Watershed Characterization and Vulnerability Assessment using Geographic Information System and Remote Sensing

Department of Environment and Natural Resources
Forest Management Bureau
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MESSAGE

Dear Colleagues,

Greetings!

The Forest Management Bureau, the government agency mandated to provide support for the effective protection, development, occupancy management, conservation of forest lands and watersheds, presents this manual on Watershed Characterization and Vulnerability Assessment Using Geographic Information Systems and Remote Sensing.

This manual, crafted in partnership with faculty members of the University of the Philippines Los Baños - College of Forestry and Natural Resources touches on the essential components of watershed characterization - from biophysical aspects such as climate, geology and vegetation to socioeconomic variables such as income, health and education. It aims to guide watershed managers and field implementers in the creation of a holistic watershed characterization plan and vulnerability assessment. It also provides descriptions of watershed parameters and instrumentation, field methodologies and techniques in the floral, faunal and socio-economic characterization and a systematic guide on physical characterization using geographic information system and remote sensing.

We hope that this manual would serve as our share in the betterment of our work in developing and conserving our watersheds.

Dir. Ricardo L. Calderon, CESO III
Forest Management Bureau
ACKNOWLEDGEMENT

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We would like to express our sincere gratitude and appreciation to the following professors of the University of the Philippines Los Baños – College of Forestry and Natural Resources who played a vital role in the development of this training manual:

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Prof. Maricel A. Tapia
# TABLE OF CONTENTS

**Message** ........................................................................................................ iii  
**Acknowledgement** ......................................................................................... iv  
**Table of Contents** ......................................................................................... v  
**Executive Summary** ....................................................................................... 1  

**Chapter 1: Physical Characterization** ....................................................... 3  
  Physical Features .............................................................................................. 5  
  Watershed Instrumentation ............................................................................. 15  

**Chapter 2: Biological Characterization** .................................................... 27  
  Methods and Techniques of Faunal Assessment ........................................... 29  
  Methods and Techniques of Floral Assessment ............................................ 41  

**Chapter 3: Social Characterization** ............................................................ 55  
  Socio-economic Components ......................................................................... 57  

**Chapter 4: Methods in Geographic Information System (GIS)** ................. 71  
  Georeferencing, Map Projection and Data Vectorization in ArcGIS™ .......... 73  
  Watershed Delineation Using Hydrology and Arc Hydro Tools in ArcGIS™ ... 91  

**Chapter 5: Methods in Remote Sensing (RS)** ........................................... 111  
  Image Pre-Processing and Vegetation Indices Using ArcGIS™ ................. 113  
  Image Classification and Change Detection Analysis Using ArcGIS™ ...... 123  

**Annexes** ....................................................................................................... 137  
  Annex 1: Modeling Landslide Vulnerability Using ArcGIS™ ModelBuilder ... 139  
  Annex 2: Flood Modeling Using HEC-HMS And HEC-RAS ....................... 159  

**References** .................................................................................................. 187
EXECUTIVE SUMMARY

The preparation of a watershed characterization and vulnerability assessment is the first step in the sustainable management of our watershed resources. It provides watershed managers and decision-makers basis for development and conservation strategies to be implemented. With the advent of technologies like Geographic Information System (GIS) and Remote Sensing (RS), the preparation of these analyses has been made easier and more accurate.

This manual is an output of the recently conducted Trainers’ Training on Watershed Characterization and Vulnerability Assessment Using Geographic Information System and Remote Sensing. The training is aimed at capacitating FMB personnel in watershed management concepts, principles and the application of GIS in watershed delineation and characterization. It was facilitated by forestry and GIS-RS experts and professors from the University of the Philippines Los Baños – College of Forestry and Natural Resources.

The manual shows all the lecture materials during the training. The first five topics discuss the physical, biological and social characterization of the watersheds. The succeeding topics show a methodical guide in the physical characterization of watersheds using GIS and RS methodologies in ArcGIS™ software. The annexes show a methodical guide in the vulnerability assessment for landslide and flood using GIS and RS methodologies in ArcGIS™, HEC-RAS, HEC-HMS, HEC-GeoRAS and HEC-GeoHMS software.

The physical characterization of watersheds is divided between discussions of the different geo-morphometric parameters and the instruments and methodologies used to describe these parameters and water quality as well. A table summarizes all the morphometric parameters that can be calculated for the physical characterization of watersheds. There is a detailed discussion on the computation and interpretation of the computed values for form factor, relief ratio, drainage, density and length of overland flow. The watershed instrumentation topic starts with a discussion on the hydrologic processes and water balance. The different instruments used for determining water yield are then enumerated and described. It is followed descriptions of the physical, chemical and biological components in determining water quality. Sample computations and exercises are provided for both topics.

The biological characterization of watersheds is focused on the discussions on faunal and floral assessments. For the faunal assessment, key terms and definitions are provided. Methodologies in sampling mammals, birds, reptiles and amphibians are then enumerated and described. A sample wildlife/fauna survey form is also provided. For the floral assessment, the importance of vegetation in watershed vulnerability assessment is discussed followed by the vegetation and forest formations found in the Philippines. The different parameters in determining stand structure and biodiversity assessment are also described. Sample computations and exercises are provided for both topics.

The social characterization of watersheds discusses the different components of socio-economic survey and demography and their variables and indicators. The methodologies for stakeholder analysis and vulnerability to climate change are also discussed. Sample tables for data collection of both analyses are also provided.

The methodologies for GIS and RS cover topics ranging from basic concepts and processing to specific watershed applications. The software used in this manual is ArcGIS™ version 10.2 for both GIS and RS. ArcGIS™ version 10.0 and 10.1 can also be used but may have...
some differences in the interface. The Arc Hydro Tool extension is used for the watershed characterization part.

The first topic discusses basic GIS processing in converting analogue maps into digital format i.e. georeferencing and projecting maps and creating vector shapefiles. It is followed by tools (i.e. Hydrology Tools and Arc Hydro Tool) specifically developed for watershed characterization. These are used to derive watershed boundaries, stream network and order, and compute morphometric parameters discussed in the physical characterization. The remote sensing part covers topics on satellite image pre-processing, derivation of vegetation indices, image classification by land cover type, and multi-temporal change detection.

Two additional topics are included in this manual: vulnerability assessment to landslides and floods. These topics are complementary to the Ecosystems Research and Development Bureau’s (ERDB) Manual on Vulnerability Assessment of Watershed. The landslide vulnerability exercise uses a modified version of ERDB’s landslide vulnerability criteria and processed through ArcGIS™ ModelBuilder. The flood vulnerability exercise uses the modeling approach and processed through ArcGIS™, HEC-HMS, HEC-RAS, HEC-GeoHMS, and HEC-GeoRAS.

The methodologies in GIS present an advanced approach to delineation and characterization that was not used in previous characterization reports. For instance, watershed boundaries digitized manually from topographic maps before do not correspond to boundaries generated from Digital Elevation Models (DEM). The latter is presumed more accurate. A Digital Elevation Model (DEM) can also be used to generate stream networks and stream orders that are formerly done manually using topographic maps. Lastly, the topics in RS give additional information on the vegetative status of the watersheds.
Chapter 1: Physical Characterization
PHYSICAL FEATURES

INTRODUCTION

Watershed is a land area drained by a stream or fixed body of water and its tributaries having a common outlet for surface runoff (PD 705). Normally, its boundary or divide is delineated topographically, following the ridges in a landscape. However, its area can also be outlined based on the bedrock formation that impacts groundwater. This divide is called the phreatic. The difficulty of groundwater study and the convenience of using a contour map to outline the watershed boundary resulted to the use of the topographic divide instead of the phreatic divide. Inside a watershed, water is channeled through a network of tributaries. Depending on its surface area, a watershed can be classified as either small, medium, or large. Those that cover a great extent are referred to as river basins. The Cagayan River Basin in the north and the Agusan River Basin in the South exemplify this type. Due to vast coverage of some of these watersheds, it is divided into sub-watersheds. This is basically a watershed within a bigger watershed, delineated by isolating a tributary or network of tributaries, similar to demarcating the whole watershed.

The condition of the watershed is crucial in the overall health of ecosystems. In fact, even the economy is highly affected by what’s going on within a watershed. It is for this reason that its management should be given emphasis. In order to do so, a thorough understanding of its features, components, and behavior should be achieved. Some literatures refer to the management of watershed as the ridge-to-reef approach. This underlines that a watershed is composed of various interacting ecosystems from the upland to the lowland. In the headwater area is the forest ecosystem, and the typical outlet leads to the coastal/marine ecosystem. Somewhere in the middle lie the agro- and urban ecosystems. The overall goal of watershed management is to harmonize these ecosystems for the continuous provision of goods and services. Flood incidences and siltation of bodies of water are typical indicators of improperly managed watersheds. This normally is a result of the degradation of the forest ecosystem.

Managing watersheds is a difficult task. However, it is of help to know the very nature of the watershed that is to be managed. This is because watersheds behave differently and some of its behavior, e.g. peak flow, is just within its normal trend or pattern and not indicative of the alteration that is taking place within its area. This is similar to understanding baseline information prior to the application of a treatment in an experiment. In other words, not all flood incidences are the result of an impaired watershed condition. Similarly, not all landslides are due to lack of forest vegetation. These could be a result of the ruggedness of the watershed or an abnormal rain event.

This handout covers the physical component of watershed characterization. The objective of which is to discuss each parameter and how it affects the general behavior of the watershed. Towards the end, an example on how each parameter is calculated is provided. An exercise designed for practice calculations is also provided.

WATERSHED CHARACTERIZATION

The characterization of watershed covers the physical, biological, social and economic component of the watershed, as well as the determination of issues, vulnerability, issues and opportunities for development interventions. In general, it describes the very nature of the watershed and its components. The physical characterization typically
covers the morphometric features of the watershed, as well as the land use, geology, climate, hydrology and soils. The biological component pertains to the flora and fauna in the area. The social and economic components are normally integrated under the banner socio-economic, and provide details on demographic and other relevant information concerning the watershed occupants and other stakeholders. Only the physical characterization is covered in this module. The rest are discussed in separate modules.

Components of Physical Characterization

The Department of Environment and Natural Resources (DENR) issued Memorandum Circular 2008-05 (DENR MC 2008-05) identifying 10 components that should be described under the Physical Environment for watershed characterization. These are as follows:

1. Geophysical location
2. Topography/Geo-morphological features
3. Geology
4. Soil
5. Land classification/legal status of land
6. Land capability
7. Land use
8. Climate
9. Hydrology
10. Infrastructure

Of these components, the geomorphological features are given emphasis in this module, as it is normally what's lacking in numerous watershed management characterization/plan. Several literatures also call for the calculation of other morphometric parameters to describe the overall hydrologic features of the watershed. Besides, the other features are also easily incorporated through existing references and maps [e.g. Soil Survey Report from the Bureau of Soils and Water Management (BSWM) for the soil features and land capability]. The content of the description under each feature is also described in the DENR MC 2008-05.

Geo-morphometric Parameters

The geo-morphometric parameters describe the physical feature of the watershed, in terms of its ruggedness, overall shape, drainage qualities, and dissection. These features are included in the characterization since it impacts the quantity and rate of water coming out of the watershed. These are also indicative of the responsiveness of the watershed to rain events or its susceptibility to natural calamities like floods and erosion. Vincy, Rajan, and Pradeepkumar (2012) summarized the geo-morphometric parameters that can be calculated for a watershed (Table 1). It is categorized into three aspects: Areal, Relief, Linear.

It is important to note that not all of these parameters are calculated for a watershed, as some of these parameters are indicative of the same thing (e.g. circularity ratio vs. form factor, which both gives us information on the general shape of the watershed). It is however, a must that at least one of these similar indicative-parameters be reported in the watershed characterization. In general, the calculated parameters are the area, bifurcation ratio, form factor, relief ratio, slope, drainage density, and length of overland flow. These parameters are also the ones indicated in the DENR MC 2008-05.

In terms of area, the following classification is used based on size:
Form factor indicates the compactness of the watershed. A higher form factor means the watershed is circular in nature. A low form factor means it is elongated (Figure 1). A circular watershed means the rainwater received by the watershed will reach the outlet at the same time. In other words, it will bunch up at the outlet and could induce river swelling and eventually, flooding. An elongated watershed, on the other hand, will mean a longer time for rainwater to travel from the headwater to the outlet, allowing the tributaries to channel and release the water "slowly."

![Figure 1. Sample form factor values and indicative basin shape. (Source: http://classes.warnercnr.colostate.edu/g454/files/2011/01/Lab-4-Basins.pdf)](http://classes.warnercnr.colostate.edu/g454/files/2011/01/Lab-4-Basins.pdf)

Relief ratio is the quotient of the basin relief (the difference in the highest and lowest elevation) and the watershed length. It indicates the slope of the watershed. A higher relief ratio means higher peak flow and faster movement of storm water to the outlet.

The drainage density is the ratio between the total length of the stream and the watershed area. It tells us the length of a stream on a per unit area basis. Low drainage densities are often associated with widely spaced streams due to the presence of less resistant materials (lithologies or rock types), or those with high infiltration capacities. A high drainage density indicates the watershed is heavily dissected. This could mean the watershed is prone to erosion.

The length of overland flow indicates the distance travelled by runoff water before it reaches a tributary or merges to form a concentrated flow. A longer overland flow means fewer propensities for flooding since it will take a long time for it to reach tributaries and cause it to swell.
Table 1. The geo-morphometric parameters that can be calculated for a watershed to describe its physical features (Modified from Vincy, Rajan, and Pradeepkumar, 2012).

<table>
<thead>
<tr>
<th>Morphometric parameter</th>
<th>Formula</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Linear aspects</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Stream order (u)</td>
<td></td>
<td>Hierarchical rank</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>2. Stream length (L_u)</td>
<td></td>
<td>Length of the major stream</td>
<td>km</td>
</tr>
<tr>
<td>3. Total stream length (TL_u)</td>
<td>L_sm = L_u/N_u</td>
<td>Sum of all L_u</td>
<td>km</td>
</tr>
<tr>
<td>4. Mean stream length (L_sm)</td>
<td>L_u = Total stream length of order ‘u’</td>
<td>km</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N_u = Total number of stream segments of order ‘u’</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Perimeter (P)</td>
<td></td>
<td></td>
<td>km</td>
</tr>
<tr>
<td>6. Stream length ratio (R_I)</td>
<td>R_i = L_u/L_u-1</td>
<td>L_u = Total stream length of order ‘u’</td>
<td>Dimensionless</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L_u-1 = Total stream length of its next lower order</td>
<td></td>
</tr>
<tr>
<td>7. Order length ratio (O_L)</td>
<td>O_L = L_u/L_u+1</td>
<td>L_u = Total stream length of order ‘u’</td>
<td>Dimensionless</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L_u+1 = Total stream length of its next higher order</td>
<td></td>
</tr>
<tr>
<td>8. Bifurcation ratio (R_b)</td>
<td>R_b = N_u/N_u+1</td>
<td>N_u = Total number of stream segments of order ‘u’</td>
<td>Dimensionless</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N_u+1 = Number of stream segments of the next higher order</td>
<td></td>
</tr>
<tr>
<td>9. Mean bifurcation ratio</td>
<td>R_b,m</td>
<td>Average of bifurcation ratios of all orders</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>10. Basin length (L_b)</td>
<td></td>
<td></td>
<td>km</td>
</tr>
<tr>
<td>11. Rho coefficient (ρ)</td>
<td>ρ = R_i/R_b</td>
<td>Ratio of stream length ratio and bifurcation ratio</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>Morphometric parameter</td>
<td>Formula</td>
<td>Description</td>
<td>Units</td>
</tr>
<tr>
<td>------------------------------------------------</td>
<td>--------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>-------------</td>
</tr>
<tr>
<td><strong>B. Relief aspects</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. Basin relief (B_h)</td>
<td>B_h = H-h</td>
<td>Vertical distance between the lowest and highest points</td>
<td></td>
</tr>
<tr>
<td>13. Relief ratio (R_r)</td>
<td>R_r = B_h/L_b</td>
<td>Ratio of basin relief and length</td>
<td>Dimensionless</td>
</tr>
<tr>
<td>14. Ruggedness number (R_n)</td>
<td>R_n = B_h \times D_d</td>
<td>B_h = Basin relief</td>
<td>Dimensionless</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D_d = Drainage density</td>
<td></td>
</tr>
<tr>
<td>15. Melton’s Ruggedness number (MR_n)</td>
<td>MR_n = B_h/A^{0.5}</td>
<td>B_h = Basin relief</td>
<td>Dimensionless</td>
</tr>
<tr>
<td></td>
<td></td>
<td>A = Area of watershed</td>
<td></td>
</tr>
<tr>
<td>16. Slope (S)</td>
<td>S = (ΔE/L)\times100%</td>
<td>ΔE = Elev_{max} – Elev_{min} along the principal flow path</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L = Length of the watershed along the main stream (by measuring the valley</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>length and not meandering curve)</td>
<td></td>
</tr>
<tr>
<td><strong>C. Areal aspects</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17. Area (A)</td>
<td></td>
<td></td>
<td>km^2</td>
</tr>
<tr>
<td>18. Drainage density (D_d)</td>
<td>D_d = T_L_u/A</td>
<td>Ratio of total stream length and area</td>
<td>km.km^{-2}</td>
</tr>
<tr>
<td>19. Constant of channel maintenance</td>
<td>C = 1/D_d</td>
<td>Inverse of drainage density</td>
<td>km.km^{-2}</td>
</tr>
<tr>
<td>20. Circularity ratio (R_c)</td>
<td>R_c = (4nA)/P^2</td>
<td>A = Area of watershed</td>
<td>Dimensionless</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P = Perimeter</td>
<td></td>
</tr>
<tr>
<td>21. Elongation ratio (R_e)</td>
<td>R_e = (2/L_b)[(A/n)^{0.5}]</td>
<td>A = Area of watershed</td>
<td>Dimensionless</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L_b = Basin length</td>
<td></td>
</tr>
<tr>
<td>22. Compactness constant (C_c)</td>
<td>C_c = P/(4nA)^{0.5}</td>
<td>A = Area of watershed</td>
<td>km</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P = Perimeter</td>
<td></td>
</tr>
<tr>
<td>Morphometric parameter</td>
<td>Formula</td>
<td>Description</td>
<td>Units</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>--------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>23. Drainage texture (R_t)</td>
<td>$R_t = D_d \times F_s$</td>
<td>The product of drainage density and stream frequency</td>
<td>km</td>
</tr>
<tr>
<td>24. Stream frequency (F_s)</td>
<td>$F_s = N/A$</td>
<td>Ratio between the total number of streams and area</td>
<td>km$^{-2}$</td>
</tr>
</tbody>
</table>
| 25. Form factor (F_t)       | $F_t = A/L_b^2$          | $A = $ Area of watershed  
$L_b = $ Basin length                  | Dimensionless |
| 26. Texture ratio (T)       | $T = N1/P$               | Ratio of the total number of 1$^{st}$ order stream and perimeter            | km$^{-1}$ |
| 27. Shape index (S_w)       | $S_w = L^2/A$            | $L = $ Length of the watershed along the main stream (by measuring the valley length and not meandering curve) | Dimensionless |
| 28. Shape factor (S_r)      | $S_r = 1/F_t$            | Reciprocal form factor                                                      | Dimensionless |
| 29. Length of overland flow (L_g) | $L_g = 1/(2D_d)$       | $D_d = $ Drainage density                                                   | km     |
| 30. Lemniscate ratio (K)    | $K = L_b^2/4A$           | $L_b = $ Basin length  
$A = $ Area of watershed                  | Dimensionless |
SAMPLE DATA/CALCULATIONS

1.

A low bifurcation ratio means a higher risk of flooding. Values ranging from 3 to 5 indicate a natural drainage system that formed in a homogeneous rock.

Source: USGS
2. The following information were derived by Eze and Efiong (2010) for the Calabar River Basin, Nigeria:

<table>
<thead>
<tr>
<th>Drainage basin parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basin order</td>
<td>5</td>
</tr>
<tr>
<td>Total number of streams</td>
<td>223</td>
</tr>
<tr>
<td>Total stream length</td>
<td>516.34 km</td>
</tr>
<tr>
<td>Length of overland flow</td>
<td>1.47 m</td>
</tr>
<tr>
<td>Axial width</td>
<td>43.00 km</td>
</tr>
<tr>
<td>Axial length</td>
<td>62.00 km</td>
</tr>
<tr>
<td>Basin area</td>
<td>1,514.00 km²</td>
</tr>
<tr>
<td>Basin perimeter</td>
<td>235.00 km</td>
</tr>
<tr>
<td>Relative perimeter</td>
<td>36.48 km</td>
</tr>
<tr>
<td>Circularity ratio</td>
<td>0.34</td>
</tr>
<tr>
<td>Elongation ratio</td>
<td>0.64</td>
</tr>
<tr>
<td>Form factor</td>
<td>0.34</td>
</tr>
<tr>
<td>Compaction coefficient</td>
<td>1.70</td>
</tr>
<tr>
<td>Highest basin elevation</td>
<td>0.98 km</td>
</tr>
<tr>
<td>Lowest basin elevation</td>
<td>0.015 km</td>
</tr>
<tr>
<td>Relief ratio</td>
<td>0.014</td>
</tr>
<tr>
<td>Average bifurcation ratio</td>
<td>3.57</td>
</tr>
<tr>
<td>Drainage density</td>
<td>0.34 km⁻¹</td>
</tr>
<tr>
<td>Stream frequency</td>
<td>0.15 km⁻¹</td>
</tr>
<tr>
<td>Drainage intensity</td>
<td>0.05</td>
</tr>
<tr>
<td>Longest dimension parallel to the principal drainage line</td>
<td>68.00 km</td>
</tr>
</tbody>
</table>

3. The following information were reported for the one of the Energy Development Corporation (EDC)-managed focus watersheds in Negros Occidental:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>2,874 ha</td>
</tr>
<tr>
<td>Elongation ratio</td>
<td>0.4</td>
</tr>
<tr>
<td>Maximum elevation</td>
<td>1,798 m</td>
</tr>
<tr>
<td>Minimum elevation</td>
<td>63</td>
</tr>
<tr>
<td>Relief ratio</td>
<td>0.1</td>
</tr>
<tr>
<td>Basin length</td>
<td>14,760 m</td>
</tr>
<tr>
<td>Mean elevation</td>
<td>481 masl</td>
</tr>
<tr>
<td>Mean slope</td>
<td>0.20</td>
</tr>
<tr>
<td>Drainage density</td>
<td>10.1 m ha⁻¹</td>
</tr>
<tr>
<td>Stream density</td>
<td>0.01 ha⁻¹</td>
</tr>
<tr>
<td>Length of overland flow</td>
<td>0.05 m</td>
</tr>
</tbody>
</table>
EXERCISE

1. Given the following information for a watershed (hypothetical):

   - **Area** = 150 km\(^2\)
   - **Perimeter** = 30 km
   - **Length of the watershed** = 15 km
   - **Elev\(_{\text{max}}\)** = 1,200 masl
   - **Elev\(_{\text{min}}\)** = 5 masl
   - No. of 1\(^{\text{st}}\) order stream = 8, 2\(^{\text{nd}}\) order stream = 3, 3\(^{\text{rd}}\) order stream = 1
   - **Total stream length** = 15 km

   Calculate:
   a. Shape factor
   b. Circularity ratio
   c. Elongation ratio
   d. Relief ratio
   e. Drainage density (in km/km\(^2\))
   f. Bifurcation ratio
   g. Length of overland flow

2. Using the figure below, determine the watershed’s bifurcation ratio and stream frequency. Assume an area of 1,000 km\(^2\).
SOLUTION

1. a. Shape factor ($S_f$) = $1/F_f$, where $F_f = A/L_b^2 = 150 \text{ km}^2/(15\text{ km})^2 = 0.67$. Therefore, $S_f = 1/0.67 = 1.49$

   b. Drainage density ($D_d$) = $TL_u/A = 15\text{ km}/150\text{ km}^2 = 0.1 \text{ km/km}^2$

   c. Circularity ratio ($R_c$) = $(4nA)/P^2 = 4n150\text{ km}^2/(30\text{ km})^2 = 2.09$

   d. Elongation ratio ($R_e$) = $2/L_b[(A/\pi)^{0.5}] = (2/15)[(150\text{ km}^2/\pi)^{0.5}] = 0.92$

   e. Relief ratio ($R_r$) = $B_h/L_b = (1.2\text{ km}-0.005\text{ km})/15\text{ km} = 0.08$

   f. Bifurcation ratio = $8/3 = 2.7$
      
      $= 3/1 = 3.0$

      Average $2.9$

   g. Length of overland flow ($L_o$) = $1/(2D_o) = 1/(2\times0.1) = 5 \text{ km}$

2.

