breaker - A wave breaking on a shore, over a reef, etc. Breakers may be classified into four types:

Breaker depth – The still-water depth at the point where a wave breaks.

Cliff – A high, steep face of rock greater than 3 m in height.

Coastline – (1) Technically, the line that forms the boundary between the coast and the shore. (2) Commonly, the line that forms the boundary between the land and the water.

Crest length, wave - The length of a wave along its crest.

Crest of berm - The seaward limit of a berm. Also called berm edge.

Crest of wave - (1) the highest part of a wave. (2) That part of the wave above still-water level.

Current, coastal - One of the offshore currents flowing generally parallel to the shoreline in the deeper water beyond and near the surf zone; these are not related genetically to waves and resulting surf, but may be related to tides, winds, or distribution of mass.

Foredune - The front dune immediately behind the backshore.

Foreshore - The part of the shore, lying between the crest of the seaward berm (or upper limit of wave wash at high tide) and the ordinary low-water mark, that is ordinarily traversed by the uprush and backrush of the waves as the tides rise and fall.

Geomorphology - That branch of both physiography and geology which deals with the form of the earth, the general configuration of its surface, and the changes that take place in the evolution of landform.

High Water Mark - A line or mark left upon tide flats, beach, or alongshore objects indicating the elevation of the intrusion of high water. This mark is physical evidence of the general height reached by wave run up at recent high waters.

Inshore (in beach terminology) - The zone of variable width between the shoreface and the seaward limit of the breaker zone.

Intertidal zone (technical definition) - The zone between the mean higher high water and mean lower low water lines.

Nearshore (zone) - In beach terminology an indefinite zone extending seaward from the shoreline well beyond the breaker zone. It defines the area of NEARSHORE CURRENTS.

Nearshore current system - The current system caused primarily by wave action in and near the breaker zone, and which consists of four parts: the shoreward mass transport of water; longshore currents; seaward return flow, including rip currents; and the longshore movement of the expanding heads of rip currents.

Offshore - (1) In beach terminology, the comparatively flat zone of variable width, extending from the breaker zone to the seaward edge of the Continental Shelf. (2) A direction seaward from the shore.

Offshore current - (1) Any current in the offshore zone. (2) Any current flowing away from shore.

Pocket beach - Usually a small beach formed between two littoral barriers or headlands.

Profile, beach - The intersection of the ground surface with a vertical plane; may extend from the top of the dune line to the seaward limit of sand movement.

Rubble - (1) Loose angular water-worn stones along a beach. (2) Rough, irregular fragments of broken coral rock.

Slope - The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating 1 unit vertical rise in 25 units of horizontal distance; or in a decimal fraction (0.04); degrees ($2^{\circ} 18'$); or percent (4%).

Wave height - The vertical distance between a crest and the preceding trough.

Wave period - The time for a wave crest to traverse a distance equal to one wavelength.
The time for two successive wave crests to pass a fixed point.

Wave direction - The direction from which a wave approaches.