$1^{st}$ order = 24

$2^{nd}$ order = 10

$3^{rd}$ order = 1

Bifurcation ratio = $24/10 = 2.4$

$= 10/1 = 10.0$

Average $6.2$
WATERSHED INSTRUMENTATION

INTRODUCTION

Watersheds are primarily known for supplying water. However, it is important to point out that several goods and services may come out of it. Its headwater areas are normally occupied by forest vegetation that can be harvested sustainably. Similarly, mineral resources may be present that can be extracted responsibly without impairing the overall function of the watershed. Other than these, the land/soil in itself is a resource that should be given emphasis. Most of the problems we experienced right now are due to lack of concern to soil resources leading to its erosion. Not to be left behind are the other biological resources that can be found in a watershed. These could either be other plant forms or faunal component that play significant role in the overall health of various ecosystems.

Unfortunately, majority of the watersheds in the country are impaired. Problems that are associated with this condition come in a cyclical pattern: flooding during rainy months, droughts during dry periods. This is coupled with other consequences we normally hear in news or read in the newspaper, like the loss of productivity of its land, difficulty in river navigation, siltation of dams, landslides, etc. These scenarios are most likely the result of poor watershed management that arises due to political scenarios, socio-economic conditions, and insufficient understanding of the watershed concept.

Knowing how a watershed behaves is crucial to its management, especially if we want to assess how it responds to alterations of its components (e.g. land use) or management strategy. For this purpose, we normally make use of the water yield and quality as indicators of this condition. Just like a doctor who typically asks for blood chemistry when a patient comes in with a high fever, watershed managers can gauge watershed health through the symptoms indicated in its water component. This could either be a declining water yield or the deterioration of water quality. Thereafter, a causation analysis can be done to identify factors that contributed to the resulting condition, which eventually should lead to intervention. Again, this is very much similar to when a doctor prescribes a medicine to cure a condition that was diagnosed through its symptoms.

How do we then determine water yield and quality from a watershed? When do we say that it actually changes through time as a result of the changing condition in the watershed? Both of these questions can be answered through watershed instrumentation, where monitoring stations will be placed in strategic locations (normally the outlet/s) within the watershed. The earlier this can be done for a watershed, the better, as baseline information/trend should first be established. These data will be the bases of comparison for succeeding years.

This handout/lecture material discusses the basic of watershed instrumentation. Some of the hydrologic processes intended to support the water balance concept is presented in the beginning. The middle part tackles the different techniques by which water yield can be measured, while the latter part covers some of the water quality parameters that can be monitored to assess water health.

HYDROLOGIC PROCESSES

The hydrologic cycle is an integral part of understanding the watershed. Hydrologic cycle refers to the natural sequence through which water passes into the atmosphere as water
vapor, precipitates to the earth and returns to the atmosphere through evaporation. The amount of water that comes in and out of the watershed is a result of these processes.

**Precipitation**
Precipitation refers to any moisture that reaches the earth surface. This includes rain, snow, fog, dew, and hail. Obviously, the most common form of precipitation in the country is rain. The amount of precipitation, measured using a rain gauge, is usually the one of interests to a hydrologist. Using this data and the area of the watershed, he/she can calculate the volume of water that should come out of the watershed.

**Infiltration**
Infiltration refers to the entry of water in the soil column. Once water is in the soil, the downward movement of water is referred to as percolation. This process is important in recharging groundwater. Groundwater feeds perennial rivers in a watershed.

**Runoff**
Runoff or overland flow refers to the component of the precipitation that flows on the land surface. It is produced when rainfall intensity exceeds the soil infiltration rate or when the soil becomes saturated with water (saturation overland flow) such that it can no longer absorb additional precipitation. The production of runoff in a watershed highly impacts its responsiveness to storm events as water travels faster to streams quicker than perhaps what it can channel out, causing the river to swell and overflow and eventually flooding nearby areas.

**Evapotranspiration**
Evapotranspiration refers to the combined evaporation and transpiration processes. Both refer to the loss of moisture in vapor form in the atmosphere, the former from any surface, while the latter through plant stomates or lenticels. This component of the precipitation is measured using established equations (e.g., Penman) or through instrumentation (evaporation pan).

**Water balance**
The term water balance simply refers to the partitioning of precipitation into its various components. It is simply determining how much of the precipitation actually became runoff, helps in the groundwater recharge, or evaporated through evapotranspiration. In equation form, it is presented as:

\[ P = Q + ET + \Delta S \]

Where:
- \( P \) = Precipitation
- \( Q \) = Stream flow
- \( ET \) = Evapotranspiration
- \( \Delta S \) = Change in soil or bedrock storage

The water balance equation is useful in understanding the movement of water in a watershed. Similarly, learning how the precipitation is partitioned into the different components (e.g., % of water that becomes part of stream flow) in a watershed can tell us the characteristic of the watershed. How these components changes with the alteration of the land use or management strategy in a watershed will also tell us of its effectiveness.
Stream flow measurement/Stream gauging

The determination of water yield from a watershed requires either an instantaneous measurement of stream flow from its main tributary or setting up instrumentation that will record and monitor stage height for long term purposes. Obviously, the data that will be gathered through this is also one of the inputs needed in the water balance equation.

STREAM INSTRUMENTATION

The choice for stream gauging is dependent on the size of the stream to be monitored. Some of the choices are as follows:

a. Weir

Weir is a structure that forces water to flow through and over a simple geometric cross-section for which the flow hydraulics are known (Figure 1). The notch is either triangular (V-notch) or rectangular in shape. A corresponding equation is used for each shape.

![Figure 1. A 90° V-notch weir installed in a gully to measure storm flow volume during rain events.](image)

b. Flume

Flume is similar to a weir in a way that it forces water in a geometric cross-section. However, this device has an extension that converts turbulent flow to laminar flow prior to passing in the geometric cross-section. Flumes also come in various shapes and sizes. The most popular are the H-flume and the Parshall flume (Figure 2).
Figure 2. An H flume (a) and Parshall flume (b), for streamflow measurement. (Source: Hudson, 1993)

c. Stage height recorder

Water level or stage height recorders are needed since water depth is one of the parameters needed to calculate watershed discharge. In some cases, a calibrated meter is placed in the side of weirs/flumes or any other device and a regular personnel records the stage height at various times in a day. Nowadays, sophisticated instruments with built-in recorders are placed beside these devices for continuous recording of stage height at certain time interval (Figure 3). Some of these instruments also have data transmittal capability to send data automatically to a base station for real-time monitoring of water level in a watershed. This is quite useful especially in areas that are prone to flashfloods, where a significant increase in stage height should trigger an early warning system/device to warn the populace.

Figure 3. A pressure transducer for monitoring water level in a well or stream. (Source: http://www.inmtn.com/HOBO_Water_Level_Logger.html)
d. Flow meter

A flow meter is a device that measures the rate of water flow in a tributary. The flow rate, coupled with the stage height, determines stream discharge. The determination of the rate of water flow need not be sophisticated. It should however, be accurate. Some crude techniques for measuring flow rate include the use of a floating material, like a “ping pong” ball or a dye. In both techniques, a relative straight stream section of known distance is selected and the material is drop on the upstream end and timed until it reaches the other end in the downstream section. A more accurate method is the use of a flow meter (Figure 4). If properly used and calibrated, it can give better stream flow rates. Old models make use of cups or propeller to measure rate. Nowadays, the Doppler technology is also used for measuring this value (Figure 5). During measurements, one reading is taken if the river is shallow. Two measurements, at the 0.2 and 0.8 section of the total depth, are determined for deep streams.

![Figure 4. Old types of flow meter for measuring stream flow rate. (Source: Hudson, 1993)](http://water.usgs.gov/edu/images/streamflow2-4.jpg)

![Figure 5. Acoustic Doppler Velocimeter for measuring stream flow rate. (Source: http://water.usgs.gov/edu/images/streamflow2-4.jpg)]
**Watershed Discharge**

A watershed discharge is calculated using the formula:

\[
Q = VA
\]

Where

- \( Q \) = Discharge (m\(^3\) s\(^{-1}\))
- \( A \) = Stream cross sectional area (m\(^2\))
- \( V \) = Stream velocity (m s\(^{-1}\))

![Figure 6. Determination of stream discharge from a stream. (Source: http://water.usgs.gov/edu/images/streamflow2-1.gif)](http://water.usgs.gov/edu/images/streamflow2-1.gif)

**Rating Curve**

A rating curve is a graph showing the relationship between stage height and stream discharge (Figure 7). This graph is established so that the tedious measurement of stream flow rate is avoided. Using the prepared graph for a watershed, a discharge can be determined at a particular stage height, a parameter that is easy to measure from the stream. To develop a rating curve, several measurements of discharge (flow rate and stage height) have to be performed at various stage heights in order to develop the curve. The range should cover low flow and high flow volume. In some instances, even the sediment concentration at various water levels is incorporated in the rating curve (sediment rating curve). For ease of measurement and if applicable, it is recommended to install weirs or flume, where equations for determining stream discharge at different stages have been established.
Figure 7. An example of a rating curve, a graph showing the relationship between stage height and stream discharge. (Source: Hudson, 1993)

WATER QUALITY

Water quality refers to the overall characteristics of water, covering the biological, physical, and chemical properties. The state of water is very important in a watershed as it impacts its potential use, the biological resources that are dependent on it, and the amount of processing it needs to enhance its suitability for a certain use. The water quality is also indicative of the condition of the watershed. In some instances, contaminated water is a result of point sources of pollution, e.g., piggeries that directly dump its wastewater to the river. In other cases, the source of contamination is unknown, and is referred to as non-point sources. Regardless, both conditions should raise a red flag that should alert watershed managers and put them into action.

The following are the parameters that determine water quality:

Physical components

a. Total suspended solids (TSS) - a measure of the concentration of suspended sediments in water. An indicator of the degree of erosion that is taking place or has taken place in the watershed. Measured through water sampling and filtration technique.
b. Temperature – the hotness or coldness of water in the stream. It can affect biological organisms directly and indirectly. Some aquatic organisms are sensitive to temperature during the breeding stage. Temperature affects the amount of dissolved oxygen in water. Measured using portable multi-parameter instruments.
c. Turbidity – refers to the clarity of water. It impacts the amount of sunlight a stream receives. Similarly, it determines the depth the sunlight reaches. Turbidity is measured using a Secchi disk or a turbidity meter.

Chemical components

a. pH – a measure of the alkalinity or acidity of water. Highly impacts aquatic organisms and solubility of nutrients in water. Measured using a pH meter.
b. **Dissolved oxygen (DO)** – amount of oxygen present in water. It affects aquatic organisms from micro to macro level. Measured using a DO meter.

c. **Biological oxygen demand (BOD)** – a measure of the amount of oxygen bacteria will consume while decomposing organic matter under aerobic conditions. It affects the amount of DO in water. Measured by taking samples in the field and analyzed in the laboratory.

d. **Dissolved solids** – refers to the amount of dissolved nutrients in water, as total dissolved solids (TDS). Measured using a conductivity meter.

e. **Nutrient concentration/toxins** – refers to the presence or absence of a chemical contaminant, one that exceeds the safe level. It is of great significance in determining the usefulness of water and the health of the aquatic ecosystem. Measured by taking samples in the field and analyzed in the laboratory.

**Biological components**

a. **Pathogens** – refers to the biological contaminant that poses serious health concern. Measured by analyzing fecal coliform count, specifically *Escherichia coli* species, from the water sample.

b. **Exotic species** – refers to non-native aquatic organisms that were introduced in the river/lake system. Normally of concern since it creates havoc to the overall health of the aquatic ecosystem.

**Water samplers and water quality meters**

For long term watershed monitoring like a watershed experiment, automatic water samplers and water quality probes are installed. Popular brands include the ISCO and the Global Water samplers (Figure 8). These equipment are capable of collecting samples at the user’s preferred amount and time interval. Several water sample bottles are also built-in to facilitate collection. Normally, the user collects and replaces each bottle during site visit. Multi-parameter water quality probes and flow/stage height meter can also be attached to its data recorder for monitoring purposes. This device can also be set to collect data at a specified time interval.

SAMPLE PROBLEMS IN WATER BALANCE

1. a. Complete the root zone water budget table.
   Crop factor = 1.0; Available water = 10 cm

<table>
<thead>
<tr>
<th></th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>10.0</td>
<td>10.0</td>
<td>8.0</td>
<td>7.2</td>
<td>10</td>
</tr>
<tr>
<td>Ks</td>
<td>1.0</td>
<td>1.0</td>
<td>0.8</td>
<td>0.72</td>
<td>1</td>
</tr>
<tr>
<td>PET</td>
<td>0.2</td>
<td>2.0</td>
<td>1.0</td>
<td>0.2</td>
<td>1.5</td>
</tr>
<tr>
<td>AET</td>
<td>0.2</td>
<td>2.0</td>
<td>0.8</td>
<td>0.14</td>
<td>1.5</td>
</tr>
<tr>
<td>F′</td>
<td>9.8</td>
<td>8.0</td>
<td>7.2</td>
<td>7.06</td>
<td>8.5</td>
</tr>
<tr>
<td>P</td>
<td>5.0</td>
<td>0.0</td>
<td>0.0</td>
<td>20.0</td>
<td>0.0</td>
</tr>
<tr>
<td>F″</td>
<td>14.8</td>
<td>8.0</td>
<td>7.2</td>
<td>27.06</td>
<td>8.5</td>
</tr>
<tr>
<td>Q</td>
<td>4.8</td>
<td>0.0</td>
<td>0.0</td>
<td>17.06</td>
<td>0.0</td>
</tr>
<tr>
<td>F‴</td>
<td>10.0</td>
<td>8.0</td>
<td>7.2</td>
<td>10</td>
<td>8.5</td>
</tr>
</tbody>
</table>

\[ K_s = \frac{F}{S}, \text{ where } S = FC-PWP \]
\[ \text{AET} = K_c K_s \text{PET}, \text{ where } K_c = \text{Crop factor} \]
\[ F' = F - \text{AET} \]
\[ F'' = F' + P \]
\[ Q \Rightarrow \text{if } F'' > S, \text{ then } F'' - S; \text{ if } F'' < S \]
\[ F‴ = F'' - Q \]

b. What fraction of the week’s rainfall was converted to runoff?

\[ \%\text{Runoff} = \left(\Sigma \text{runoff}/\Sigma \text{precipitation}\right)100\% \]
\[ = \left(\frac{21.86}{25}\right)100\% \]
\[ = 87.4\% \]

2. Given the following information:
   Watershed area = 10,000 ha
   Annual rainfall = 3,000 mm
   Mean annual flow = 4.5 m³ sec⁻¹

Calculate the average annual evapotranspiration in cm yr⁻¹.

Step 1. Determine the volume of water coming out of a watershed
\[ = (4.5 \text{ m}^3 \text{ s}^{-1})(3600 \text{ s hr}^{-1})(24 \text{ hr day}^{-1})(365 \text{ days yr}^{-1}) = 141,912,000 \text{ m}^3 \text{ yr}^{-1} \]

Step 2. Divide the volume by the area of the watershed to get runoff (R) depth
\[ = (141,912,000 \text{ m}^3 \text{ yr}^{-1})/\left[10,000 \text{ ha} \left(10,000 \text{ m}^2 \text{ ha}^{-1}\right)\right] = 1.41 \text{ m} \]

Step 3. Calculate ET = P – R
\[ = 3.0 \text{ m} - 1.41 \text{ m} = 1.59 \text{ m} \]

D is the depth of the stream at the mid-point of each section.
EXERCISE

Field measurement of stream flow/discharge and water quality (Refer to Figure 6).

Procedure

1. Select a stream cross-section. It should have at least 10 m of relatively straight upstream section prior to the point of measurement. Likewise, it should be as close as possible to the point of instrumentation.
2. Measure the stream width.
3. Divide stream width into 10 sections (less if narrow, more if wide). At each interval, measure depth of water and stream flow rate. The depth of water is measured from stream bed to water level. Use the flow meter to determine stream flow rate. Take one reading if the stream is shallow. Otherwise, take two readings, one at the 0.2 mark of the depth and the other one at the 0.8 mark (e.g. if depth is 2 m, the 0.2 and 0.8 mark will be at 0.4m and 1.6m from the bottom). All readings should be taken at the downstream side of the transect. This is to avoid errors in measurement due to the blockade and turbulence created by the measurer.
4. Calculate cross-section area and discharge in each section. Take the sum to determine stream discharge (See sample table above).
5. Using the portable multi-parameter meter, take the water pH, DO, turbidity, and conductivity. Compare your results to a bottled water reading.
Chapter 2:
Biological Characterization
METHODS AND TECHNIQUES OF FAUNAL ASSESSMENT

INTRODUCTION

Useful and more accurate tools for assessment and monitoring population and habitat trends are necessary to respond to existing and emerging threats to biodiversity, threatened species, and ecosystem function on our public lands. With proper design and analysis techniques, baseline biodiversity information and long-term monitoring of target species and landscapes can provide important insight into the responses of organisms and ecosystems to complex threats such as land-use change and climate change. Long-term datasets and protocol development help the resource managers to refine inventory and monitoring plans and develop management recommendations that are adaptable to changing environmental conditions and emerging threats.

Furthermore, effective conservation and management of faunal resources such as terrestrial vertebrate and invertebrate fauna requires knowledge of the distribution, abundance, and demography of individual species to evaluate alternative management scenarios. However, access to historic and current data is often hampered by an inadequate data base information system, that is, an interface between field observations and the tools necessary to compile and view these data.

How the abundance and distribution of animal populations change through time in response to management actions is one of the most common and challenging questions for researchers and managers. Reliable conclusions about relationships between populations and management actions are only possible if results of assessment and monitoring are credible and sufficient. A wide variety of cost-effective and reliable methods to inventory and monitor vertebrate species have been developed by researchers and scientists. These have been adopted as standard methods, both nationally and internationally.

KEY TERMS AND DEFINITIONS

**Sampling** – the process of selecting a number of individuals for a study in such a way that the individuals represent the larger group from which they are selected.

**Sample** – the representatives selected for a study whose characteristics exemplify the larger group from which they are selected.

**Inventory** – the process of making a detailed, itemized list, report, or record of things.

**Survey** – a process of estimating the population and determining the location or distribution of organisms and their habitats for the purpose of better managing the land.

**Census** – the procedure of systematically acquiring and recording information about the members of a given population.

**Census index** – refers to a count or ratio which is relative in some sense to the total number of animals in a specified population.

**Density** – refers to abundance or the number of individual per unit area.
**Systematic sampling** – the process of selecting individuals within the defined population from a list by taking every Kth individual (e.g. every third, etc.).

**Random sampling** – the process of selecting a sample that allows individual in the defined population to have an equal and independent chance of being selected for the sample.

**Stratification** – the procedure of grouping sampling units into categories or into different layers (strata) on the basis of a distinguishing characteristics (e.g. vegetation types, water availability, etc.).

**FAUNAL SAMPLING**

**Methods of Counting Wildlife**

There are three main methods for counting wildlife to determine population density: 1) **total counts**; 2) **sample counts**; and, 3) **index counts**. The choice of how to do the count, whether on foot, from a vehicle or from an aircraft, will depend on the species to be counted, the size and relief of the area, the resources available and the objective of the count.

1) **Total count** (also called direct count) aims to count all the animals in a specific area which is called the census unit (e.g. National Park, district or any locality). Total counts can only provide a minimum estimate of the total population size. Total counts should be used only when:

- the wildlife area is relatively small (under 10 km²) and oftentimes completely fenced, which means that no animals can enter or leave.
- a single species is being counted in a restricted area.

Other than in small or restricted areas, total counts are rarely used because: a) they only provide a minimum estimate; b) the level of precision cannot be measured; and, c) they are much more costly than sample counts.

2) **Sample count** aims to estimate the numbers of animals in the total area within the census units from the number counted in a smaller area (sample unit). Sample counts make two important assumptions: a) that all the animals in the sample area or unit are seen and accurately counted; and, that animals are spread evenly throughout the whole area or census unit for which the population is being estimated.

The extent, to which these assumptions are valid, is at the root of all the problems associated with counting wildlife. It is unlikely that all the animals in the sample area will be seen and counted or that animals will be evenly distributed throughout an area. For example we know that animals naturally congregate in areas of good habitat and where there is water. So careful planning has to take this uneven distribution into account if accurate and precise results are to be obtained.

**How are sample counts carried out?**

Initially the total area is divided up into blocks or transects, known as sample units (Figure 1). A selection of these transects is then searched and counted. The total
**population estimate** is found by multiplying the average number of animals in this sample of transects by the total number of transects across the total area.

![Map of transects and sampling units](image)

Figure 1. An example of a map showing an area divided into transects or sampling units.

In the example above, the sample area has been divided into 10 equal sized transects. Each dot represents an animal. A sample of four transects, in this case randomly chosen, gives a total of 42 animals counted. The average number of animals, over the four transects called the **sample mean**, is 10.5 animals. Therefore, over 10 transects the estimated total population is $10 \times 10.5$ or 105 animals.

As animals are never distributed evenly within the sample area, each transect differs in the number of animals it has. This means that a number of different total population estimates can be obtained, depending on which transects are actually counted. If a further set of 4 transects is counted, a number that is higher or lower than the true number of 105 animals present will emerge (see Figure 1). The greater the number of sample transects, the closer the estimate will be to the true number.

Three factors will determine how to carry out a sample survey: 1) the size of the wildlife area; 2) the kind of habitat; and, 3) the resources (human and financial) at your disposal. In very large wildlife areas (usually more than 1000 km²) like in open grassland, savannah or scrub, the only feasible method of undertaking a sample count is from an aircraft. Even though it is a sample count, it will be very expensive. Aerial surveys are reliable only for large dark-bodied animals such as elephant, buffalo and sable. It is impossible to get meaningful estimates for smaller antelope species or for predators because they are too small to be seen, or they are camouflaged or nocturnal and so cannot be seen easily. In areas where there is a strong element of community involvement in natural resource management, sample surveys may be carried out on foot.

**What factors affect the accuracy and precision of sample surveys?**

Anything which affects the distribution of animals or their likelihood of being counted will affect the accuracy of the sample:

- visibility of animals. The results of sample surveys are more accurate for large, dark bodied animals such as elephant, buffalo and sable, which are easily seen.
- type and state of habitat. It is more difficult to carry out sample surveys in hilly or mountainous areas. Sample surveys are normally carried out in the dry season when animals are easier to see because many of the trees will have lost their leaves.
- animal behavior. Sample surveys of animals found in large herds can be inaccurate, as they are not easily counted.
- distribution of habitat. Wildlife is usually found where there is food, water and shelter. So the survey needs to sample all types of habitat equally.

3) An **index count** method aims, by using a standard approach, to produce an indirect measurement of the status of the population in the total area. For an **index** to provide useful management information, data for it must be collected repeatedly over a period of time using exactly the same method/technique each time.

One of the types of method or **index** commonly used is an **index of abundance**. It gives an indication of the status of an animal population based on the numbers of animals seen per unit of time or distance, in a particular area over several seasons.

Sampling for index count method can be done through aerial surveys (use of aircrafts), road strip counts by land vehicle, and walked transects. In the Philippine setting and in terms of the size of wildlife in the country, the walked transects (Figure 2) is the more feasible one.

![Figure 2. An example of a transect walk method in sampling wildlife in a particular area.](image)

In a transect walk method (also called King Strip Census Method), observers traverse an established transects (although existing road/trail networks may be used) in the wildlife area under survey. This is applicable to many species of birds and animals which ‘flush’ or fly away when approached or sighted beyond a certain distance (critical distance). The observers count all the animals seen and measure their perpendicular distance from transect with a range finder and an angleometer. The sample area is calculated from the average distance that animals are seen from the position of the observer and the
total distance traversed. If the size of the area is known then the total population of wild animals in the area can be estimated (see sample population estimate below).

\[
\text{Pop'n Estimate} = \frac{AZ}{2LD}
\]

Where:
- \( A \) = area;
- \( Z \) = number of animals flushed;
- \( L \) = transect length;
- \( D \) = mean flushing distance.

**Why are index methods important?**

Index methods or indices are important for establishing trends in populations over time. As long as the method used to collect the data is consistent, indices are technically acceptable. The data for many indicators is relatively easy to collect and the costs are relatively low. So, index methods are affordable for park/resource managers and/or local government units.

**What are the advantages and disadvantages of a walked transect?**

The advantages of a walked transect are that:
- observers walking on foot through a wildlife area will probably see a greater range of species than any of the other methods,
- it is a relatively cheap method of estimating wildlife populations.
- it allows a high level of community participation.

**Other Techniques of Estimating Density or Population Size**

1) **Time-area counts or Point counts.** In this method, the observer counts all the animals (or species) seen in an area from one point over a limited observation period (usually 30-45 min to 1 hour). Observation is repeated at several sites until index stabilizes. The density is estimated with the given formula below:
Population Density Index \( (I) = I = \text{animals counted ÷ nR} \)

where: \( R \) = the observation radius (the point-distance from the observer to the predetermined limit of observation usually 25-30m)

2) **Capture-mark-recapture Method.** This is also known as Lincoln-Petersen method, considered as the most basic animal census procedure. A portion of the population is captured, marked, and released. Later, another portion is captured and the number of marked individuals within the sample is counted. Since the number of marked individuals within the second sample should be proportional to the number of marked individuals in the whole population, an estimate of the total population size can be obtained by dividing the number of marked individuals by the proportion of marked individuals in the second sample. Below are the formulae for estimating the population and the population range.

\[
\text{Population estimate} = \frac{N}{M} = \frac{(n+1)}{(m+1)} \\
\text{where: } N = \text{Population Estimate} \quad M = \text{marked individuals during the 1st sampling} \quad N = \text{number of individuals captured during the 2nd sampling} \quad M = \text{marked individuals from the 2nd sampling}
\]

\[
\text{Population range} = N_{95} = N ± (t\times SE); \quad \text{Student’s t-test tabular value: } t_{95\%} = 1.96; \quad t_{99\%} = 2.58 \\
\text{Standard Error} = SE = \text{square root of } \left[ \frac{M^2(n+1)(n-m)}{(m+1)^2(m+2)} \right]
\]

3) **Cumulative capture-curve or Leslie graph (removal method).** This involves capturing, marking, releasing (or kill) as many animal as possible, eventually 100% are marked (killed). Then, a cumulative capture curve (Leslie graph) is constructed to yield a population estimate. The regression correlation is being applied here.

\[
Y = a + bX \\
\text{where: } Y = \text{no. of animals caught} \quad X = \text{cumulative no. of animals}
\]

**STANDARD INVENTORY TECHNIQUES OF TERRESTRIAL VERTEBRATES**

**Transect Survey of Birds**

Standard line transects with routes measuring 1.5 to 2.0 kilometers are selected for each site. Each transect route are traversed by one observer traveling by foot at the speed of 15 minutes for every 250 meters of the transect line. Observations of transect counts of birds are employed for a minimum of 30-40 man-hours of observation time per site. Observers record the following information/ parameter in a standard data sheet. Whether it is observed by sight or call, the data includes the following notes: species name, number of individuals, perpendicular distance from the transect line (if possible), type of habitat, elevation, strata/vertical distance from the ground and other remarks (seen or heard or flying, perched, participation in mixed feeding parties, call, foraging behavior, seen singly, in pairs or in a flock, etc.).
Transect counts are done several times a day especially during early morning, (5:30 am to 10:00 am) and late afternoon (3:00 pm to 6:30 pm), thus completing a total of 40 hours of transect counts for each site. The methodology is based primarily on Danielsen et al, 1991; Mallari, 1992; Miranda, 1987 and Gonzalez, 1993. Identification of sighted birds are based on du Pont (1971) and King and Dickinson (1975). Nomenclature and classification of bird species are based on Sibley and Monroe (1990) and Dickinson et al. (1991).

For each species recorded during the transect counts are included for the computation of Bird Species Diversity (BSD) using the Shannon-Weiner function (H) and Simpson's Diversity Index, indices for species diversity.

Other basic information on the avian fauna are compared, such as endemism, number of migrant species/introduced species, feeding guilds, and the number of species with significant conservation status. Also Bird species richness (BSR), Bird species density (P), Equitability or Even Index (e = Peilou's formula, 1966) are used to determine the avifaunal composition of the study area.

**Mist-netting of Birds and Volant Mammals (Bats)**

Mist-nets are used to catch volant vertebrates such as birds and bats. Nets are kept open during the daytime (5:00 am to 6:00 pm) to catch birds (net-day) and left open at night (6:00 pm to 5:00 am) to capture nocturnal birds and bats. Mist-nets with an average mesh size of 36 mm and an average height of 2.5 meters in three lengths (6.0, 12.0 and 18.0 meters) are employed. Mist-netting stations composed of 15-25 nets (or 150-250 meters) are set-up in each site and operated for 3-5 consecutive nights and days.

Nets are set 2-3 meters high (as ground nets) while the bottom edges of the net are generally around a meter above the ground. Mist nets are strategically placed along the tops of ridges, near cliffs and in patches of thick forest growth with possible flyways of understory birds and bats. Occasionally sky nets are hoisted up with a pulley and some nylon rope on top tall tree trunks at a height of about 10-30 meters to capture upper canopy species. Nets are checked for captured birds every two hours (except during rainy days where it is checked more often) from sunrise to late afternoon. Nets are guarded for insectivorous bats (net-watching) from 6:00 to 8:00 p.m. and are checked again at 10:00 p.m., as well as 5:00 a.m. the next day.

Netted animals are carefully removed from the nets and placed in cloth bags to minimize stress prior to processing. Specimens captured are identified up to the species level (or subspecies level for birds, when possible). Standard biometric parameters are measured, i.e. for birds - bill length, wing cord, tarsus length; for bats - total length, forearm and ear lengths. Basic information (stated earlier for non-volant mammals) is noted on standard field catalogue sheets. All captured animals are given concentrated sugar water and/or juice. Then marked/banded and released after processing. Voucher specimens are sometimes collected for verification of some species in the laboratory.

Species richness, abundance, etc. are determined based on the computed number of captures per net-night (nocturnal species) and net-day (diurnal species) on every site (Netting success). Relative abundance by overall and individual species captured (individuals captured per net-night or net-day: one net-night/day is equivalent to
one net set for one night/day). Species effort curves similarly used for non-volant mammals are constructed to monitor and determine daily if the maximum number of species on the area has probably been recorded. This is indicated by a horizontal graph (Heaney, 1991).

**Trapping of Non-volant mammals**

Various traps consisting of National live traps, Sherman live traps, and Victor snap traps are operated for four to five trap-nights at each site. Traps are baited with either live annelid earthworms individually tied to the traps or pieces of freshly steamed coconut meat coated with peanut butter, as well as occasional viands of fish/meat. Most traps are set on the ground (80-90%), often along runways, near holes or among root tangles. Traps are spaced at five to ten meters intervals, while some of traps are strategically placed on tree branches along possible pathways for arboreal species. Position of the trap and condition of the microhabitat are noted. Traps are rebaited twice each day - during early morning and late afternoon. One trap-night is equivalent to one trap set for one night. An average of 300-400 trap-nights is set per study site.

Captured animals are identified up to the species level if possible. The body measurements and weight are taken using a measuring tape/foot ruler/dial calipers and Pesola spring scales, respectively and recorded on standard field catalogues. Other basic information is also noted in a field catalogue sheet, i.e. sex, age, habitat, present reproductive conditions, etc. Animals captured are marked and released except for voucher specimens of probable new records whose identification needs further verification in the laboratory (i.e. examination of cranial features and its measurements). Species richness, abundance, etc. are determined by the standard number of animals captured per 100 trap-nights (trapping success).

**Transect line for Herpetofauna**

A transect line similarly used for birds is selected for each site, and is traversed for observations on herpetofaunal species. Observations are limited to a maximum perpendicular distance of 25 meters on both sides of the transect. Transect lines are serviced during the day for diurnal reptiles and at night for nocturnal reptiles and amphibians. Species observed per transect count are noted, or collected for verification/identification up to the species level. Specimens are collected either by hand, insect nets, dip nets (for tadpoles), plastic bags, sticks, pit traps, snap traps, etc. Captured individuals are processed for body measurements (biometrics: such as snout-to-vent lengths, total length, hind limbs length, weight etc.) and other baseline information (similarly done for birds and mammals) and recorded on standard field catalogue sheets. They are later marked and released (except for voucher specimens). For identification, head scales, number of mid-dorsal scales (reptiles), extent of webbing and disk enlargement (amphibians), coloration, microhabitat, etc. are also noted. Habitats (e.g. stream, montane forest) and microhabitats (e.g. under rocks, leaf axils of palms and aroids, tree holes, forest litter) are recorded for each species collected.

The quadrant method (using small squares) is also employed in some of the sites where herpetofauna is expected. Some ten (10) quadrants measuring 1 x 1 meter are placed at randomly selected sites within an area covering 100 x 100 meters. These quadrants are thoroughly searched during the night especially for amphibians.
Species richness, abundance etc. are noted based on the transect counts, (similar to birds). Computations done for determining Bird Species Diversity are also used to determine the status of the herpetofaunal diversity on each site.
SAMPLE COMPUTATIONS

There is no computation for species composition, distribution or occurrence. For computation of density and diversity indices, see below.

<table>
<thead>
<tr>
<th>SPECIES</th>
<th>NO. INDIVIDUALS.</th>
<th>RELATIVE ABUNDANCE</th>
<th>SHANNON INDEX $p_i (\ln p_i)$</th>
<th>SIMPSON'S INDEX $(p_i^2)$</th>
<th>RELATIVE DENSITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mangrove Blue Flycatcher</td>
<td>2</td>
<td>0.091</td>
<td>-0.22</td>
<td>0.0083</td>
<td>8</td>
</tr>
<tr>
<td>Honey Buzzard</td>
<td>1</td>
<td>0.045</td>
<td>-0.14</td>
<td>0.0021</td>
<td>4</td>
</tr>
<tr>
<td>Fantail</td>
<td>2</td>
<td>0.091</td>
<td>-0.22</td>
<td>0.0083</td>
<td>8</td>
</tr>
<tr>
<td>Phil Bulbul</td>
<td>5</td>
<td>0.227</td>
<td>-0.34</td>
<td>0.0517</td>
<td>20</td>
</tr>
<tr>
<td>Nectarinia jugularis</td>
<td>3</td>
<td>0.136</td>
<td>-0.27</td>
<td>0.0186</td>
<td>12</td>
</tr>
<tr>
<td>Yellow Vented</td>
<td>2</td>
<td>0.091</td>
<td>-0.22</td>
<td>0.0083</td>
<td>8</td>
</tr>
<tr>
<td>Emerald Dove</td>
<td>1</td>
<td>0.045</td>
<td>-0.14</td>
<td>0.0021</td>
<td>4</td>
</tr>
<tr>
<td>Magpie Robin</td>
<td>1</td>
<td>0.045</td>
<td>-0.14</td>
<td>0.0021</td>
<td>4</td>
</tr>
<tr>
<td>Flowerpecker</td>
<td>1</td>
<td>0.045</td>
<td>-0.14</td>
<td>0.0021</td>
<td>4</td>
</tr>
<tr>
<td>Coucal</td>
<td>1</td>
<td>0.045</td>
<td>-0.14</td>
<td>0.0021</td>
<td>4</td>
</tr>
<tr>
<td>Dove</td>
<td>1</td>
<td>0.045</td>
<td>-0.14</td>
<td>0.0021</td>
<td>4</td>
</tr>
<tr>
<td>Shrike</td>
<td>2</td>
<td>0.091</td>
<td>-0.22</td>
<td>0.0083</td>
<td>8</td>
</tr>
<tr>
<td>TOTAL</td>
<td>22</td>
<td>1</td>
<td>-2.323</td>
<td>0.116</td>
<td>88</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BIODIVERSITY PARAMETERS</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Number of Species</td>
<td>12</td>
</tr>
<tr>
<td>Total Abundance</td>
<td>22</td>
</tr>
<tr>
<td>Shannon-Weiner Diversity Index</td>
<td>2.32</td>
</tr>
<tr>
<td>Shannon Evenness Index</td>
<td>0.94</td>
</tr>
<tr>
<td>Simpson Diversity Index</td>
<td>0.88</td>
</tr>
<tr>
<td>Simpson Dominance Index</td>
<td>0.116</td>
</tr>
</tbody>
</table>

RELATIVE ABUNDANCE = abundance (or number of individuals) of each species ÷ total abundance
SHANNON-WEINER INDEX = $H = -\Sigma p_i (\ln p_i)$
SIMPSON'S DOMINANCE INDEX = $C = \Sigma (p_i^2)$
SIMPSON'S DIVERSITY INDEX = 1 - C
RELATIVE DENSITY OF A SPECIES = abundance of the species ÷ (transect length X transect width)
### WILDLIFE/FAUNA SURVEY FORM

Sheet: ___________

Date: ______________________  Plot/Transect No.: __________

Name of Recorder: ___________________  Weather: __________________

Habitat Type: ___________________

<table>
<thead>
<tr>
<th>No.</th>
<th>Name of Species</th>
<th>Species Code</th>
<th>Animal Type Code</th>
<th>Animal Sign Code</th>
<th>Frequency</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>002</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>003</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>004</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>005</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>006</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>007</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>n</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Animal Type Code
1 = Amphibian
2 = Bird
3 = Mammal
4 = Reptile
5 = Fish
6 = Roosting site
7 = tracks

#### Animal Sign Code
1 = seen
2 = heard
3 = droppings
4 = burrow
5 = carcass
6 = Roosting site
7 = tracks

#### Weather Code
1 = sunny
2 = fair
3 = cloudy
4 = rainy
5 = stormy
6 = windy

**Remarks** (could be the following)
- Body/Plumage color
- Body size (small, medium, big, large)
- For birds: beak size or length (short, long & slender, broad); beak color (black, red, gray, etc.); beak shape (pointed, curve, straight, etc.); tail length (short, medium, long)
- Distinctive markings (body stripe, body spots, unique body parts, etc.)
- Sounds or calls (twiiit, coo-croo, hoot-hoot, etc.)
- Other observations
INTRODUCTION

Watershed characterization is an activity that involves the gathering of information describing the bio-physical and socio-economic condition of a watershed from the forest down to the coastal areas (as the case may be) and determination of issues, vulnerability, and opportunities for development interventions in order to have an understanding of and control over the various biological, physical and socio-economic processes in the watershed (DENR-ERDB, 2011). On the other hand vulnerability assessment is a profile discussing the relationship between natural and anthropogenic hazards and recipient subject (watershed). The vulnerability assessment identifies the strength and weaknesses of the recipient subject in relation to the identified hazard (DENR-ERDB, 2011).

A comprehensive watershed characterization and vulnerability assessment could provide a science-based evaluation on the magnitude of vulnerability of a watershed to natural and anthropogenic factors. It could also help determine the type of interventions as well as mitigating measures that should be conducted to ensure adequate protection from the environmental hazard, an essential component in the formulation of an integrated watershed management plan.

Watershed vulnerability to environmental hazards is dependent on two main attributes, namely bio-physical and anthropogenic forces. Both attributes can have aggravating or mitigating factors affecting the vulnerability of watershed resources.

Based on the watershed vulnerability assessment (WVA) manual developed by ERDB-DENR, the scope of watershed characterization and vulnerability assessment should cover any hazards posing threat to various watershed resources as presented below:

<table>
<thead>
<tr>
<th>Watershed Resource</th>
<th>Hazard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil/Geology</td>
<td>Erosion/Landslide</td>
</tr>
<tr>
<td>Vegetation</td>
<td>Fire/Deforestation/Biodiversity Loss</td>
</tr>
<tr>
<td>Water</td>
<td>Pollution/Flooding</td>
</tr>
<tr>
<td>Fauna</td>
<td>Poaching/Biodiversity Loss</td>
</tr>
<tr>
<td>Human</td>
<td>Flooding/Landslide</td>
</tr>
</tbody>
</table>

IMPORTANCE OF VEGETATION AND FLORA RESOURCES IN WVA
(after ERDB-DENR, 2011)

A. Vulnerability of watershed to landslides

1. Slope 30-35%
2. Soil morphology 10%
3. Climate 20%
4. Geology 20-25%
5. Vegetation Cover 10%
6. Anthropogenic factors 5-10%
B. Vulnerability of watershed to soil erosion

1. Slope 30-40%
2. Soil morphology 20%
3. Climate 20%
4. Vegetation Cover 20%
5. CROPPING MANAGEMENT PRACTICES (10-15%)

C. Vulnerability of watershed to forest/grass fire

<table>
<thead>
<tr>
<th>BIO-PHYSICAL FACTORS</th>
<th>CLASS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. VEGETATION (can be used in analysis of land use map)</td>
<td>1</td>
<td>Vegetation types negligibly favor the occurrence and spread of the fire in the watershed</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Vegetation types favor a minimal scale of occurrence and spread of fire in the watershed</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Vegetation types favor the occurrence and spread of fire but only in isolated areas of the watershed</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Vegetation types highly favor the occurrence and spread of fire in large parts of the watershed</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Vegetation types strongly favor the occurrence and spread of the fire in major parts of the watershed</td>
</tr>
</tbody>
</table>

D. Vulnerability of watershed to illegal cutting, deforestation and/or biodiversity loss

<table>
<thead>
<tr>
<th>BIO-PHYSICAL FACTORS</th>
<th>CLASS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. NATURE OF FOREST</td>
<td>1</td>
<td>Age and composition of tree species in the watershed make said species very lowly preferred and gathered illegally</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Age and composition of tree species in the watershed make said species lowly preferred and gathered illegally</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Age and composition of tree species in the watershed make said species moderately preferred and gathered illegally</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Age and composition of tree species in watershed make said species highly preferred and gathered illegally</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Age and composition of tree species in the watershed make said species very highly preferred and gathered illegally</td>
</tr>
</tbody>
</table>
### E. Vulnerability of watersheds to other resources degradation

<table>
<thead>
<tr>
<th>BIO-PHYSICAL FACTORS</th>
<th>CLASS</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. NATURE OF RESOURCES</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>The inherent characteristics of the resources do not make it easily degradable naturally or obtainable through illegal means</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>The inherent characteristics of the resources sometimes make it easily degradable naturally or obtainable through illegal means</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>The inherent characteristics of resources often make it easily degradable naturally or obtainable through illegal means</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>The inherent characteristics of the resources most often make it easily degradable naturally or obtainable through illegal means</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>The inherent characteristics of the resources most always make it easily degradable naturally or obtainable through illegal means</td>
</tr>
<tr>
<td><strong>B. RELATIVE IMPORTANCE OF THE RESOURCE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>The resource is not very important to the daily lives of the communities and gatherers</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>The resource is seldom important to the daily lives of the communities and gatherers</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>The resource is sometimes important to the daily lives of the communities and gatherers</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>The resource is often very important to the daily lives of the communities and gatherers</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>The resource is always very important to the daily lives of the communities and gatherers</td>
</tr>
<tr>
<td><strong>C. MARKET FOR ILLEGALLY GATHERED GOODS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>Market and prices do not favor illegal gathering and wanton exploitation of the resource</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Market and prices seldom favor illegal gathering and wanton exploitation of the resource</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Market and prices sometimes favor illegal gathering and wanton exploitation of the resource</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Market and prices often favor illegal gathering and wanton exploitation of the resource</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Market and prices always favor illegal gathering and wanton exploitation of the resource</td>
</tr>
</tbody>
</table>
VEGETATION/FLORA CHARACTERIZATION

A. **Vegetation and Forest Formations**

The natural vegetation of the Philippine Islands is generally a mosaic of different kinds of forests commonly known as forest formations (Whitmore 1984). Following the scheme and nomenclature used by Whitmore (1984), the primary vegetation may be divided into 12 types, such forest formations can be recognized elsewhere in Southeast Asia on the basis of their structure and physiognomy, but there could be substantial differences in species composition.

1. **Mangrove forest**

This formation occurs along clayish seashores and in the tidal zones in river estuaries. It can be bordered at its inland side by old shorelines of low hills, by tidal freshwater swamp or more or less sandy transition forest. Along its borders on the lateral side, it merges gradually into the beach formation.

The mangrove forest is a complex and unique community of medium to large-sized trees, shrubs, vines and palms, oddly thriving with luxuriant growth in the least inviting habitats which have the barest and limited conditions for the growth and survival of higher plant life. It is a very peculiar type of forest essentially occurring within the intertidal zones (between high and low tide levels) of sheltered tidal flats, coves, bays and estuarine areas, which sometimes extends so many kilometers inland along the banks of the upper stretches of streams and rivers where the water is brackish, along the coast of tropical and subtropical regions.

Mangroves of large and contiguous extent are found along the Northern coast of Panay Island in Capiz and Aklan; along the coastal areas of San Juanico Strait, Janabas Channel, Masqueda Bay, Carigara Bay, and Biliran Island in Samar and Leyte; between Puerto Princesa to Aborlan Coastal area fronting Sulu Sea. Bahili vicinity Oyster Inlet, Malampaya Sound and parts of Southern and Northern Palawan mainland, Culion, Linapacan, Dumaran, Rosa, Balabao and the smaller islands along Green island bay of the Palawan Group; Pangil Bay area in Misamis; the coastal area fringing Sibuguey Bay, Margosa-tubig to Pagadian area fronting Moro Gulf and Illana Bay and the island of Oluntanga and Sacol in Zamboanga del Sur and Basilan Province; the coastal area from Polloc Harborto Barrio Linek in Cotabato; and in the Sulu Island Group that includes the islands of Tongquil, Balangiungin, Simisa, Bongao, southern Tawi-Tawi, southern Jolo, eastern Data, Cabingaam, Siasi, and Lapac.

The Malesian region, including the Philippines has limited number of tree species in a mangrove forest. The following are the principal and the most abundant: *Rhizophora apiculata, Rhizophora mucronata, Bruguiera cylindrica, Bruguiera gymnorrhiza, Bruguiera parviflora, Bruguiera sexangula, Ceriops decandra, Ceriops tagal, Avicennia marina, Avicennia officinalis, Sonneratia alba and Sonneratia caseolaris.*

The brackish-water formation occurs on the inland edge of the mangrove and the upper tidal limit of estuaries. This formation generally merges with the mangrove of which it is often considered a part. It is dominated by the distinctive acaulescent palm *Nypa fruticans* that usually forms extensive pure stands especially along water courses. The only *Phoenix* found in the Far East region, *Phoenix padulosa* commonly known as 'Mangrove Date Palm' is restricted to this formation (Whitmore 1984).
2. Beach forest

This formation forms a narrow strip of woodland along the sandy and gravelly beaches of the seacoast. Most of the species have fruits and seeds adapted for water dispersal. Generally, mangrove forest throughout Malesia has uniform floristic composition.

The principal species occurring in the Philippine beach forests are: Barringtonia asiatica, Calophyllum inophyllum, Casuarina equisetifolia, Erythrina orientalis, Hibiscus tiliaceus, Messerschmidia argentea, Thespesia populnea, Thespesia populneoides, Pongamia pinnata, Scaevola frutescens and Terminalia catappa.

Two species of vines Desmodium umbellatum and Ipomoea pes-caprae usually dominate the herbaceous vegetation of a beach forest. Pandanu sctorius also occur commonly in this forest formation.

3. Peat swamp forest

This formation occurs in areas where the water table is higher than the surrounding areas. The peat soil is one in which the organic matter shows a loss on ignition greater than 65%. The soil is usually acidic with pH usually less than 4.0. The only incoming water is from rain which is extremely deficient in mineral nutrients (Whitmore 1984). Whitmore (1984) indicated the presence of peat swamp forests in southern Philippines. Unfortunately, the flora of this formation has never been documented.

4. Fresh-water swamp forest

This formation occurs in areas where there is regular or occasional inundation of mineral-rich fresh-water from rivers and streams with the water level fluctuating, thus allowing periodic drying of the soil surface. The soil has fairly high pH usually greater than 6.0. Whitmore (1984) cited two areas of this formation in Mindanao, one at the middle Agusan valley and the other on the west of Pagalungan. Metroxylon sagu is said to be the dominant species in fresh water swamp forest, though, floristic composition of this type in the Philippines has not yet to be studied.

5. Forest over limestone

Better known as the "Molave" (Vitex parviflora) forest, the limestone forest in the Philippines occupies low limestone hills, either coastal or bordering large uplifted river valleys, which are mainly composed of crystalline limestone covered by a shallow or very thin soil.

This formation is generally open, characterized by few scattered large trees often short-boled, irregular in form and with wide-spreading crowns. The intervening space is often filled with small trees and climbing and small erect bamboos. It occurs in regions where the dry season is very pronounced. The forest has deciduous foliage, especially on rough topography.

A number of leguminous trees are dominant in this formation, viz. Afzelia rhomboidea, Sindora supa, Intsia bijuqa, Albizia acle, Wallaceodendron celebicum, Pterocarpus indicus and Kingiodendron alternifoliurn. Other dominant species include Pterocymbium tinctorium, Zizyphus talanai, Toona calantas, Mimusops elengi, Maranthes corymbosa, Wrightia pubescens, Lagerstroenia piriformis, and Heritiera sylvatica, and such smaller trees as Diospyros ferrea, Pterospermum diversifolium and Mallotus floribundus.
6. **Forest over ultramafic rocks**

This forest formation occurs in soil rich in heavy metals. It is generally characterized by sclerophyllous stunted vegetation. Some of the ultramafic forests in Mt. Victoria, Palawan are only about 2-5 meter tall. Other ultramafic forests in the Philippines can be found on eastern Isabela, Luzon, northeastern Mindanao, and on Dinagat Island.

Ultramafic forests in the country contain unique flora which includes *Scaevola micrantha*, *Brackeridgea palustris*, *Exocarpus latifolius* and species of *Gymnostoma Suregada*, *Archidendron*, and *Pouteria*. An endemic tree species *Xanthostemon verdugonianus* (iron wood) can be found also in the ultramafic forests of Dinagat Island and also on the northeastern tip of Mindanao and northern Leyte.

7. **Tropical lowland evergreen rain forest**

This is the typical tropical rain forest formation in the Philippine Islands. Considered as the most luxuriant of all the plant communities, it is conventionally regarded as having three tree layers; the top layer occupied by the dominant species attaining height of more than 45 m tall, the emergent trees ranging from 20-40 m in height; and the shade dwelling species.

This formation occurs from coastal flats up to 900 m elevation (Whitmore 1984). In the Philippines, this forest formation is best developed in the eastern parts where rainfall is more or less uniform throughout the year or where there is only a short dry season. It includes the dipterocarp and mixed-dipterocarp forests. The Dipterocarpaceae forms the major component of the forest and its emergents but is also characterized by dense growth of climbing, thorny palms (rattans) and lianas, epiphytes, herbaceous plants on the forest floor, arecoid tree palms, and seedlings and saplings of the emergents.

8. **Tropical semi-evergreen rain forest**

This formation includes a mixture of evergreen trees occupying the top of the canopy and few deciduous trees usually comprise up to one-third of the evergreen trees. It occurs in areas where there is yearly water stress of some duration and perhaps bounds the zone of monsoon climates. At present, delimitation of this formation in the islands has not yet been established, but the deciduous “Yakal-lauan” and “Lauan-apitong” subtypes described by Whitford (1911) probably belong here as well as the semi-deciduous forest reported on Palawan Island.

9. **Tropical moist deciduous forest**

This formation occurs in areas where water is very limiting. The water deficiency of plants in this forest formation usually result to shedding of the leaves, thus, making it different from any other vegetation in the Philippines. According to Whitmore (1984a), this formation occurs in the central part of the Philippines adjacent to the rain forests of the eastern coasts. He also believed that the deciduous dipterocarp forest subtypes described by Whitford (1911) belong to this formation. A more comprehensive study on this forest formation should be done because of the very limited information on its floristic diversity.

10. **Tropical lower montane rain forest**

This forest formation in the Philippines is better known as the pine forest. Two native species of pines were recorded in the country, *Pinus insularis* and *Pinus merkusii*.
*Pinus insularis* thrives and best developed in the high plateau region of the Cordillera Mountains on Luzon, reaching an altitude ranging from c. 700 to 1800 m elevation. It occurs in a region with a distinct dry season.

Pine forests also occur in Zambales in western Luzon and on Mindoro Island. Both the *Pinus insularis* and *Pinus merkusii* occur in Zambales with an altitudinal range of usually 500 to 1500 m. On Mindoro, only the *Pinus merkusii* occurs in altitude of more than 900 m.

11. **Tropical upper montane rain forest**

The tropical upper montane rain forest in the Philippines is commonly known as the "mossy" forest. It occurs on mountains above 1000 m elevation with the upper limits varying depending on the locality and height of the mountain. It is best developed in areas where topography is rough and constantly changing. It consists of steep ridges and canyons. Generally the climatic conditions are exceedingly moist with great exposure to winds. Thus, the vegetation is usually dwarfed, and the trees are often crooked. The trunks and branches of trees are generally covered with mosses, hence, the name ‘mossy forest was derived.

The principal species of trees in this formation are gymnosperms of the genera *Dacrydium*, *Dacrycarpus* and *Podocarpus* as well as the angiosperm genera such as *Lithocarpus*, *Symplocos*, *Engelhardtia*, *Syzygium* and *Myrica*. Species of the family Melastomataceae (*Astronia*, *Medinilla*, and *Melastoma*) and Ericaceae (*Rhododendron* and *Vaccinium*) are also common in mossy forest together with the tree ferns of the genus *Cyathea*.

12. **Subalpine rain forest**

In the Philippines this formation is known only on the summit of Mt Halcon-Mt Sialdang range of Mindoro Island, with elevation ranging from 2470-2587 m. The soil is shallow, acidic, and nutrient poor resulting to a vegetation which is generally open. The dominance of small, woody dicots in subalpine rain forest makes it different from the summit vegetation of the other high mountains (e.g., Mt Pulag, Luzon) where grasses and sedges dominate with few herbaceous elements.

B. **Stand Structure**

**DENSITY** - abundance refers to number while density refers to number per unit area.

\[
\text{Density} = \frac{\text{number of individuals}}{\text{area sampled}}
\]

**RELATIVE DENSITY** - density relative to the abundance of other species as a function of space and/or time.

\[
\text{Relative Density} = \frac{\text{density for a species}}{\text{total density for all species}} \times 100
\]

**FREQUENCY** - number of times the species occurs
Frequency = \frac{\text{number of plots in which species occur}}{\text{total number of plots sampled}}

**RELATIVE FREQUENCIES**

Relative Frequency = \frac{\text{frequency value for a species}}{\text{total frequency for all species}} \times 100

**BIOMASS** - used to express dominance of species, weight of the individuals, useful in analyzing trophic structure and flow of energy. For convenience in the analysis, foliage cover or basal area (sometimes volume) is use to express dominance.

Dominance = \frac{\text{basal area or volume for a species}}{\text{area sampled}}

Relative Dominance = \frac{\text{dominance for a species}}{\text{total dominance for all species}} \times 100

**Importance value** – summation of relative density, relative frequency and relative dominance values for each species, standard measurement in forest ecology to determine the rank relationships of species.

Importance Value = \text{Relative Density} + \text{Relative Frequency} + \text{Relative Dominance}

### C. Diversity Analysis

<table>
<thead>
<tr>
<th>Biodiversity Parameter</th>
<th>Unit Value</th>
<th>Rationale or Importance</th>
<th>Formula</th>
<th>Data Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species Richness</td>
<td>Number of species per stratum</td>
<td>Ready measure of diversity</td>
<td>Total count of species per stratum</td>
<td>Number of individuals per life form</td>
</tr>
<tr>
<td>Importance Value (IVi)</td>
<td>Relative frequency (RFi), Relative Cover (RCi), Relative Density (RDi)</td>
<td>Changes in dominance structure and composition may be evaluated based on these values</td>
<td>IVi = RFi + RCi + RDi A limit to the number of taxa to be included here should be set accordingly (i.e. &gt; 0.5)</td>
<td>Frequency, density and basal areas of trees in each stratum</td>
</tr>
<tr>
<td>Shannon's Index (H')</td>
<td>Index per stratum pooled across all plots or Index per plot pooled across strata</td>
<td>Indices may be used for comparison. Index is sensitive to sample size and may not be good for extrapolation</td>
<td>[H' = \sum p_i \ln p_i] where pi ni/N and ni is the abundance of species I while N is the total number of individuals</td>
<td>Number of individuals per species</td>
</tr>
<tr>
<td>Simpson's Index (Ds)</td>
<td>Index per stratum pooled across all plots</td>
<td>Indices may be used for comparison. Initially a measure of dominance but later translated to diversity</td>
<td>( D_s = 1/\lambda ) where ( \lambda = \frac{\sum n_j(n_1-1)}{N(N-1)} ), ( N_i ) as defined above</td>
<td>Number of individuals per species</td>
</tr>
<tr>
<td>---------------------</td>
<td>------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------</td>
<td>----------------------------------</td>
</tr>
<tr>
<td>Evenness Measures</td>
<td>Index per plot</td>
<td>Dominance relationships may be shown by the index. Index separates the equitability component of Shannon's Index.</td>
<td>( E = \frac{H_{\text{observed}}}{H_{\text{max}}} ), where ( H_{\text{max}} ) is ( \ln S ) and ( S ) is the number of species</td>
<td>Number of individuals per species</td>
</tr>
<tr>
<td>Species-accumulation curves</td>
<td>Number of species accumulated per stratum</td>
<td>Plot of species accumulated relative to number of plots allows an extrapolation of the number of species</td>
<td>Newly encountered species are summed and plotted against accumulated plots. Michaelis-Menten Model was used for extrapolation</td>
<td>Number of unique record of species per plot</td>
</tr>
<tr>
<td>Fisher's Index (( \alpha ))</td>
<td>Index per stratum</td>
<td>This index has been shown to be useful for extrapolation especially, from data generated from small plots</td>
<td>( S = \alpha \ln \left(1 + \frac{N}{\alpha}\right) ) With modification including extrapolation on ( \alpha /1000 ) and ( S/1000 ) basis.</td>
<td>Total number of species and number of individuals per stratum</td>
</tr>
<tr>
<td>Rarefaction</td>
<td>Number of individuals and species per stratum</td>
<td>The method enables the comparison of data with different sample sizes</td>
<td>Rarefied sample based on Hulbert's Equation. The MMF model curve fit was used to extrapolate on species per number of individuals basis</td>
<td>Total number of species and individuals per stratum</td>
</tr>
<tr>
<td>Comparative studies</td>
<td>Species collected versus reportedly present</td>
<td>This method is a straightforward assessment of the species collected during the field studies and those obtained from secondary data</td>
<td>Listing and measuring percentage similarities</td>
<td>Number of collected materials</td>
</tr>
<tr>
<td>Multivariate Analysis</td>
<td>Plot data and pooled data for each stratum</td>
<td>The methods enable a visual appreciation of complex information</td>
<td>Principal Component Analysis (PCA), Correspondence Analysis (CA) and Cluster Analysis (CA)</td>
<td>Number of individuals in plots and summarized in pooled data</td>
</tr>
<tr>
<td>SHE Analysis</td>
<td>Plot data per stratum</td>
<td>The method allows the evaluation of species richness and equitability as unique system components. Enables the detection of abundance distribution in data.</td>
<td>Cumulative computation of ( \ln S ), ( \ln E ), and ( H ) as a function of abundance ( H' + \ln S = \ln E )</td>
<td>Number of individuals in plots and summarized in successive samples</td>
</tr>
</tbody>
</table>
TOOLS FOR ANALYSIS

- BioDiversity Professional (BdPro)
- Multi Variate Statistical Procedure (MVSP)
- Diversity software
- TwinSpan
- SPSS
- MS Excel
- BioMon
SAMPLE CALCULATIONS

For the purposes of illustration, consider the following hypothetical data:

<table>
<thead>
<tr>
<th>Quadrat 1</th>
<th></th>
<th>Quadrat 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree No.</td>
<td>Species</td>
<td>DBH</td>
</tr>
<tr>
<td>1</td>
<td>Nickel tree</td>
<td>11</td>
</tr>
<tr>
<td>2</td>
<td>Nickel tree</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>Nickel tree</td>
<td>11</td>
</tr>
<tr>
<td>4</td>
<td>Nickel tree</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>Nickel tree</td>
<td>12</td>
</tr>
<tr>
<td>6</td>
<td>Nickel tree</td>
<td>15</td>
</tr>
<tr>
<td>7</td>
<td>Mangkono</td>
<td>19</td>
</tr>
<tr>
<td>8</td>
<td>Malabayabas</td>
<td>22</td>
</tr>
<tr>
<td>9</td>
<td>Malabayabas</td>
<td>11</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Quadrat 2</th>
<th></th>
<th>Quadrat 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree No.</td>
<td>Species</td>
<td>DBH</td>
</tr>
<tr>
<td>1</td>
<td>Malabayabas</td>
<td>26</td>
</tr>
<tr>
<td>2</td>
<td>Malabayabas</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>Lanipau</td>
<td>12</td>
</tr>
<tr>
<td>4</td>
<td>Malaruhat</td>
<td>13</td>
</tr>
<tr>
<td>5</td>
<td>Lupot</td>
<td>12</td>
</tr>
</tbody>
</table>

| Quadrat 3 | | | | |
|-----------|---|---|---|
| Tree No.  | Species | DBH | Tree No.  | Species | DBH |
| 1         | Batino   | 12  | 1         | Malabayabas | 19 |
| 2         | Batino   | 14  | 2         | Agoho del monte | 10 |
| 3         | Batino   | 12  | 3         | Lanipau   | 20  |
| 4         | Batino   | 10  | 4         | Lanipau   | 11  |
|           |          |     | 5         | Lanipau   | 11  |
|           |          |     | 6         | Mangkono  | 23  |
|           |          |     | 7         | Mangkono  | 12  |
|           |          |     | 8         | Malabayabas | 19 |
|           |          |     | 9         | Lanipau   | 13  |
|           |          |     | 10        | Agoho del monte | 11 |
|           |          |     | 11        | Lanipau   | 11  |
|           |          |     | 12        | Lanipau   | 11  |
|           |          |     | 13        | Mangkono  | 11  |
|           |          |     | 14        | Malabayabas | 10 |
|           |          |     | 15        | Agoho del monte | 10 |
|           |          |     | 16        | Agoho del monte | 11 |
|           |          |     | 17        | Agoho del monte | 10 |

*DBH = Diameter at breast height

Given:
Number of Quadrats = 5
Size of quadrats = 20m x 20m = 400m²
Area sampled = 5 x 400m² = 2000m²

Take the case of Agoho del monte for the computation of the different parameters:

\[
\text{Density} = \frac{\text{number of individuals}}{\text{area sampled}} = \frac{6}{2000m^2} = 0.003
\]

\[
\text{Relative Density} = \frac{\text{density for a species}}{\text{total density for all species}} \times 100
\]
Density for all species should be computed first before relative density of each species can be obtained. In this set of data, total density for all species is 0.021 individuals/m². To continue with the computation for Agoho del monte.

\[
\text{Relative Density} = \frac{0.0025}{0.021} \times 100 = 11.9
\]

Agoho del monte occurred only in one quadrat (Q5) therefore:

\[
\text{Frequency} = \frac{1}{5} = 0.2
\]

Total frequency for all species = 3.4

\[
\text{Relative frequency} = \frac{0.2}{3.4} \times 100 = 5.882
\]

Dominance can be expressed in basal area which can be computed by multiplying the square of DBH (in meter) with the basal area constant \((BA = 0.7854 \times (DBH)^2)\).

\[
\text{Dominance} = 0.7854 \times (0.79)^2 = 0.49
\]

\[
\text{Relative Dominance} = \frac{0.49}{3.9} \times 100 = 12.56
\]

The summation of all relative values for each species is their importance value:

\[
\text{Importance Value (Agoho del monte)} = 11.9 + 5.882 + 12.56 = 30.34
\]
### Table 1. Summary computation for the importance value of each species.

<table>
<thead>
<tr>
<th>Species</th>
<th>Number</th>
<th>Density</th>
<th>RDen</th>
<th>No. Plot</th>
<th>Freq</th>
<th>RF</th>
<th>DBH</th>
<th>Dom</th>
<th>RDom</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agoho del monte</td>
<td>5</td>
<td>0.0025</td>
<td>11.905</td>
<td>1</td>
<td>0.2</td>
<td>5.882</td>
<td>79</td>
<td>0.490</td>
<td>12.557</td>
<td>30.344</td>
</tr>
<tr>
<td>Apitong babui</td>
<td>1</td>
<td>0.0005</td>
<td>2.381</td>
<td>1</td>
<td>0.2</td>
<td>5.882</td>
<td>25</td>
<td>0.049</td>
<td>1.257</td>
<td>9.521</td>
</tr>
<tr>
<td>Batino</td>
<td>4</td>
<td>0.0020</td>
<td>9.524</td>
<td>1</td>
<td>0.2</td>
<td>5.882</td>
<td>48</td>
<td>0.181</td>
<td>4.636</td>
<td>20.042</td>
</tr>
<tr>
<td>Binukaw</td>
<td>1</td>
<td>0.0005</td>
<td>2.381</td>
<td>1</td>
<td>0.2</td>
<td>5.882</td>
<td>18</td>
<td>0.025</td>
<td>0.652</td>
<td>8.915</td>
</tr>
<tr>
<td>Binunga</td>
<td>3</td>
<td>0.0015</td>
<td>7.143</td>
<td>1</td>
<td>0.2</td>
<td>5.882</td>
<td>35</td>
<td>0.096</td>
<td>2.465</td>
<td>15.490</td>
</tr>
<tr>
<td>Hauili</td>
<td>2</td>
<td>0.0010</td>
<td>4.762</td>
<td>1</td>
<td>0.2</td>
<td>5.882</td>
<td>22</td>
<td>0.038</td>
<td>0.974</td>
<td>11.618</td>
</tr>
<tr>
<td>Kakawate</td>
<td>2</td>
<td>0.0010</td>
<td>4.762</td>
<td>1</td>
<td>0.2</td>
<td>5.882</td>
<td>25</td>
<td>0.049</td>
<td>1.257</td>
<td>11.902</td>
</tr>
<tr>
<td>Lanipau</td>
<td>4</td>
<td>0.0020</td>
<td>9.524</td>
<td>2</td>
<td>0.4</td>
<td>11.765</td>
<td>56</td>
<td>0.246</td>
<td>6.309</td>
<td>27.598</td>
</tr>
<tr>
<td>Lupot</td>
<td>1</td>
<td>0.0005</td>
<td>2.381</td>
<td>1</td>
<td>0.2</td>
<td>5.882</td>
<td>12</td>
<td>0.011</td>
<td>0.290</td>
<td>8.553</td>
</tr>
<tr>
<td>Malabayabas</td>
<td>8</td>
<td>0.0040</td>
<td>19.048</td>
<td>3</td>
<td>0.6</td>
<td>17.647</td>
<td>144</td>
<td>1.629</td>
<td>41.720</td>
<td>78.414</td>
</tr>
<tr>
<td>Malaruhat</td>
<td>1</td>
<td>0.0005</td>
<td>2.381</td>
<td>1</td>
<td>0.2</td>
<td>5.882</td>
<td>13</td>
<td>0.013</td>
<td>0.340</td>
<td>8.603</td>
</tr>
<tr>
<td>Mangkono</td>
<td>4</td>
<td>0.0020</td>
<td>9.524</td>
<td>2</td>
<td>0.4</td>
<td>11.765</td>
<td>93</td>
<td>0.679</td>
<td>17.401</td>
<td>38.690</td>
</tr>
<tr>
<td>Nickel tree</td>
<td>6</td>
<td>0.0030</td>
<td>14.286</td>
<td>1</td>
<td>0.2</td>
<td>5.882</td>
<td>71</td>
<td>0.396</td>
<td>10.142</td>
<td>30.310</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>0.021</strong></td>
<td><strong>3.4</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>3.904</strong></td>
<td></td>
</tr>
</tbody>
</table>

RDen - Relative density; No. Plot – the number of plot/s the species occur; Freq – frequency; RF – Relative frequency; DBH – Diameter at breast height; Dom – dominance (expressed in basal area); RDom – Relative dominance; IV – Importance value.
Chapter 3: Social Characterization
SOCIOECONOMIC COMPONENTS

INTRODUCTION

Watershed characterization is important to measure project performance before making any changes to project processes. If we do not have baseline data then there is no way to evaluate whether a change is making a difference. It is used during the project to indicate progress towards the goal and objectives, and after the project to measure the amount of change. It allows those involved in the project to understand the initial livelihood conditions of the people, and what needs to be done to reach the goal of improving the livelihoods of the poor. Thus, baseline characterization builds necessary foundation for the plan and obtains proper information for effective planning, implementation and monitoring (Anantha, Wani and Sreedevi 2009).

One component of watershed characterization is the description of the socio-economic system. Among the main purposes of this socio-economic characterization are to identify existing and potential production constraints, and propose potential areas for targeting technology transfer for sustainable development. It requires huge information from a number of sources, published, unpublished and micro-level field investigation. Careful identification of socio-economic indicators may provide an opportunity for better implementation and monitoring of watershed development programs (Anantha, Wani and Sreedevi 2009).

This handout presents the general methods and techniques for the socio-economic economic characterization of watersheds. It also includes the procedure for stakeholder analysis and vulnerability assessment.

COMPONENTS OF SOCIO-ECONOMIC CHARACTERIZATION

The Department of Environment and Natural Resources (DENR) issued Memorandum Circular 2008-05 (DENR MC 2008-05) identifying 11 components that should be described under Socio-Economic Survey and Demography Section of the Watershed Characterization Report. These are as follows:

1. Population Density
2. Age Structure
3. Household/Family Size
4. Livelihood and Income/Profile/Sources
5. Sectoral Production
6. Employment Pattern and Projection
7. Social, Educational, and Medical Services
8. Transportation and Communication
9. Tourism and Recreation
10. Religious Sectors, Political and Social Organization
11. Behavioral and Cultural Patterns

Table 1 presents some variables or indicators of the socio-economic system that are essential in describing the above items, as well as the purpose for collecting these and the methods of collection (as will be described in the next section).
Table 1. Information needed for socio-economic characterization of watersheds (Anantha, Wani and Sreedevi 2009).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Purpose</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1) Demographic Condition</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Household profile (age, sex, education, marital status, etc.)</td>
<td>For understanding demographic condition</td>
<td>Data collection and analysis</td>
</tr>
<tr>
<td>Primary and secondary occupation</td>
<td>-do-</td>
<td>Data collection and analysis</td>
</tr>
<tr>
<td>Literacy (male and female)</td>
<td>-do-</td>
<td>Data collection and analysis</td>
</tr>
<tr>
<td>Livelihood options (farm and non-farm activities)</td>
<td>For watershed development plans</td>
<td>Data collection and analysis</td>
</tr>
<tr>
<td><strong>2) Agriculture</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cropping systems</td>
<td>To introduce new cropping interventions and management to bridge yield gaps</td>
<td>Sampling/survey</td>
</tr>
<tr>
<td>Crop-wise input use (seeds, fertilizers, organics, pesticides, etc.)</td>
<td>-do-</td>
<td>Sampling/survey</td>
</tr>
<tr>
<td>Yields obtained</td>
<td>-do-</td>
<td>Sampling/survey</td>
</tr>
<tr>
<td>Trends in area</td>
<td>-do-</td>
<td>Historical records</td>
</tr>
<tr>
<td>Trends in crop production</td>
<td>-do-</td>
<td>Historical records</td>
</tr>
<tr>
<td>Trends in crop yield</td>
<td>-do-</td>
<td>Historical records</td>
</tr>
<tr>
<td>Land ownership</td>
<td>Land and water management and crop planning</td>
<td>Sampling/survey</td>
</tr>
<tr>
<td>Land use pattern</td>
<td>-do-</td>
<td>Sampling/survey</td>
</tr>
<tr>
<td>Area, production and yield</td>
<td>-do-</td>
<td>Sampling/survey</td>
</tr>
<tr>
<td>Crop utilization and commercialization</td>
<td>-do-</td>
<td>Sampling/survey</td>
</tr>
<tr>
<td>Input use</td>
<td>-do-</td>
<td>Sampling/survey</td>
</tr>
<tr>
<td>Irrigation</td>
<td>-do-</td>
<td>Sampling/survey</td>
</tr>
<tr>
<td><strong>3) Livestock</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Availability of feed and fodder</td>
<td>For land use and livestock planning</td>
<td>Data collection and analysis</td>
</tr>
<tr>
<td>Livestock breed</td>
<td>-do-</td>
<td>Sampling/survey</td>
</tr>
<tr>
<td>Milk production</td>
<td>For economic feasibility</td>
<td>Sampling/survey</td>
</tr>
<tr>
<td>Meat production</td>
<td>-do-</td>
<td>Sampling/survey</td>
</tr>
<tr>
<td><strong>4) Economic Variables</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Employment (workforce and agricultural laborers)</td>
<td>For sources of income and availability of work</td>
<td>Data collection and analysis</td>
</tr>
<tr>
<td>Migration</td>
<td>-do-</td>
<td>Sampling survey</td>
</tr>
<tr>
<td>Income across different landholdings</td>
<td>For land productivity and capacity</td>
<td>Data collection and analysis</td>
</tr>
<tr>
<td>Income and consumption</td>
<td>For poverty status</td>
<td>Data collection and analysis</td>
</tr>
<tr>
<td>Consumption expenditure</td>
<td>-do-</td>
<td>Sampling/survey</td>
</tr>
<tr>
<td>Disposable income on various activities (e.g., clothing, food,</td>
<td>-do-</td>
<td>Sampling/survey</td>
</tr>
<tr>
<td>Characteristics</td>
<td>Purpose</td>
<td>Method</td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>----------------------------------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>shelter, etc.)</td>
<td>-do-</td>
<td>Sampling/survey</td>
</tr>
<tr>
<td>Poverty-related indicators</td>
<td>-do-</td>
<td>Sampling/survey</td>
</tr>
<tr>
<td>Financial institutions (formal/ informal)</td>
<td>For understanding the livelihood opportunities</td>
<td>Sampling/survey</td>
</tr>
<tr>
<td>5) Rural infrastructure facilities (roads, market, transport, etc.)</td>
<td>For watershed development plans</td>
<td>Sampling/survey</td>
</tr>
<tr>
<td>6) Economic feasibility of improved technologies</td>
<td>-do-</td>
<td>Sampling/survey</td>
</tr>
</tbody>
</table>

**METHODS FOR SOCIAL CHARACTERIZATION**

1) General Procedure and Practices

**Sampling Procedure**

There are number of methods available to collect data for an enquiry. However, care should be taken to avoid error caused by multiple methods. Stratified Random Sampling procedure should be followed to collect information. It is the purest form of probability sampling with each member of the population having an equal and known chance of being selected. When there are very large populations, it is often difficult or impossible to identify every member of the population, so the pool of available subjects becomes biased. The commonly used probability method is superior to random sampling because it reduces sampling error. A stratum is a subset of the population that shares at least one common characteristic. Random sampling is then used to select a sufficient number of subjects from each stratum. Stratified sampling is often used when one or more of the strata in the population have a low incidence relative to other strata. For instance, the watershed may be divided into upstream and downstream, according to land use, or political jurisdiction.

**Selection of Households**

In most cases, the number of households within the watershed will be too large to feasibly survey every household. In this case, one must pick a representative sample of households. Sampling means that only some of the households in the watershed area are picked for survey. The concept of ‘representative’ is important and means that the sample of households interviewed must reasonably represent the entire group. To accomplish this, a random sample needs to be chosen. In situations where there is a census of the entire targeted population, households can be randomly chosen by various means such as picking every fifth household (systematic sampling) or using a random numbers table (if there is a sampling frame).

**Methods of Data Collection**

Data collection means gathering information to address those critical evaluation areas included in watershed characterization. There are many methods available to gather information, and a wide variety of information source. The most important issue related to

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data collection is selecting the most appropriate information or evidence to answer our questions. Several approaches are adopted to generate desired information. These include:

- Secondary data collection
- Community group interviews
- Household survey (interview, questionnaire survey)
- Frequent visits to the study area and regular discussions with the respondents
- Direct observations
- Participatory rural appraisal
- Rapid rural appraisal
- Case studies

To plan data collection, one must think about the questions to be answered and the information sources available. Also, we must begin to think ahead about how the information could be organized, analyzed, interpreted and then reported to various audiences. The selection of a method for collecting information must balance several concerns, including: resources available, credibility, analysis and reporting resources, and the skill of the evaluator. Thus, either of the approaches may be selected depending upon the objectives of the study. However, questionnaire is an appropriate and widely used instrument to collect data in social science research in addition to many participatory approaches. Therefore, care needs to be taken while preparing the questionnaire (Box 1 for checklist). In addition, the following points need to be considered when planning a baseline survey:

- The baseline survey should be strongly linked with the critical aspects of the project’s Monitoring & Evaluation plan.
- There is need to understand the current condition in which the baseline survey will be conducted. (Ex.: What season of the year is it? What political condition prevails? What is the current state of the economy? Will the baseline survey occur during, or follow on from, extraordinary events such as natural disasters, political upheavals or economic shocks?

**Box 1: Checklist for forming questionnaire**

- Is this question necessary? How will it be useful? What will it tell us?
- Will you need to ask several related questions on a subject to be able to answer your critical question?
- Do respondents have necessary information to answer the question?
- Will the words in each question be universally understood by the target audience?
- Are abbreviations used? Will everyone in the sample understand what they mean?
- Is the question too vague? Does it get directly to the subject matter?
- Can the question be misunderstood? Does it contain unclear phrases?
- Have you assumed that the target audience has adequate knowledge to answer the question?
- Is the question too demanding? For example, does it ask too much on the part of the respondent in terms of calculations/estimation?
- Is the question biased in a particular direction, without accompanying questions to balance the emphasis?
- Are you asking two questions at one time?
- Is the question wording likely to be objectionable to the target audience in any way?
- Are the answer choices mutually exclusive?
- Is the question technical accurate?
- Is an appropriate referent provided? For example: per year, per hectare, etc.
Analyzing the Data

The first step in analyzing data is to determine what method of data analysis would be used. If most of the information collected contains numbers, then the data is quantitative data. If the information collected consists of words, then the data is qualitative data. With quantitative data, the analysis does not begin until all data are collected. In contrast, most qualitative data analysis begins as data are collected. For example, when conducting group interviews, group discussions, the transcripts are analyzed as soon as possible in order to generate additional questions for follow-up interviews.

If most of the information collected contains numerical (quantitative) data, then descriptive statistics (frequency counts, mean, median, mode, standard deviation, etc.) can be used to characterize the data (See Table 2 for an example). If most data collection was done using focus group interviews, open-ended questions, or case studies, then data will be in the form of qualitative data. Unlike being able to use a hand calculator or computer program to analyze numerical data, the qualitative data of words need to be analyzed initially by reading and sorting through the data. With qualitative data, how the data is ordered, categorized, and arranged is important because most qualitative data are words that must be interpreted for content. This process will include carefully reading the information, and then identifying, coding, and categorizing the main themes, topics, and or patterns in the information. Coding is simply attaching some alpha-numeric symbol to phrases, sentences, or string of words that follow a similar theme or pattern. This process allows placing these phrases of similar themes into a category for further analysis.

Table 2. Percentage distribution and summary statistics of farm characteristics of three selected barangays in a watershed.

<table>
<thead>
<tr>
<th>Farm Characteristics</th>
<th>Barangay 1 (n=46)</th>
<th>Barangay 2 (n=139)</th>
<th>Barangay 3 (n=128)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Farm Size, in ha</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1 – 1</td>
<td>65.22%</td>
<td>56.20%</td>
<td>72.66%</td>
</tr>
<tr>
<td>1.1 – 2</td>
<td>15.22%</td>
<td>16.06%</td>
<td>10.94%</td>
</tr>
<tr>
<td>2.1 – 3</td>
<td>8.70%</td>
<td>11.68%</td>
<td>8.59%</td>
</tr>
<tr>
<td>3.1 – 4</td>
<td>4.35%</td>
<td>6.57%</td>
<td>3.13%</td>
</tr>
<tr>
<td>4.1 – 5</td>
<td>2.17%</td>
<td>2.92%</td>
<td>3.13%</td>
</tr>
<tr>
<td>&gt; 5</td>
<td>4.35%</td>
<td>6.57%</td>
<td>1.56%</td>
</tr>
<tr>
<td>Mean</td>
<td>1.65</td>
<td>1.90</td>
<td>1.19</td>
</tr>
<tr>
<td>Range</td>
<td>0.187 – 12.5</td>
<td>0.1 – 14.5</td>
<td>0.1 – 7.5</td>
</tr>
<tr>
<td><strong>Production system</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monocropping</td>
<td>79.50%</td>
<td>33.91%</td>
<td>30.09%</td>
</tr>
<tr>
<td>Crop rotation</td>
<td>5.12%</td>
<td>7.83%</td>
<td>27.43%</td>
</tr>
<tr>
<td>Multiple cropping</td>
<td>15.38%</td>
<td>49.57%</td>
<td>32.75%</td>
</tr>
<tr>
<td>Agroforestry</td>
<td>0.00%</td>
<td>8.69%</td>
<td>9.73%</td>
</tr>
</tbody>
</table>

2) Stakeholder Analysis²

Stakeholder is any person, organized or unorganized, who share a common interest or stake in a particular issue or system. Effective watershed management planning requires

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² Based on the methodology developed by Dr. Juan M. Pulhin and Asst. Prof. Rose Jane J. Peras for the Formulation of Watershed Management Plans For Energy Development Corporation (EDC)-Managed Watersheds.
answering the following key questions to facilitate the implementation of its planned activities (Reed n.d.):

- Who are the interested parties?
- Who has the power to influence what happens?
- How do these parties interact?
- How could they work more effectively together?

Stakeholder analysis is a process that (i) defines aspects of a global and natural phenomenon affected by a decision or action; (ii) identifies individuals, groups and organizations that are affected by or can affect those parts of the phenomenon; and (iii) prioritizes these individuals and groups for involvement in the decision-making process (Reed 2009 in Reed n.d.).

Procedure

Materials Needed: Brown paper, colored paper cards, paper cut in three sizes (small, medium, large), masking tape, colored pens, tape recorder, and calculator

Participants: Representatives from the different sectors in the watershed (Note: It may be useful to conduct separate analysis for community members/POs and other stakeholder institutions

Methodology:
1. Conduct an FGD of about 10-12 participants, at least half of which are women
2. Ask the FGD participants to identify the different groups/institutions currently involved or have interests in the area. Ask them to write each of these in the colored paper cards. In identifying the stakeholders, color coding should be adopted to differentiate the following types:

   Type 1 – Forest user groups within the community

   Type 2 – Mediating institutions, both internal and external to the community, including state and civil society institutions
   Type 2.1 - Internal state mediators
   Type 2.2 - External state mediators
   Type 2.3 - Civil society mediators

   Type 3 – External economic interests or user groups

3. For each group identified, ask the FGD participants to describe the composition or membership of the group (example, farmers, women, NGO workers, etc.). Ask also the participants about the interests of the groups in relation to the natural resources being studied and record answers in Table 1.

Table 1. Stakeholders and their interests

<table>
<thead>
<tr>
<th>Stakeholders/Composition</th>
<th>Stakeholder’s Interests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest User Groups</td>
<td></td>
</tr>
<tr>
<td>Upland farmers</td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td></td>
</tr>
</tbody>
</table>
3. etc.

Mediating Institutions

1.

2.

External economic interest

4. Ask the FGD participants to group the cards into what they perceive as alliances. For each cluster, ask the issue or issues which cement or bind the alliance. Record this by filling out Table 2.

Table 2. Institutional alliances

<table>
<thead>
<tr>
<th>Members of the alliance</th>
<th>Issues which cement the alliances</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. Ask the FGD participants to group the cards into what they perceive as conflicting groups. For each cluster, ask the issue or issues/problems that cause their conflicts. Record this by filling out Table 3.

Table 3. Institutional Conflicts

<table>
<thead>
<tr>
<th>Conflicting Groups</th>
<th>Source of Conflict</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6. Ask the FGD participants to re-sort the cards into four categories:

Category 1 – those which are important but with less influence
Category 2 – those which are very important but with less influence
Category 3 – those which are important and with high influence
Category 4 – those which are very important and with high influence
Indicate the results in the prepared template.

7. Based on the findings from items 1-6, ask the participants to identify specific activities that would promote sustainable resource management involving the different stakeholders. Record their recommendations in Table 4.

Table 4. Template for participation

<table>
<thead>
<tr>
<th>Proposed Activities</th>
<th>Stakeholders Involved</th>
<th>Mechanism for Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3) Vulnerability Assessment to Climate Change

Vulnerability is described as “a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity” (McCarthy et al. 2001, p.995). Vulnerability is therefore most often conceptualized as a function of exposure, sensitivity and adaptive capacity.

\[ V = f (E, S, AC) \]

Based on the above equation, \(\text{exposure}\) is the degree, duration and/or extent in which the system is in contact with, or subject to, the perturbation (Adger 2006 and Kasperson et al. 2005 in Gallopin 2006). \(\text{Sensitivity}\) is the degree to which a system is affected, either adversely or beneficially, to climate variability, climate change or extreme events (IPCC 2001 in IPCC WG II 2007). The effects may also be direct or indirect. Smit and Wandel (2006) distinguished exposure and sensitivity as almost inseparable properties of a system and are dependent on the interaction between the characteristics of the system and on the attribute of the climate stimulus. Meanwhile, \(\text{adaptive capacity}\) is the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC 2001 in IPCC WG II 2007). The forces that influence the ability of the system to adapt, such as economic wealth, technology and infrastructure, information, knowledge and skills, equity, among others, determine its adaptive capacity (Smit and Wandel 2006; Ionescu et al. 2009).

Schematically, the climate change adaptation group would diagram vulnerability as presented in Figure 1. This shows that exposure and sensitivity would result to potential impacts, and the impacts and adaptive capacity would determine the vulnerability.
Figure 1. Schematic presentation of vulnerability based on the IPCC’s Third Assessment Report (TAR) and 4AR.

However, the focus has changed with the release of the latest IPCC report (i.e., the AR5). IPCC AR5 (2014) shifted its attention from vulnerability to climate risks, as the latter supports decision-making in the context of climate change and complements other elements. The change is also reflected in the new definition of vulnerability by IPCC AR5, i.e., “the propensity or predisposition to be adversely affected”. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC 2014).

This new tradition started when the IPCC released its report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) in 2012. The report, from which the IPCC AR5 Working Group II was built on, marries climate change adaptation and disaster risk management. With this new approach, vulnerability became a component of risk (from the disaster risk and management tradition), and it is the most palpable manifestation of the social construction of risk. Risk is interpreted using the below equation, as well as vulnerability (Mendoza 2014):

\[
R = \text{Hazard} + \text{Exposure} + \text{Vulnerability},
\]

where Vulnerability = \( f (\text{sensitivity} + \text{adaptive capacity}) \)

Figure 2 presents the illustration of the core concepts of SREX and AR5 reports. It evaluates the influence of natural climate variability and anthropogenic climate change on hazards that can contribute to risk. It also considers the role of socioeconomic process in trends in exposure and vulnerability, and its implications to risks (IPCC 2012). Thus, risk of climate-related impacts results from the interaction of climate-related hazards (including hazardous events and trends) with the vulnerability and exposure of human and natural systems. Changes in the climate system (left) and socioeconomic processes including adaptation and mitigation (right) are drivers of hazards, exposure and vulnerability (IPCC 2014).
Figure 2. Framework for the assessment of climate change impacts, adaptation and vulnerability.

Aside from vulnerability (already defined above), other important concepts that need to be elaborated are: hazard, exposure, risk and impacts. Their definitions are also presented below (IPCC 2014):

- **Hazard** – the potential of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources.

- **Exposure** – the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.

- **Impacts** – effects on natural and human systems. In the IPCC AR5, the term *impacts* is used primarily to refer to the effects on natural and human systems of extreme weather and climate events and of climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as *consequences* and *outcomes*. The impacts of climate on geophysical systems, including floods, droughts, and sea level rise, are a subset of impacts called physical impacts.

- **Risk** – the potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard.
• **Adaptation** – the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects.

Procedure

1. **Historical Events of Climate Variability and Extremes**

   a. Ask the participants the natural occurrences in their area that reflect climate variability and extremes (e.g., over the last 50 years or so).

   b. Following the format below, record in Table 1 the major events that relate to climate variability and extremes such as:
      i. Seasonal variability
      ii. Prolonged rain
      iii. Drought
      iv. Forest Fires
      v. Destructive typhoon

     **Historical events of climate variability and extremes.**

     | Year | Description of climate variability and extremes |
     |------|-----------------------------------------------|
     |      |                                              |
     |      |                                              |
     |      |                                              |

2. **Impacts of climate variability and extremes on watershed communities**

   a. Based on the climate-related events recorded, identify the different impacts of climate variability and extremes on water, agriculture and forest sectors.

   b. Record the impacts of climate variability and extremes in Table 2.

   **Impacts to Local Communities**

<table>
<thead>
<tr>
<th>Events</th>
<th>Impacts to Local Communities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Water (domestic &amp; other uses)</td>
</tr>
<tr>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

3 Based on the methodology developed by Dr. Juan M. Pulhin for Assessment of Impacts and Adaptation to Climate Change (AIACC).
3. Identification of the different socio-economic groups affected by climate variability and extremes

a. Ask the FGD participants to identify the different socio-economic groups and institutions in their area that are affected by climate variability and extremes.

b. List the different socioeconomic groups and institutions in the first column of Table 3 and the impacts of climate variability and extremes to each group in the second column.

c. Using colored paper cards cut into circles of three sizes (small, medium and large), ask the participants to determine the degree of negative impacts of climate variability and extremes to the different groups by pasting these cards in the third column opposite the group. NOTE: The size of the circles corresponds to the degree of negative impact of climate variability and extremes to the specific group, that is, small circle means small negative impact and so on.

d. Ask the participants the reason for their choice of the degree of impacts and record this in the fourth column of Table 3.

<table>
<thead>
<tr>
<th>Socioeconomic Groups</th>
<th>Impacts of Climate Variability and Extremes</th>
<th>Degree of Negative Impacts of Climate Variability and Extremes</th>
<th>Reason for the Choice of the Degree of Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

4. Identification and Mapping of Vulnerable Groups and Places (Community Mapping)

a. Ask the FGD participants to draw a barangay map indicating the major physical features such as roads, river systems, settlement areas and purok locations.

b. With Table 3 as reference, ask the participants to indicate in the map the location of different socioeconomic groups in the barangay by pasting the different circles/triangles of various sizes.

c. Using the same map, request the participants to indicate in the map the location of vulnerable places in their barangays. Request them to explain why they have identified these places as vulnerable (e.g. steep slope therefore highly erosive area, grassland frequently subjected to forest fires, etc.)
5. Local Groups and Institutions Adaptation Strategies

a. Ask the FGD participants to identify the different adaptation strategies mechanisms of the different socioeconomic groups/institutions applied to water, agriculture and forest sectors to cope with climate variability and extremes.

b. Request the participants to explain if they find these strategies to be effective and why?

c. Request the participants to recommend strategies for the different groups to improve coping mechanisms and for the different institutions to be able to better support the local people to cope with future climate variability and extremes.

d. Record all the answers in Table 4.

Table 4. Adaptation Strategies

<table>
<thead>
<tr>
<th>Socioeconomic Groups</th>
<th>Adaptation Strategies</th>
<th>Perception of Adaptation Strategies (Effective or Not Effective, and Why?)</th>
<th>Recommendations to Improve Adaptation Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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</tr>
</tbody>
</table>
Chapter 4: 
Methods in Geographic Information System (GIS)
GEOREFERENCING, MAP PROJECTION AND DATA VECTORIZATION IN ARCGIS™

OBJECTIVES

At the end of the exercise, the participants should be able to:
1. Georeference analogue maps properly using a defined coordinate reference system;
2. Understand the concept of map projection; and,
3. Enhance skills in digitizing various kinds of feature datasets.

INTRODUCTION

One of the important functions of GIS is its ability to convert analogue maps into digital information. These data are first transformed into raster format mainly through a process called scanning. Generally, the scanned maps will have no reference information as to where the maps would fit on the earth’s surface. In the same manner, some aerial photos and remotely-sensed images also exhibit inadequate locational information. Hence, the need to align or georeference these raster data to a map coordinate system. Georeferencing associates a data to a specific location on earth and it will allow raster data to be viewed, queried and analyzed with other geographic data.

In georeferencing, it assumes that there are features in the spatial data (target data) that are also available in the raster data such as streams, buildings, roads and the like. These are referred to as ground control points. These points have X,Y coordinates and link locations on the raster data with locations in the target data. It is important to note however that more links do not mean it will yield a better registration. To generate the best result for georeferencing, at least one link near each corner of the raster is established and the others are spread in the interior.

The degree of accuracy in the transformation of raster data can also be measured by comparing the actual location of the map coordinate to the transformed position in the raster. The distance between these two points is known as the residual error. Total error is calculated using the root mean square (RMS) sum of all residuals. Consequently, this is used to compute for the RMS error. When georeferencing generates a small RMS error, this means that transformation is considerably accurate. But it should be taken into account as well other possible sources of errors such as selection of ground control points to produce best result in the process.

Map projection is also an essential aspect of GIS because it will define the common coordinate framework of different geographic data layers in a given area. These coordinate systems will play an important role in integrating various datasets as well as in the performance of several analytical operations such as map overlay analysis. Hence it is significant that one should be able to define the appropriate coordinate system to be used when integrating various data layers from different sources and coordinate systems.

After the data have been properly georeferenced and projected, digitizing can proceed. This is a process by which features on paper maps are transformed into digital format. There are two methods of digitizing. One is through the use of a digitizing tablet and the other is referred to as onscreen digitizing. Digitizing of maps can be a very tedious process and mostly are subjected to human error and variation. Hence, patience and carefulness are some important characteristics to obtain good results from the activity.
GEOREFERENCING AND MAP PROJECTION

1. First create a `C:\FMBTraining` directory. Copy the `Georeferencing and Projection` folder to this directory.
2. Open ArcMap™.
3. Click on Add Data button, navigate to your directory and double click on `Georeferencing.gdb`. Inside this geodatabase are NAMRIA map sheets of Marinduque with a scale of 1:50,000. These map sheets are Boac 3327-I, Elephant Island 3327-II, Balanacan 3328-II and Torrijos 3427-IV.
4. Select Boac from the files then click Add. When a notification appears about spatial reference, just click OK.

5. Before georeferencing, setup first your workspace directory. Click on Geoprocessing > Environments from the main menu.
6. From the Environment Settings window, expand Workspace.
7. Set the Current Workspace to `C:\FMBTraining\Georeferencing and Digitizing\Georeferencing.gdb` while the Scratch Workspace to `C:\FMBTraining\Georeferencing and Digitizing\Output.gdb`.
8. Once done, click on OK.
9. Now you can check the coordinates (in degrees) of the four corners of Boac and record their latitudes and longitudes. Type these data using spreadsheet following the format below:

<table>
<thead>
<tr>
<th>Map</th>
<th>Sheet</th>
<th>Elongdeg</th>
<th>Elongmin</th>
<th>Elongsec</th>
<th>X</th>
<th>Nlatdeg</th>
<th>Nlatmin</th>
<th>Nlatsec</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boac</td>
<td>3327-I</td>
<td>121</td>
<td>45</td>
<td>0</td>
<td>13</td>
<td>30</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boac</td>
<td>3327-I</td>
<td>122</td>
<td>0</td>
<td>0</td>
<td>13</td>
<td>30</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boac</td>
<td>3327-I</td>
<td>122</td>
<td>0</td>
<td>0</td>
<td>13</td>
<td>15</td>
<td>0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
10. Open the other three maps (Elephant Island, Balanacan and Torrijos) and encode the coordinates of the corners of these map sheets.
11. Once all the coordinates are encoded, compute for the X and Y values using the following equations:
   \[ X = [\text{Elongdeg}+(\text{Elongmin}/60)+ (\text{Elongsec}/3600)] \] and \[ Y = [\text{Nlatdeg}+ (\text{Nlatmin}/60)+ (\text{Nlatsec}/3600)] \]
12. Format the X and Y values to Number and set the number of Decimal places to 6 then save the file as GCP and the format as CSV (comma delimited) to your designated directory (C:\FMBTraining\Georeferencing and Digitizing). If you are prompted to keep the workbook in this format, just click Yes.
13. Make sure you close the spreadsheet file before opening the file in your ArcMap™. When prompted to save changes, click Don't Save.
14. In ArcMap™, click the Add Data icon and browse to your directory and add the GCP.csv file.
15. In the Table of Contents, right click at the GCP.csv file then click Display XY Data and a window appears.

   ![Display XY Data window](image)

16. In the Display XY Data window, make sure the X Field is set X and the Y Field is set to Y.
17. Observe that the description of the Coordinate System of Input Coordinates is still Unknown Coordinate System. This means that the coordinate system is still undefined. To set the coordinate system, click Edit and the Spatial Reference Properties appears.

18. Click Select then double click on Geographic Coordinate Systems. From the Browse for Coordinate System, double click on Asia then select PRS 1992.prj then click Add and then OK.
19. The coordinate system should be set to PRS 1992 because the NAMRIA map sheets for Marinduque are also set to Philippine Reference System (PRS) 1992. Make sure you always check the map source’s Horizontal Datum.

20. Note now that the coordinate system for the GCP.csv has been already set to GCS_PRS_1992. Click OK.

21. A GCP.csv Events is now added to your Table of Contents. Right click on this file then select Data and click Export Data. Navigate to your directory and type GCP_points in the Name and make sure that Shapefile is selected from the Save as Type drop down list. Click Save and click OK. When you are asked to add the exported data, just click Yes.

22. Now you can remove the GCP.csv Events and GCP.csv from the Table of Contents, leaving you with GCP_points file only in the Table of Contents. Check the Table of Contents setting from List By Source to List By Drawing Orders to hide the source directory of the file.

23. From the ArcToolbox, go to Data Management Tools > Projections and Transformations > Feature > Project and the Project window appears.

24. From the Project window, choose GCP_points from the Input Dataset or Feature Class and name the Output Dataset or Feature Class to GCP_UTM.
25. From the **Output Coordinate System**, go to **Projected Coordinate Systems > UTM > WGS 1984 > Northern Hemisphere > WGS 1984 UTM Zone 51N** then click **OK**. Click **OK** again.

26. Click the **New** icon from the main menu to create a new map document. Set the **Default geodatabase for this map**: to **C:\FMBTraining\Georeferencing and Digitizing\Georeferencing.gdb**. When prompted to save the untitled document, click **No**.

27. Add the **GCP_UTM.shp** in this new map document. You can access the file from the **C:\FMBTraining\Georeferencing and Digitizing\Output.gdb**.

28. Right click on the **GCP_UTM** and select **Properties**. Go to **Labels** tab menu and make sure **Nlatdeg** is selected from the **Label Field** drop down list. Click on **Expression** to append additional labels.
29. From the **Label Expression** window, click on **Nlatmin** then hit **Append** then click on **Nlatsec** and hit **Append** again. **Append** the **Elongdeg**, **Elongmin** and **Elongsec** as well in the expression. Click **OK** then hit **OK** again.

30. Right click on **GCP_UTM** then select **Label Features**. You can now observe the latitudes and longitudes in the points. These will guide you during georeferencing.

31. Right click on the **GCP_UTM** then click **Symbology**. Click the **Symbol** to open the **Symbol Selector** window.
32. Select the **Circle 1** symbol then from **Color**, change the color of your choosing then set the **Size** to 10. Click **OK**.

33. Zoom in to the left most part of the **GCP_UKM** points to start georeferencing of map sheets.

34. First activate the **Georeferencing** toolbar. Click on the **Customize** main menu then click **Toolbars > Georeferencing**.
35. Click the **Add Data** icon and browse to your directory and add **Boac.jpg** then hit **Add**. Zoom to the corner points where this file will be georeferenced.

36. From the **Georeferencing** toolbar, click **Georeferencing** drop down list and select **Fit To Display**.

37. Zoom in to the Upper Left (UL) corner of the map sheet. It has a **latitude** of 13°30’0” and a **longitude** of 121°45’0”.

38. From the **Georeferencing** toolbar, click on the **Add Control Points** icon. Now click on the map where the **ULX (121°45’0”)** and **ULY (13°30’0”)** coordinates are located, then click on the **GCP_UTM** feature with the same coordinates. This set that portion on the map sheet in the same location with the **GCP_UTM** coordinates.

39. Once done, repeat the same process to the other remaining three corners of Boac. Check their respective coordinates for reference.
40. After you’re finished with the four corners of Boac, check the View Link Table from the Georeferencing toolbar. Make sure that the Total RMS Error is less than 1 pixel size of the image. For this image, pixel size is approximately 10 m, thus a Total RMS Error of less than 10 m is acceptable. If not you need to repeat the georeferencing of the image. To repeat, just select the items under Link from the Link Table window and click the Delete icon.

41. Close the Link Table when the prescribed Total RMS Error is met.

42. Click the Georeferencing drop down list from the Georeferencing toolbar then select Rectify. By choosing this, you are saving a new file of the georeferenced map sheet.

43. When the Save As window appears, set the Output Location to C:\FMRTraining\Georeferencing and Digitizing and leave the default settings for the other items. Make sure the Format of the file is in TIFF then click Save.

44. Remove the Boac from the Table of Contents and replace it with the newly georeferenced file – Boac1.tif.
45. Before adding the Marinduque.shp from your Georeferencing directory, project the file because its current coordinate reference system is in PRS92.

46. Click on ArcToolbox > Data Management Tools > Projections and Transformations > Feature > Project and the Project window appears.

47. From the Input Dataset or Feature Class box, click the directory icon to locate Marinduque.shp from C:\FMBTraining\Georeferencing and Digitizing\Georeferencing.gdb\Marinduque.

48. In the Output Dataset or Feature Class box, name the output file as Marinduque_UTM.

49. Set the Output Coordinate System to WGS 1984 UTM Zone 51N and click OK then hit OK again. The projected Marinduque shapefile is now added to the display window.

50. Double click the symbol of Marinduque_UTM in the Table of Contents to open the Symbol Selector window then choose Hollow from the list. Change the Outline Width to 1.50 and Outline Color of your preference. Click OK when done.

51. Check if the georeferenced map sheet is more or less aligned with the administrative boundary of Marinduque. You can use the Tools toolbar icons to navigate over the map.
52. Once done, georeference the other remaining three map sheets of Marinduque namely, Elephant_Island, Balanacan and Torrijos.
53. Once all four map sheets are georeferenced, enable them from the Table of Contents to check the entire province.

54. Click Save and direct it to your directory and name the map document as Georeferencing.

DATA VECTORIZATION

1. Using the same map document, click on the ArcCatalog™ icon from the Standard toolbar and the Catalog tree is now activated. Click on the Connect to Folder icon and browse to C:\FMBTraining\Georeferencing and Digitizing and click OK.
“ArcCatalog software makes accessing and managing geographic data easy. One can connect to folders on local disks, to shared folders and databases that are available on the network, or to geographic information system (GIS) servers.”

2. Locate your working directory from the Catalog tree and right click on it. Click on **New** then **Shapefile**. The **Create New Shapefile** window appears.

3. Name the file as **Marinduque_Streams** and set the **Feature Type** to **Polyline** then click on **Edit** button to define the coordinate system of the shapefile.

4. From the **Spatial Reference Properties** window, select **Projected Coordinate Systems > UTM > WGS 1984 > Northern Hemisphere > WGS 1984 UTM Zone 51N**. Click **OK** then another **OK**. The **Marinduque_Streams** shapefile is now added to the Table of Contents.

5. From the **Editor** toolbar, click on the drop down list and click **Start Editing**.
6. From the **Start Editing** window, choose **Marinduque_Streams** then click **OK**.

7. Then click on the **Editor** drop down list and click on **Editing Windows > Create Features**.

8. Use the **Tools** toolbar to zoom in, zoom out and pan across the image. Locate the **Boac River** from the **Boac1.tif** and start digitizing this river and its stream networks. Once properly zoomed in to the area where you will start your digitizing, click on the **Marinduque_Streams** from the **Create Features** window and you can start populating your streams.
9. While digitizing, you can use the **Tools** toolbar to navigate over the raster image. When you want to continue with your digitizing, just select the **Marinduque Streams** from the **Create Features** window. To finish the editing, just double click or right click and choose **Finish Sketch**. Then you can begin digitizing another stream or tributary that is linked to the Boac River.

10. To save your work, just click on the **Editor** toolbar drop down list and select **Save Edits**. Finally, if you want to stop the editing, just click on the **Editor** toolbar drop down list and select **Stop Editing**. If prompted to save your work, just hit **OK**.
11. To set transparency of one image file over the other, just click **Customize > Toolbars > Effects**.

12. Make sure from the **Effects** toolbar, the file that you want to be active is selected from the dropdown list.
13. Click on **Adjust Transparency** from the toolbar and drag the slider to set the transparency of that image. Try setting it to 40. Now you can check how fit the mosaic is and it can be utilized as well during digitizing.

14. Click **Save** to preserve your work.
WATERSHED DELINEATION USING HYDROLOGY AND ARC HYDRO TOOLS IN ARCGIS™

OBJECTIVES

At the end of the exercise, the participants should be able to:

1. Delineate the boundary of a watershed using digital elevation model;
2. Understand the different concepts in the Hydrology and Arc Hydro toolsets of ArcGIS; and,
3. Calculate basic morphometric parameters of a watershed.

INTRODUCTION

Watershed delineation is an initial process in the development of management plans in a watershed. This is commonly done using topographic maps where ridges and stream networks are defined. This also provides the extent of the landscape from which the different resources are characterized and described. Traditionally, contour lines from topographic maps are used to delineate the boundary of a watershed. The main outlet of the watershed is first identified from the network of streams and this is usually located at the furthest downstream point of the river. However, at present, watershed boundaries are mostly defined using digital elevation models (DEMs) derived from advanced geospatial technologies such as satellite imaging and LiDAR technology.

Once the watershed boundary is defined, various information about the resources found within the area are extracted using several GIS processing tools. The main purpose of these tools is to provide an avenue to perform analysis and manage geographic datasets.

WATERSHED DELINEATION IN HYDROLOGY TOOLS

1. Copy the Watershed Delineation folder to C:\FMBTraining directory.
2. Open ArcMap.
3. Click on the Add Data button. Navigate to C:\FMBTraining\Watershed Delineation folder then double click on Watershed.gdb then choose dem then click Add.
4. Click on Geoprocessing > Environments.
5. From the Environment Settings window, expand Workspace.
6. Click on the directory icon on the Current Workspace then click the Connect to Folder icon.
7. Navigate to C:\FMBTraining\Watershed Delineation.
8. Set the Current Workspace to C:\FMBTraining\Watershed Delineation\Watershed.gdb then click Add.
9. In the Scratch Workspace box, navigate to Current Workspace to C:\FMBTraining\Watershed Delineation\Output.gdb then click Add.
10. Next, expand the Raster Analysis from the Environment Settings.
11. Set the Cell Size to Same as layer dem.
12. Click OK to close the Environment Settings window.
13. To begin the delineation of watershed, open your ArcToolbox.
14. Go to Spatial Analyst Tools then expand the Hydrology toolset.
15. First click on the Fill tool. This tool is used to remove any imperfections (sinks) in the digital elevation model. A sink is a cell that does not have a defined drainage value associated with it.

16. From the Input raster drop down list, select dem.
17. In the Output surface raster, just change the file name to Fill. Click OK.
18. Double click the Flow Direction tool. A flow direction grid assigns a value to each cell that indicates the direction of flow. This is important in hydrologic modeling because it determines the destination of the water flowing across the surface of the landscape.
19. For every 3x3 cell neighborhood, the grid processor finds the lowest neighboring cell from the center. Each number in the matrix below corresponds to a flow direction – e.g. if the center cell flows due west, its value will be 16; if it flows north, its value is 64.

20. From the Input surface raster, click the drop down arrow and choose fillsink.

21. In the Output flow direction raster, set the file name to FlowDir. Click OK.

22. From the Spatial Analyst Tools > Hydrology, double click on Flow Accumulation.

23. The Flow Accumulation tool calculates the flow into each cell by accumulating the cells that flow into each downslope cell.

24. From the Flow Accumulation window, set the Input flow direction raster to FlowDir.

25. In the Output accumulation raster, change the name to FlowAccu. Click OK.
26. Right click the FlowAccu in the Table of Contents then click Properties.
27. Click on the Symbology tab. Set the Show: to Classified, Classes to 2 then click Classify.

28. From the Classification window, change the value of the first class found in the Break Values to 1000. Leave the highest value in the second class as is.
29. Click OK.
30. On the **Color Ramp**, change the white color of the symbol to yellow.
31. Double click on the symbol then choose any shade of yellow (e.g. Solar Yellow).
32. Click **OK**.

33. The cells displayed in yellow have at least 1000 upstream cells flowing through them.
34. Flow accumulations are significant because they allow us to locate cells with high cumulative flow. Each cell has an outlet called pour point that indicates the location where water would flout out of the cell. Pour points must be located in cells of high cumulative flow.
35. Next is to create pour (outlet) points.
36. Open **ArcCatalog** and navigate to **C:\FMBTraining\Watershed Delineation**.
37. Right click over the **C:\FMBTraining\Watershed Delineation**, then click **New** then choose **Shapefile**.
38. Type **Pour** in the **Name** text box the set **Feature Type** to **Point**.
39. Click **Edit** then expand **Projected Coordinate Systems**. Go to **UTM > WGS 1984 > Northern Hemisphere > WGS 1984 UTM Zone 51N**. Click **OK** then click **OK** again.

40. The **Pour** shapefile is now added to the **Table of Contents**.
41. Double click on the **Pour** symbol to open the **Symbol Selector**.
42. Choose any symbol and color then hit **OK** when done.
43. Click the **Editor Toolbar**. Click the **Editor** drop down then click **Start Editing**.
44. Select **Pour** then click **OK**.
45. From the **Editor Toolbar**, click the **Editor** drop down then go to **Editing Windows > Create Features**. Now we are ready to identify the outlet of our watershed. The outlet of the watershed usually has the highest flow accumulation value in a given stream network.
46. Add the Boac_River.shp from C:\FMBTraining\Watershed Delineation\Watershed.gdb directory. Use this drainage network to guide in identifying which watershed to delineate.

47. When done, click Editor then Stop Editing. Click Yes when prompted to save your edits.

48. Now click the Snap Pour Point from Spatial Analyst Tools > Hydrology. The tool snaps to the closest area of high accumulation and converts the pour points to the raster format needed for input to delineating the watersheds.

49. From the Input raster or feature pour point data in the Snap Pour Point window, choose Pour.

50. Set the Pour point field to Id the set the Input accumulation raster to FlowAccu.

51. Change the Output raster name to SnapPour.

52. Click OK.
53. It’s time to delineate the watersheds. Double click on the Watershed tool from the Spatial Analyst Tools > Hydrology.
54. Set the Input flow direction raster to FlowDir, Input raster or feature pour point data to SnapPour, and Output raster to Watershed.
55. Click OK.
56. To convert the watershed to shapefile, go to ArcToolbox and click on Conversion Tools > From Raster > Raster to Polygon.
57. In the Raster to Polygon window, set the Input raster to Watershed and the Output polygon features to Boac_Watershed.
58. Click OK. Make sure the Simplify polygons box is checked.
59. **Save** your map document and name it **Watershed Delineation**.

**STREAM ORDER GENERATION**

1. Using the same map document, extract the flow accumulation first of the Boac Watershed. Go to **ArcToolbox > Spatial Analyst Tools > Extraction > Extract by Mask** and a window appears.
2. From the **Input raster** box, choose **FlowAccu** while in the **Input raster or feature mask data**, select **Boac_Watershed**.
3. Lastly, in the **Output raster**, just type **Extract**. Click **OK**.
4. Right click on **Extract** from the **Table of Contents** then go to **Properties**.
5. From the **Properties** window, select **Classified** from the **Show** box and set the number of **Classes** to **2** only then click **Classify**.
6. In the **Break Values**, set the threshold of the first class only to **1,000** while maintaining the threshold value of the second. Click **OK** then another **OK**.

![Classification window](image)

7. Go to **ArcToolbox > Spatial Analyst Tools > Reclass > Reclassify**.
8. From the **Reclassify** window, choose **Extract** from the **Input raster** and the **Reclass field** should be **Value**. Click on **Classify**.
9. Set the number of **Classes** to **2** and the **Break Values** to **1000** in the first class while maintaining the threshold value in the second. Click **OK**.
10. Name the **Output raster** as **Reclass** then click **OK**.

11. Go to **ArcToolbox** > **Spatial Analyst Tools** > **Extraction** > **Extract by Attributes** to extract the stream raster.
12. From the **Extract by Attributes** window, choose **Reclass** file for the **Input raster** then click on the SQL window from the **Where clause** box.
13. In the **Query Builder** window, double click on **Value** then click on the **equal sign** (=) and click the **Get Unique Values** and double click on 2. Click **OK**.
14. Name the **Output raster** as **Streams**. Click **OK**.

15. To generate the stream orders, go to **ArcToolbox > Spatial Analyst Tools > Hydrology > Stream Order**.
16. In the **Input stream raster**, select **Streams** while in the **Input flow direction raster**, choose **FlowDir**. Name the **Output raster** as **SO_Strahler**. Click **OK**.

17. There are two methods in stream ordering in ArcGIS - **Strahler** method and **Shreve** method. In Strahler, the stream order only increases when streams of the order intersect. On the other hand, stream ordering in Shreve is done by magnitude wherein the magnitudes are additive downslope. This means when two links intersect, their magnitudes are added and assigned to the downslope link.
18. Try generating a stream order using Shreve method as well and name the **Output raster** as **SO_Shreve**. Compare the results of the two methods.
WATERSHED DELINEATION USING ARC HYDRO TOOLS

1. Install **HEC-GeoHMS** and **Arc Hydro Tools**.
2. Open **ArcMap**.
3. Copy the **Watershed Delineation** folder and paste to **C:\FMBTraining**.
4. Go to **Customize > Toolbars** and check **Arc Hydro Tools** and **HEC-GeoHMS**.
5. Go to **Customize > Extensions** and make sure **Spatial Analyst** is checked as well.
6. Go to **Geoprocessing > Environments**. Expand your **Workspace** and set the **Current Workspace** (C:\FMBTraining\Watershed Delineation\Watershed.gdb) and **Scratch Workspace** (C:\FMBTraining\Watershed Delineation\Output.gdb).
7. Click the **Add Data** button and navigate to your directory (C:\FMBTraining\Watershed Delineation\Watershed.gdb) and add the **dem** and **Boac_River**.
8. DEM reconditioning and filling the sinks may not be required at all times depending on the quality of the initial DEM. DEM reconditioning involves modifying the elevation data to be more consistent with the input vector stream network. This simply assumes that the stream network data are more reliable than the DEM.
9. **Save** your work and name it **Watersheds**.
10. Go to **Terrain Preprocessing > DEM Manipulation > DEM Reconditioning**.
11. From this window, choose \texttt{dem} for the \texttt{Raw DEM}, \texttt{Boac\_River} for \texttt{AGREE stream}. Leave other values in their default. Click OK.

12. What \texttt{AgreeDEM} does is it pushes the raw DEM along the stream to create a distinct profile along the streams which otherwise does not exist in raw DEMs.

13. Now go to \texttt{Terrain Preprocessing > Data Manipulation > Fill Sinks}.

14. Select \texttt{AgreeDEM} as the input for \texttt{DEM}. Leave other options unchanged. Click OK.

15. Go to \texttt{Terrain Preprocessing > Flow Direction}. This function computes the flow direction for a given grid. The output values in the cells indicate the direction of the steepest descent from that cell.

16. Make sure that \texttt{Fil} is used as the input for \texttt{Hydro DEM}. Click OK.

17. Next go to \texttt{Terrain Preprocessing > Flow Accumulation}. This function computes the flow accumulation grid that contains the accumulated number of cells upstream of a cell, for each cell in the input grid.

18. Make sure that the input for the \texttt{Flow Direction Grid} is \texttt{Fdr} and the \texttt{Flow Accumulation Grid} is \texttt{Fac}. Click OK.

19. From the \texttt{ArcHydro} toolbar, go to \texttt{Terrain Preprocessing > Stream Definition}. Confirm that the input for the \texttt{Flow Accumulation Grid} is \texttt{Fac} and the output in the \texttt{Stream Grid} as \texttt{Str}.
20. The value in the stream threshold represents 1% of the maximum flow accumulation. Accept this default value and click OK.

21. Next go to **Terrain Preprocessing > Stream Segmentation**. This function creates a grid of stream segments that have a unique identification. Either a segment may be a head segment, or it may be defined as a segment between two segment junctions.

22. Make sure that **Fdr** and **Str** are the inputs for the **Flow Direction Grid** and the **Stream Grid**, respectively. Leave other settings as is then click OK.

23. Now go to **Terrain Preprocessing > Catchment Grid Delineation**. This function creates a grid in which each cell carries a value (grid code) indicating to which catchment the cell belongs. The value corresponds to the value carried by the stream segment that drains that area, defined in the stream segment link grid.

24. Confirm that the input to the **Flow Direction Grid** and **Link Grid** are **Fdr** and **StrLnk**, respectively. Leave the default name for the **Catchment Grid** then click OK.
25. Go to Terrain Preprocessing > Catchment Polygon Processing. Make sure that the input to the Catchment Grid is Cat and Catchment for the Catchment box then click OK.

![Image of Catchment Polygon Processing](image1.png)

26. The polygon feature class Catchment is added to the Table of Contents. Open the attribute table of Catchment. Notice that each catchment has a HydroID assigned to it and the Length and Area attributes are also computed.

27. Go to Terrain Preprocessing > Drainage Line Processing. This function converts the input Stream Link grid into a Drainage Line feature class. Each line in the feature class carries the identifier of the catchment in which it resides.

28. Ensure that the input to Stream Link Grid is StrLnk and Flow Direction Grid is Fdr. Click OK.

![Image of Drainage Line Processing](image2.png)

29. Now go to Terrain Preprocessing > Adjoint Catchment Processing. This function generates the aggregated upstream catchments from the Catchment feature class.

30. Make sure that the inputs to Drainage Line and Catchment are Drainage Line and Catchment, respectively. Leave the output name as is then click OK.
31. Now go to **Terrain Preprocessing > Drainage Point Processing**. Leave the other default inputs. Click **OK**.

32. Browse the **Arc Hydro** toolbar and look for the **Batch Point Generation** button. This will be used to locate the outlet of the watershed. Click **OK**.

33. Zoom in to the outlet of the **Boac River**. Click the outlet and the **Batch Point Generation** window appears.

34. Type in the **Name** box **Boac Outlet** then hit **OK**.

35. Now go to **Watershed Processing > Batch Watershed Delineation**.

36. Make sure that **Fdr** is the input to **Flow Direction Grid**, **Str** to **Stream Grid** and **Snap Stream Grid**, **Catchment** to **Catchment**, **AdjointCatchment** to **AdjointCatchment** and leave the output names as is. Click **OK**. Now you have the delineated watershed of Boac.
37. Right click on the Watershed from the Table of Contents and select Open Attribute Table. Here you will find the area of the watershed which is under the field Shape_Area. The area is estimated around 215,378,198.63 m² or 21,537.82 ha or 215.38 km². The perimeter, on the other hand, is estimate around 124,560.15 m or 124.56 km.

38. Now go to Watershed Processing > Longest Flow Path. Set the Drainage Area to Watershed and the Flow Direction Grid as Fdr. Leave the output name as is. Click OK. Open the attribute table and the longest flow path is estimated around 43,933.05 m or 43.93 km.

39. Next go to Watershed Processing > Basin Length Points. Set the Basin Length Grid to Cat, Drainage Area to Watershed, Longest Flow Path to Longest Flow Path and accept the default output name. Click OK.

40. Go to Watershed Processing > Basin Length. Leave everything as is then click OK.

41. Open the attribute table and the basin length is specified under Shape_Length. The Basin Length is now calculated at 27,061.43 m or 27.06 km.

42. Go to Spatial Analyst Tools > Hydrology > Stream Order.
43. From the **Input stream raster**, choose **StrLnk**. In the **Input flow direction raster**, select **Fdr** and in the **Output raster**, type **SO_Strahler**. Click **OK**.

![Image of a geographic information system (GIS) software interface showing a stream network and a table of statistics]

44. The stream orders (need to be counted manually) and bifurcation ratios generated for the watershed are as follows:

<table>
<thead>
<tr>
<th>Stream Order</th>
<th>Number of Streams</th>
<th>Bifurcation Ratio</th>
<th>Watershed Bifurcation Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>29</td>
<td>29/6 = 4.83</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>6/2 = 3.0</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>2/1 = 2.0</td>
<td>3.28</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

45. As for the elongation ratio, below is its calculation:

\[
\text{Elongation Ratio} = \frac{2}{27.06 \text{ km}} \times \left(\frac{215.38 \text{ km}^2}{3.1416}\right)^{0.5} = 0.61
\]

46. In terms of its circularity ratio, the following calculations are made:

\[
\text{Circularity Ratio} = \frac{4 \times 3.1416 \times 215.38 \text{ km}^2}{(124.56 \text{ km})^2} = 0.17
\]

47. The form factor of the watershed is also calculated and the solution is shown below:

\[
\text{Form Factor} = \frac{215.38 \text{ km}^2}{(27.06 \text{ km})^2} = 0.29
\]

48. Now go to **Conversion Tools > From Raster > Raster to Polyline**.

50. In the **Input raster**, choose **SO_Strahler** and set the **Output polyline features** to **Streams_Strahler**. Make sure the **Simplify polylines** box is checked then click **OK**. Clip the generated steams to the watershed boundary if necessary.

51. Open the attribute table and the length of streams are indicated in the **Shape_Length** field. Generate the statistics by right clicking on the aforementioned field name then click on **Statistics**. The total length of streams is estimated around **116,007.83 m** or **116.0 km**. Using this value, the drainage density can now be determined using the solution below:

\[
\text{Drainage Density} = \frac{116.0 \text{ km}}{215.38 \text{ km}^2} = 0.54 \text{ km}^{-1}
\]
52. For the stream density, the total number of streams from the stream orders and the watershed area are used:

\[ \text{Stream Density} = \frac{38}{215.38 \text{ km}^2} = 0.18 \text{ km}^{-2} \]

53. As for the length of overland flow, it is calculated using the solution below:

\[ \text{Length of Overland Flow} = \frac{1}{(2 \times 0.54 \text{ km})} = 0.93 \text{ km} \]

54. After the channel morphology calculations, the watershed-relief features can also be determined using the generated results from the delineation. First the elevation must be extracted using Spatial Analyst > Extraction > Extract by Mask. In the Input raster, select dem while in the Input raster or feature mask data, select Watershed. Set the Output raster to boac_elev. Click Save then hit OK. The elevations are now generated which range from 4 masl to 867 masl.

55. Using this data on elevation, the basin relief, relief ratio and relative relief can now be calculated. The following are the solutions for these said parameters:

- \[ \text{Basin Relief} = 867 \text{ masl} - 4 \text{ masl} = 863 \text{ masl} \]
- \[ \text{Relief Ratio} = \frac{863 \text{ m}}{27,061.43 \text{ m}} = 0.03 \]
- \[ \text{Relative Relief} = \frac{867 \text{ m}}{124,560.15 \text{ m}} = 0.007 \text{ or } 0.01 \]

56. Finally, the slope is computed using Spatial Analyst > Surface > Slope. In the Input raster, choose boac_elev and in the Output raster, type boac_slope then click Save. Set the Output measurement to PERCENT_RISE then click OK. The slope of the watershed ranges from 0% to around 201%.
Chapter 5: Methods in Remote Sensing (RS)
IMAGE PRE-PROCESSING AND VEGETATION INDICES USING ARCGIS™

OBJECTIVES

At the end of the exercise, the participants should be able to:

1. Conduct pre-processing of satellite images such as conversion of DN values to radiance and reflectance;
2. Perform layer stacking of Landsat images; and,
3. Generate vegetation indices such as the Normalized Difference Vegetation Index (NDVI) and Soil Adjusted Vegetation Index (SAVI).

INTRODUCTION

Remotely sensed data that are captured and received by different imaging sensors on various satellite platforms contain some errors and deficiencies. Because of this inherent characteristic of raw satellite data, initial corrections and calibrations are indispensable to remove such flaws from the satellite images. These are termed pre-processing techniques. In general, these methods can be categorized into three namely, geometric correction methods, radiometric correction methods and atmospheric correction methods. Geometric correction is done when the images or products derived from the image are used together with other geographic data layers. Meanwhile, radiometric correction is mainly applied to digital image datasets to ascertain the quality and performance of the sensors. One of the most significant radiometric data activities is the conversion of digital numbers to radiance and reflectance. Lastly, the atmospheric correction methods are done to remove or minimize the effects of scattering in the atmosphere before the energy reaches the earth’s surface.

Data extracted from satellite images also provide significant understanding of our environment. One of the most studied interactions of features on earth is vegetation. Typically, vegetation absorbs the red and blue wavelengths, reflects the green, strongly reflects the near infrared wavelength and displays strong absorption features in wavelengths where atmospheric water is present. Measuring such variations and studying their relationship to one another can provide significant information about plant health, water content, environmental stress and other important characteristics of the environment. These relationships are described as vegetation indices.

DN, RADIANCE AND REFLECTANCE

1. Copy the Image Processing folder and paste it to your working directory (C:\FMBTraining)
2. Open ArcMap.
3. Click on Customize menu then click on Extensions. Make sure all extensions are checked. Close the Extensions window.
4. Click the Add Data icon and browse to your directory where L511605011930402_b1.tif of Landsat 5 TM is located. This is Band 1 of the satellite image. Individual bands are displayed in grey scales with digital number from 1 to 255.
5. Right click on the image and go to **Properties**.
6. In the **Layer Properties** window, click on **Source** tab and navigate the **Statistics** part. If there is none yet, calculate the statistics from **ArcToolbox**. However, if the image has statistics already, proceed to **Step 8**.
7. From **ArcToolbox**, click on **Data Management Tools > Raster > Raster Properties > Calculate Statistics**.
8. From the **Calculate Statistics** window, choose `I511605011930402_b1.tif` for the **Input Raster Dataset**. Leave the default settings then click **OK**.
9. Use the **Identify** tool and navigate over the image. The **Pixel** value in the **Identify** window corresponds to the **Digital Number (DN)** value of the satellite imagery. Check the pixel or DN values of various land cover types in the image (e.g. water, forest, urban, open area, etc.).
10. Convert the DN values to radiance using the following equation and table below:

\[
L_\lambda = gain \times DN + bias
\]

Landsat 5 TM spectral range, post-calibration dynamic ranges and mean exoatmospheric solar irradiance.

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Spectral Center</th>
<th>LMIN</th>
<th>LMAX</th>
<th>GAIN</th>
<th>BIAS</th>
<th>ESUN_\lambda</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band 1</td>
<td>0.452-0.518</td>
<td>0.485</td>
<td>-1.52</td>
<td>169</td>
<td>0.671339</td>
<td>-2.19</td>
</tr>
<tr>
<td>Band 2</td>
<td>0.528-0.609</td>
<td>0.569</td>
<td>-2.84</td>
<td>333</td>
<td>1.322205</td>
<td>-4.16</td>
</tr>
<tr>
<td>Band 3</td>
<td>0.626-0.693</td>
<td>0.660</td>
<td>-1.17</td>
<td>264</td>
<td>1.043976</td>
<td>-2.21</td>
</tr>
<tr>
<td>Band 4</td>
<td>0.776-0.840</td>
<td>0.840</td>
<td>-1.51</td>
<td>221</td>
<td>0.876024</td>
<td>-2.39</td>
</tr>
</tbody>
</table>
11. Using the appropriate values for a specific band, calculate the radiance equivalence of \textbf{i511605011930402\_b1.tif}.
12. From the ArcToolbox, click on Spatial Analyst Tools > Map Algebra > Raster Calculator.
13. Calculate the radiance for \textbf{i511605011930402\_b1.tif} using this sample equation:

\[
\text{Radiance}_{\text{BAND1}} = 0.671339 \times \text{BAND 1} - 2.19
\]

\textbf{Note: BAND 1 = "i511605011930402\_b1.tif"}

14. Go to your directory and set the Output raster name to \textbf{band1\_rad} then click OK.
15. Convert the radiance to reflectance. While radiance is the variable that is being recorded by Landsat sensors, conversion of this quantity into reflectance generates better comparison among different imagery. This removes differences caused by the position of the sun and the differing amounts of energy output by the sun in each band. The conversion can be derived using the following expression:

\[
\rho = \frac{\prod \times L_{\lambda} \times d^2}{ESUN_{\lambda} \times \cos \theta_s}
\]

where:
- \( \rho \) - unitless planetary reflectance
- \( L_{\lambda} \) - spectral radiance
- \( d \) - earth-sun distance in astronomical units
- \( ESUN_{\lambda} \) - mean solar exoatmospheric irradiance
- \( \theta_s \) - solar zenith angle (cosine of the solar zenith angle is also equals
to the sine of the solar elevation angle and the angle should be expressed to radian (degrees × 3.141592654/180))

16. Check the solar elevation angle of the image from the i511605019930402.hdr file (e.g. sun elevation angle is 55°).

17. Check the earth-sun distance (d) of the imagery based on the acquisition date of the image. For this particular image, d is equal to 0.99954.

18. To calculate the reflectance of Band 1, use the previously generated file band1_rad. Open the Raster Calculator from ArcToolbox and encode the following values for Band 1:

\[
\text{Reflectance}_{BAND1} = \frac{(3.141592654 \times BAND~1 \times \text{Square}(0.99954))/(1983 \times \sin(55 \times 3.141592654/180))}{100}
\]

Note: BAND 1 = “band1_rad”
19. Type the **Output raster** name as **band1_ref**. Click **Save** and finally, **OK**.

20. During the conversion from DN values to reflectance, it is possible to generate small negative values. These values are not physical and should be set to zero. Please note, however, that if large negative values were acquired from the process, this may suggest some problems in the implementation of the process. Using the **Raster Calculator** from the **ArcToolbox**, adjust the values on **band1_ref** using this equation:

\[
\text{Reflectance}_{\text{corrected}} = \text{CON}(\text{BAND 1} < 0.0, 0.0, \text{BAND 1})
\]

*Note: BAND 1 = "band1_ref"

21. Type the **Output raster** name as **band1_cref**. Click **Save** then click **OK**.

22. Repeat the same process for **Bands 2, 3, 4, 5 and 7**. Provide appropriate names following the same format as that of Band 1.

23. After the reflectance values are calculated, Save your working map document.

**LAYER STACKING**

1. First, add all six bands to your working ArcMap document (e.g. band1_rad, band2_rad, band3_rad, band4_rad, band5_rad and band7_rad).
2. Make sure that they are also arranged in an increasing band number in the Table of Contents window.
3. Click on **Windows** main menu then click on **Image Analysis** and another window appears.
4. Highlight all six bands from the **Image Analysis** window then navigate the lower portion of the window and find the **Processing** commands.

5. Along this portion, click on **Composite Bands** to combine all the layers selected into a multiband image.

6. What you see now is a **True Color Composite** of the area. Band combination is 321.
7. Try other band combinations such as 432. This particular image is referred to as a **False Color Composite**. Assign Band 4 to Red, Band 3 to Green and Band 2 to Blue.

8. Try other band combinations and layout them if you want.

**VEGETATION INDICES**

1. Use the corrected reflectance values of **Band 3 (Red)** – `band3_cref.tif` and **Band 4 (NIR)** – `band4_cref.tif` to calculate the vegetation index.

2. First, the **Normalized Difference Vegetation Index (NDVI)** will be calculated using the following expression:

   \[
   NDVI = \frac{NIR - RED}{NIR + RED}
   \]

3. Implement the equation using the **Raster Calculator**. Type in the **Output raster** name to **NDVI** then click on **Save** and finally, click **OK**.
4. Check the range if the values is from -1 to +1. If the values are not between these values, you may have some problems in the syntax or in the implementation of the Raster Calculator. Check again.

5. Double click on the symbol of NDVI to open the Select Color Ramp window.

6. Choose your color ramp for the NDVI map.
7. Next is to calculate the **Soil Adjusted Vegetation Index (SAVI)** with the following equation below:

\[
SAVI = \frac{(1 + L)(NIR - RED)}{NIR + RED + L}
\]

where:
- SAVI – soil adjusted vegetation index
- NIR – near infrared band
- RED – red band
- L – soil adjustment factor

8. Type **SAVI** for the name in the **Output raster** filename. Click **Save** then **OK**.
9. Check the SAVI values with NDVI. Their values relatively vary where SAVI has more confined values as compared with NDVI whose values are more spread.

10. Double click on the symbol of SAVI to open the Select Color Ramp window. Then choose the color you want to assign to the image.
IMAGE CLASSIFICATION AND CHANGE DETECTION ANALYSIS USING ARCGIS™

OBJECTIVES

At the end of the exercise, the participants should be able to:

4. Conduct image classification using unsupervised classification technique;
5. Perform accuracy assessment; and,
6. Evaluate land cover changes from two different periods.

INTRODUCTION

Satellite images capture various objects and features of the earth’s surface. These can be in the form of thematic or metric information. The former provides descriptive data about the earth’s surface such as soil, vegetation and land cover while the latter includes location, height and their derivatives such as area, volume, slope and the like. Thematic information are usually obtained through visual interpretation or computer-based digital image analysis while metric information are extracted using principles of photogrammetry.

Image classification is defined as the process of classifying multispectral or hyper-spectral images into patterns of varying gray or assigned colors that represent clusters of statistically different sets of multiband data, some of which can be correlated with separable classes, features or materials. According to Weng (2010), some basic elements of image interpretation are as follows:

- **Tone** refers to each distinguishable variation from white to black and is a record of light reflection from the land surface onto the image
- **Color** refers to each distinguishable variation on an image produced by a multitude of combinations of hue, value and chroma
- **Size** provides another important element in discrimination of objects and features and should be used in reference with its background
- **Shapes** provide diagnostic information in identification such that man-made features often have straight edges while natural features tend to have irregular boundaries
- **Texture** refers to the frequency of change and arrangement in tones
- **Pattern** pertains to the spatial arrangement of objects
- **Shadow** relates to the size and shape of an object
- **Association** helps in identifying human-made features since they tend to indicate or to confirm the existence of another

Another important aspect of remote sensing that is associated with image classification is its ability to perform change detection analysis across different periods. Since most environmental phenomena constantly change over time such as vegetation and climate, it is therefore significant that these changes are accurately accounted and detected. This is essential to understand the dynamics of change that had happened over the years and utilize this information in predicting future trends and scenarios of the area. Humans have been modifying land to obtain food and other essentials for thousands of years, however, current rates and intensities are causing unprecedented changes in the ecosystems and environmental processes at local, regional and global scales. This made monitoring of land use and land cover changes even more significant than ever.
IMAGE CLASSIFICATION

1. Copy the Land Cover Analysis folder and paste it to your C:\FMBTraining directory.
2. Open ArcMap.
3. Go to Geoprocessing and click on Environments.
4. Expand the Workspace and in the Current Workspace box, navigate to C:\FMBTraining\Land Cover Analysis and select image Classification.gdb.
5. Click Add.
6. In the Scratch Workspace box, navigate to C:\FMBTraining\Land Cover Analysis Outputs.gdb and click Add.
7. Click OK.
8. Click Add Data button and browse to C:\FMBTraining\Land Cover Analysis\Classification.gdb.
9. Add all six bands (e.g. band1_1993, band2_1993, band3_1993, etc.). Click Yes when prompted to create pyramids.
10. Arrange the bands in an ascending order. On top of the layer is band1_1993 while the one in the bottom is band7_1993.

11. Click on Windows > Image Analysis.
12. From the Image Analysis window, select all the six bands then click the Composite Bands from the Processing sub-window. Note that this multiband layer is just temporary.
13. Right click on the created composite layer then click on **Data > Export Data**.
14. In the **Export Raster Data** window, set the location to **C:\FMBTraining\Land Cover Analysis\Outputs.gdb**. Click **Add**.
15. Type in the **Name** box **landsat1993** and click **Save**.

16. Click **Yes** to add the exported data to the **Table of Contents**.
17. Right click on **landsat1993** image and select **Properties**.
18. Go to **Symbology** tab and set the band combinations for the **RGB** to **321**. Click **OK**.
19. Click **Customize** then **Toolbars** and check **Image Classification**.
20. From the **Image Classification** toolbar, select `landsat1993` from the drop down.
21. Click the **Classification** drop down and choose the **Iso Cluster Unsupervised Classification**.
22. In the **Number of classes** text box, type **30**.
23. In the **Output classified raster**, type **unsup1993**. Click **OK**.

24. Right click on **unsup1993** in the **Table of Contents** then choose **Properties**.
25. Go to **Symbology** tab and from **Show** window, select **Unique Values**.
26. Choose the **Color Scheme** (e.g. black to white). Click **OK** when done.
27. Expand the **unsup1993** and you will observe the 30 classes that were generated by the Iso Cluster algorithm.
28. Change the color of each class following the land cover classes below:
   - **Water** – 1 [Ultra Blue]  
   - **Built-up** – 2 [Amethyst]  
   - **Agriculture/Grassland** – 3 [Peridot Green]  
   - **Open/Bare** – 4 [Solar Yellow]  
   - **Forest** – 5 [Fir Green]
29. You can use the **landsat1993** multiband image to aid you in identifying the land cover classes.
30. Use the **Identify** button to also help you in the process of assigning classes.
31. Once you are done with all the 30 classes, you may now reclassify the spectral classes into informational classes or land cover classes.
32. **Save** the map document and name it **Image Classification**.
33. Go to **Spatial Analyst Tools > Reclass > Reclassify**.
34. In the **Input raster**, select **unsup1993**.
35. In the **Reclassification**, click on **Unique** to enlist all 30 classes.
36. You can now set the classes on the **New values** field. Take note of the numerical representation of each land cover class [1 **Water**; 2 **Built-up**; 3 **Agriculture**; 4 **Open/Bare**; and 5 **Forest**].
37. Once you are finished, set the **Output raster name** to **makiling1993**.
38. Click **OK**.
39. Click **Save**.
40. Follow the same procedure to generate another thematic layer of the area and name it **makiling2002**.

**ACCURACY ASSESSMENT**

1. You need to assess now the reliability of the image that was classified. To do that, you have to generate random points first for validation.
2. Go to **ArcToolbox**.
3. Click on **Data Management Tools > Feature Class > Create Random Points**.
4. From the **Create Random Points**, type **RandomPoints** in the **Output Point Feature Class**.
5. In the **Number of Points > Long**, type 25.
6. Leave other default settings then click **OK**.
7. The random points have been created. You can change the symbology if you wish to.
8. Right click on **RandomPoints** and click **Open Attribute Table**.
9. Click on **Table Options** then **Add Field**.
10. In the **Add Field** window, type **Actual** in the **Name** text box and select **Short Integer** under **Type**.
11. Click OK.
12. Click Start Editing, select RandomPoints then click OK.
13. Take note, you will encode numerical values representing the land cover classes: 1 – Water; 2 – Built-up; 3 – Agriculture; 4 – Open/Bare Areas; and 5 – Forest.

14. You can use the original composite image i.e. landsat1993 to identify the different land cover classes.
15. After you have completed all 25 points, click on Editor drop down, click Save Edits then click Stop Editing.
16. Now we can extract values from the classified image to compare with the actual values.
17. From the ArcToolbox, click on Spatial Analyst Tools > Extraction > Extract Values to Points.
18. From the **Extract Values to Points** window, select **RandomPoints** from the **Input point features** drop down.
19. In the **Input raster** box, select the **makiling1993** and type **ExtractPoints** in the **Output point features**.
20. Click **OK**.
21. Open the attribute table of **ExtractPoints**.
22. From the **Table Options**, click **Add Field**.
23. Type **Classified** in the **Name** text box and select **Short Integer** from the **Type** drop down. Click **OK**.
24. Right click on the **Classified** field and click **Field Calculator**.
25. Double click **RASTERVALU** from the **Fields** then click **OK**.
26. Go to the attribute table of **ExtractPoints**. Notice the **Classified** field has the values already as that of **RASTERVALU**.

27. Select and right click on **RASTERVALU** then select **Delete Field**. Click **Yes**.
28. Now you can use the **Actual** and **Classified** fields to generate the error matrix for the assessing accuracy of the image.
29. Select the **Actual** and **Classified** fields then right click on **Actual** and click **Sort Ascending**.
30. Fill up the table below based on the random points you generated:

**Sample Error Matrix**

<table>
<thead>
<tr>
<th>Classified</th>
<th>Actual</th>
<th>TOTAL</th>
<th>User’s Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>1</td>
<td>50</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>1</td>
<td>57.14</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>1</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>5</td>
<td>83.33</td>
</tr>
<tr>
<td>TOTAL</td>
<td>4</td>
<td>6</td>
<td>Overall Accuracy = 17/25 = 68%</td>
</tr>
</tbody>
</table>

Note: 1 Water  2 Built-up  3 Agriculture  4 Open/Bare  5 Forest

31. Click **Save** and name your map document as **Image Classification**.

**LAND COVER CHANGE ANALYSIS**

1. Uncheck all thematic layers in the **Table of Contents** except for **makiling1993**.
2. Right click on **makiling1993** and click **Open Attribute Table**.
3. Click the **Table Options** then click **Add Field**.
4. Type **AREA** in the **Name** text box and select **Double** under **Type**.
5. Set **Precision** to 20 and **Scale** to 2. Click **OK**.
6. Right click on **AREA** and click **Field Calculator**.
7. On the **Field Calculator** window, enter the following expression:
   \[ \text{[Count]} \times 28.5 \times 28.5 / 10000 \]

8. Click on **Table Options** and click **Export**.
9. Click the folder directory and navigate to your working directory. In the **Name** text box, type **makilingcover1993** and choose **dBASE Table** in **Save as** type. Click **Save** then click **OK**.
10. Open the **makilingcover1993.dbf** with Microsoft Excel. Calculate the area again if during export it was not included. Use the equation in step 7.
11. Save the **Excel File** as **Relative Change**.
12. Now go back your **ArcMap** and add **makiling2002**.
13. Repeat steps 2 to 9 and name the .dbf file as **makilingcover2002**.
15. Using the two images – **makiling1993** and **makiling2002**, we can also determine the changes that happened in each land cover class over these periods.
16. To do this, go to **ArcToolbox** and navigate to **Spatial Analyst Tools > Zonal > Tabulate Area**.
17. In the **Tabulate Area** window, select **makiling1993** for the **Input raster or feature zone data** while **makiling2002** for the **Input raster or feature class data**.
18. In the Output table, name it LCC_Areas. Click OK.
19. In the Table of Contents, locate the newly added LCC_Areas and right click on it then click Open. These values are in square meters (m²).

<table>
<thead>
<tr>
<th>OBJECTID</th>
<th>VALUE</th>
<th>VALUE_1</th>
<th>VALUE_2</th>
<th>VALUE_3</th>
<th>VALUE_4</th>
<th>VALUE_5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>42441433.25</td>
<td>11125200.5</td>
<td>2938720.5</td>
<td>2029000.5</td>
<td>836617.5</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1457176.5</td>
<td>64232730</td>
<td>17503987.5</td>
<td>55444185</td>
<td>1271983.5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>63118.25</td>
<td>93318590.25</td>
<td>202192580.25</td>
<td>84911802.75</td>
<td>60339815.75</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>170372.5</td>
<td>65349827.25</td>
<td>47558049.75</td>
<td>77428106.75</td>
<td>3443127.75</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1238918.25</td>
<td>10049400.75</td>
<td>21887987.25</td>
<td>64551944.25</td>
<td>48345208</td>
<td></td>
</tr>
</tbody>
</table>

20. Click on Table Options then Export.
21. Navigate to your working directory and name the file as Land Cover Change. From the Save as type, choose dBASE file.
22. Click Save then click OK.
23. Open the file using Microsoft Excel and change the values into their equivalent land cover class to generate some interpretations of the data.
24. Convert the values to hectares.
25. To spatially interpret the results, we can identify these changes from one land cover class to another by using Combine from ArcToolbox. Go to Spatial Analyst Tools > Local > Combine.
26. From the **Combine** window, add **makiling1993** and **makiling2002** in the **Input rasters**.
27. Set the output filename to **Combine**. Click **OK**.
28. The **Combine** raster layer is added to the **Table of Contents** showing 25 possible combinations.

29. Right click on **Combine** and click **Open Attribute Table**. Observe the combination of changes from the two periods.
30. Try to select 13 from the Value field. This indicates a change from 5 in 1993 to 3 in 2002. Note that 5 represents Forest and 3 represents Agriculture. Try other Values.
Annexes
ANNEX 1: MODELING LANDSLIDE VULNERABILITY USING ARCGIS™ MODELBUILDERTM

OBJECTIVES:

At the end of the exercise, the participants should be able to:

1. Identify different factors contributing to landslide vulnerability;
2. Develop a landslide model using ArcGIS™ ModelBuilder; and
3. Generate a landslide vulnerability map using the developed model.

INTRODUCTION

The watershed is recognized as one of the priority areas for climate change mitigation and adaptation in the Philippines. Aside from being a potential carbon sink, watersheds provide several services such as hydroelectric and geothermal power generation, irrigation for agriculture, and domestic water supply, among others. A watershed is defined as a topographically delineated area of land that captures water in any form, such as rain, snow, or dew, and drains it to a common water body, i.e. stream, river, or lake (DeBarry, 2004). Its boundary is defined by the higher elevations or ridges that define which direction that rainwater will flow. Watersheds also contain various types of ecosystems that provide water, timber and non-timber forest products like food, fiber and minerals. They also provide different kinds of environmental services such as protection, aesthetics, wildlife sanctuary, and recreational amenities. However, due to the increasing environmental problems, most of these functions in the watersheds of Southeast Asia have been adversely affected by several environmental risk and hazards such as landslides, typhoons, biodiversity loss, human health risks, and water availability, among others. Hence, vulnerability assessment of watersheds to climate change has become a fundamental issue in the international community as well as in developing countries like the Philippines. Specifically, the main focus of this paper is on assessing vulnerability of landscapes to landslides and flooding using geospatial processes and techniques.

Vulnerability assessment plays an important role in understanding the dynamics and inter-relationships of various factors leading to the susceptibility of certain entities to a particular event or phenomenon. In most studies, it is also considered an essential requisite in the advancement of further research because of the information it generates from the process.

Through the years, various definitions and descriptions of vulnerability have emerged from literature. Specifically, the term vulnerability has mostly been used with different meanings in different contexts and by different authors. This has posed problems because these various interpretations sometimes create confusion among researchers and institutions. Nevertheless, Kaly et al. (2004) discerns the importance of vulnerability because of its growing international recognition in the development of indices to assess not only the country’s vulnerability or resilience but also as a measure of its sustainability. In addition, the comparison of vulnerability across countries enables the identification of ways to reduce vulnerability to climate change (Easterling et al., 2000; Frich et al., 2002; Brooks et al., 2004). This can be achieved by observing the trends in the frequency and severity of existing hazards and how these interact with the environment. Based on the latest definition of Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, vulnerability is mainly referred to as the propensity or predisposition to be adversely affected. It encompasses a variety of elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.
GEODATABASE

1. Copy the Landslides folder this exercise and Paste it to your C:\FMBTraining directory.
2. Start ArcMap.
3. Click the Geoprocessing menu then click on Environments.
4. Expand the Workspace and in the Current Workspace set it to C:\FMBTraining\Landslides\Makiling.gdb while under the Scratch Workspace, set it to C:\FMBTraining\Landslides\Output.gdb.

5. Click OK.
6. Open ArcCatalog and navigate to the Landslide folder directory.
7. Double click on Makiling.gdb and you’ll see three (3) raster datasets and four (4) feature datasets.
8. Drag and drop all seven (7) datasets to your Table of Contents in ArcMap.
9. Click Save and navigate to your working directory and provide a File name using Landslide Vulnerability.
10. Click Save.
11. Click Customize then Extensions. Make sure the Spatial Analyst is checked. Click Close.
12. To add the Spatial Analyst toolbar, go to Customize > Toolbars > Spatial Analyst.
13. Save your document.

MODELBUILDNER

1. Using ArcCatalog, right click on your Landslides folder then New > Toolbox.
2. Rename it to Landslide Modeling Tools.
3. Right click on the Landslide Modeling Tools and click New > Model.
4. An empty ModelBuilder session will open.
5. Click on Model then Model Properties.
6. Click the General tab.
7. Type LandslideVulnerability in the Name and Modeling landslide vulnerability in the Label text box.
8. Check the Store relative path names (instead of absolute paths).
9. Next, click on the **Environments** tab.
10. Expand **Processing Extent** and check **Extent**.
11. Expand **Raster Analysis** and check **Cell Size**.

12. Click **Values**.
13. Set the **Extent** of **Processing Extent** to **Same as layer dem**. Also, in the **Cell Size** under **Raster Analysis**, set it to **Same as layer dem**.

14. Click **OK** and click again **OK**.
15. Click **Save**.
16. From the Table of Contents, drag the layers rainfall, dem, rivers and structures to your model.
17. In the ArcToolbox, go to Spatial Analyst > Interpolation and drag IDW in line with the rainfall dataset in the model.
18. Then click and drag the Slope tool from Spatial Analyst > Surface into your model and place it in line with your dem data.
19. Locate the Euclidean Distance tool in the Spatial Analyst > Distance toolset.
20. Click and drag the Euclidean Distance tool in line with the rivers.
21. Repeat the previous step but this time place the Euclidean Distance tool in line with structures.
22. Click the Connect tool to link rainfall to the IDW tool. Select Input point feature.
23. Repeat this same process for dem, rivers and structures.
24. On the Model toolbar, click the Select tool and click the Auto Layout button, then click the Full Extent button to apply the current diagram properties.
25. Click Save.
26. Double click on IDW tool. Set the Z value field to RAINFALL. Click OK.
27. Right click on the output and Rename it to Monthly Rainfall.
28. Double click on Slope tool. Leave the Input raster and Output raster as the default values.
29. In the Output measurement, choose PERCENT_RISE. Click OK.
30. Right click on the output variable (Slope_dem1) and Rename it to Slope Classes then click OK.
31. However, for the rivers and structure, leave all default parameters.
32. Rename the output variables into Distance to Rivers and Distance to Structures.
33. Right click on each output variable then click on Add To Display.
34. Run the model. Click the Auto Layout and Full Extent buttons.
35. Save the model.
Slope

Distance to Rivers

Distance to Structures
RECLASSIFY

1. Locate the **Reclassify** tool in the **Spatial Analyst Tools** toolbox **Reclass** toolset. A rating of 1 to 5 will be used in this modeling where a value of 1 indicates low vulnerability and 5 indicates high vulnerability.

2. Click and drag the **Reclassify** tool onto the **ModelBuilder** in line with **Monthly Rainfall** and another to **Slope Classes**. Also drag **Reclassify** tool in line with **dem**, another **Reclassify** tool in line with **Distance to Rivers** and finally, another **Reclassify** tool in **Distance to Structures**.

3. Click the **Connect** tool and connect them.

4. Click the **Select** tool, then click on **Auto Layout** button then click the **Full Extent** button.

5. First, open the **Reclassify** tool connected to **Slope Classes** variable.
6. From the **Reclassify** window, click on **Classify** and the **Classification** window appears.

7. Click the **Classes** drop down arrow and click 5. Edit **Break Values** and set the thresholds to 8%, 18%, 30%, 50% and leave the last value as is (this will constitute the class >50%).

8. Click **OK**.

9. Rename the output variable from the **Reclassify** tool to **Reclassed Slope**.

10. Next is to reclassify the **rainfall**. Double click on **Reclassify** tool then set the **Classification Method** to **Natural Breaks (Jenks)** and set **Classes** to 5. Click **OK**.

11. Rename the output to **Reclassed Rainfall**.
12. Next is to reclassify the dem. Double click on the Reclassify tool connected to dem.
13. Click on Classify and from the Classification Method, choose Natural Breaks (Jenks) and set the Classes to 5.
14. Click **OK** then click **OK** again.
15. Rename the output variable from the **Reclassify** tool to **Reclassed Elevation**.
16. Now, open the **Reclassify** tool connected to the **Distance to Rivers** variable.
17. Click on **Classify**.
18. Set the **Classification Method** to **Natural Breaks (Jenks)** and the number of **Classes** to 5.
19. Click OK.

20. Click Reverse New Values. Clicking this makes it so that distances close to rivers have a higher new value since these are more susceptible to landslide.

21. Click OK.

22. Rename the output variable from the Reclassify tool to Reclassed Distance to Rivers.

23. Lastly, open Reclassify tool connected to the Distance to Structures variable.

24. Click on Classify and set the Classes to 5 (regardless of classification method).

25. Edit the Break Values and set the thresholds to 500, 2,000, 5,000, 8,000 and leave the last class as is (this will cover the distance >8,000). Click OK.

26. Click Reverse New Values to highlight that distances close to structures have a higher susceptibility to landslide.
27. Click **OK**.
28. Rename the output variable to **Reclassed Distance to Structures**.
29. Right click each of the variable outputs – **Reclassed Rainfall**, **Reclassed Slope**, **Reclassed Elevation**, **Reclassed Distance to Rivers**, and **Reclassed Distance to Structures** – and click **Add To Display**.
30. Click **Auto Layout** and then the **Full Extent** button.
31. Click **Run** button to execute the three **Reclassify** tools in your model.
32. Click **Save** button.

Reclassified Elevation
Reclassified Slope

Reclassified Distance to Rivers

Reclassified Distance to Structures
WEIGHTED OVERLAY

1. You are now ready to combine the reclassified datasets with the land use and geology of the area to generate landslide vulnerability.
2. You will assign the inputs the following percentages of influence or relative weights of each factor:
   a. Reclassed Slope – 30%
   b. Reclassed Rainfall – 10%
   c. Reclassed Elevation – 10%
   d. Reclassed Distance to Structures – 10%
   e. Reclassed Distance to Rivers – 10%
   f. Landuse – 15%
   g. Geology – 15%
3. Click and drag the Weighted Overlay tool, located in the Spatial Analyst toolbox Overlay toolset into the ModelBuilder.
4. Open the Weighted Overlay tool.
5. Type 1, 5 and 1 in the From, To and By text boxes.
6. Click Apply.
7. Add the Reclassed Slope to the Weighted Overlay tool. Click the Add Raster Row button and for the Input raster, select Reclassed Slope from the drop down list and leave the Input field as Value. Click OK.
8. The raster is added to the **Overlay Weighted Table**. The **Field** column displays the values of the **Reclassed Slope** data. The **Scale Value** column mimics the **Field** column because the **Evaluation Scale** was set to encompass the range of values in each input raster.

![Image of Overlay Weighted Table](image_url)

<table>
<thead>
<tr>
<th>Raster</th>
<th>% Influence</th>
<th>Field</th>
<th>Scale Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reclassed Slope</td>
<td>100</td>
<td>Value</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NODATA</td>
<td>NODATA</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Sum of influence**: 100

**Evaluation Scale**: 1 to 5 by 1

**Output raster**: C:\Users\pavilion\Documents\Training and Conference\DAPIA\D\Datasets\Landslide\Output.gdb
9. Repeat the previous step for each of the reclassified datasets including **Reclassified Rainfall**, **Reclassified Elevation**, **Reclassified Distance to Rivers**, and **Reclassified Distance to Structures**.

10. Now add the **landuse** and **geology** layers.
11. Initially, select the **landuse** from the **Input raster** box. From the **Input field**, choose **landuse** then click **OK**.
12. Change the default **Scale Values** for **landuse** following the values:
   - Annual Crop – 4
   - Built-up – 4
   - Closed Forest – 1
   - Grassland – 3
   - Inland Water – 3
   - Open Forest – 1
   - Perennial Crop – 2
   - Shrubs – 3
   - Wooded Grassland - 3

13. Now add the **geology** layer. From the **Input field**, select **geology** then click **OK**.

14. Change the default **Scale Values** for **geology** following the values:
   - Pliocene-Quaternary – 1
   - Lake – Restricted
   - Recent – 5

15. You’ll now assign a percentage of influence to each raster. This is mainly based on how much importance (or weight) each should have in the final susceptibility map.

16. In the **% Influence** column, type the percentages for each of the input rasters:
   - Reclassed Slope – 30%
   - Reclassed Rainfall – 10%
   - Reclassed Elevation – 10%
   - Reclassed Distance to Rivers – 10%
   - Reclassed Distance to Structures – 10%
   - Landuse – 15%
   - Geology – 15%
17. Click OK.
18. Rename the output variable of the Weighted Overlay to Landslide Vulnerability.
19. Right click and select Add To Display.
20. Accept the Output raster then click OK.
21. Click Auto Layout button then click Full Extent. The entire model is shown below.
22. **Run** the model then **Save** the model.
23. The final model should look like something below.
ANNEX 2: FLOOD MODELING USING HEC-HMS AND HEC-RAS

OBJECTIVES
At the end of the exercise, the participants should be able to:
1. Conduct basin development using HEC-HMS;
2. Generate rainfall-runoff model for the watershed; and,
3. Perform hydraulic modeling using HEC-RAS

INTRODUCTION
Flooding has become one of the most devastating hazards in the country that caused tremendous damage to both the environment and the economy, and has affected the lives of many Filipinos. That is why the national government is continuously trying to find ways to generate accurate flood hazard maps in major urban areas and critical watersheds in the country. This is to provide the local government units with precise information that are necessary in dispensing appropriate interventions in the affected areas. Hence this exercise introduces the use of two modeling techniques developed by the Hydrologic Engineering Center – the Hydrologic Modeling System (HMS) and the River Analysis System (RAS). HEC-HMS is a rainfall–runoff model that converts precipitation excess to overland flow and channel runoff, while HEC-RAS is a hydraulic model that generates unsteady state flow through the river channel network based on the HEC-HMS-derived hydrographs.

BASIN MODEL DEVELOPMENT USING HEC-GEOHMS

Preparation of Data
1. Copy the Flood Modeling folder to C:\FMBTraining
2. Open ArcMap™.
3. Go to Geoprocessing > Environments > Workspace.
4. Set the Current Workspace to C:\FMBTraining\Flood Modeling\Flood.gdb. On the other hand, set the Scratch Workspace to C:\FMBTraining\Flood Modeling\Output.gdb.
5. Click OK.
6. Click Add Data button and navigate to your directory to add Boac_Streams and dem. Click Add.
7. Install HEC-GeoHMS, HEC-GeoRAS, HEC-HMS and HEC-RAS if not yet pre-installed.
8. After installation, go to Customize > Extension and make sure that 3D Analyst, Spatial Analyst and Network Analyst are checked.
9. Click on Customize > Toolbars and check HEC-GeoHMS.

10. Save ArcMap and navigate to your folder (C:\FMBTraining\Flood Modeling) and name it as Flood Model.

*Basin Model Development*

1. From the HEC-GeoHMS toolbar, click on Preprocessing and execute the following parameters under this tab:
Note: HEC-GeoHMS automatically creates a folder and geodatabase to organize its output files, so there is no need to change the output directory.

- **DEM Reconditioning**
  - Input Raw DEM: dem
  - Input Agree Stream: Boac_Streams
  - Check Raise Negative Values
- **Build Walls**
  - Input DEM: AgreeDEM
- **Fill Sink**
  - Input DEM: WalledDEM
- **Flow Direction**
  - Input Hydro DEM: Fil
- **Flow Accumulation**
  - Input Flow Direction Grid: Fdr
- **Stream Definition**
  - Input Flow Accumulation Grid: Fac
  - Area SqKm to define stream: Default
  
  Note: If Area SqKm to define stream is lower than 5 leave as is. Or you match the defined streams to the streams in NAMRIA maps.
- **Stream Segmentation**
  - Input Stream Grid: Str
  - Input Flow Direction Grid: Fdr
- **Catchment Grid Delineation**
  - Input Flow Direction Grid: Fdr
  - Input Link Grid: StrLnk
- **Catchment Polygon Processing**
  - Input Catchment Grid: Cat
- **Drainage Line Processing**
  - Input Stream Link Grid: StrLnk
  - Input Flow Direction Grid: Fdr
- Adjoint Catchment Processing
  - Input Drainage Line: DrainageLine
  - Input Catchment: Catchment
- Save ArcMap

**Project Set-up**

- Start New Project
  - Project Area and Project Point – use default
  - Define New Project Window will appear
    - Project Name: Boac
    - Description: Flood modeling
    - Click OK
    - New Window with instruction will appear, click OK.
- Add Project Points
  - Click Add Project Point and click to the Outlet of the Boac Watershed
  - Note: Make sure to click on the defined stream.

  - Project Points for Boac
    - Point Name: Boac_Outlet
    - Description: Outlet 1
    - Click OK

- Generate Project
  - Generate Project, click Yes then a window will pop-up
  - Generate Project Window
    - Subbasin: Boac_Sub
    - River: Boac_River
• Click OK.

The result must be the same as the image below. Click OK when successfully completed.

Characteristics

• River Length
  ▪ Input River: Boac_River

• River Slope
  ▪ Input Raw DEM: RawDEM
  ▪ Input River: Boac_River

• Basin Slope
  ▪ Click Customize>Toolbars>Check Arc Hydro Tools
Under Arc Hydro Toolbar

- Terrain Preprocessing > Slope
  - RawDEM: Fil
  - Slope Type: Percent_Rise
  - Slope: WshSlope

Go back to GeoHMS toolbar and click on Characteristics > Basin Slope

- Input Slope Grid: WshSlope (created using Arc Hydro Tool)
- Input Subbasin: Boac_Sub

- Longest Flowpath
  - Input Raw DEM: RawDEM
  - Input Flow Direction Grid: Fdr
  - Input Subbasin: Boac:Sub

- Basin Centroid
  - Select Centroid Method: Center of gravity
  - Input Subbasin: Boac_Sub

- Centroid Elevation
  - Input Raw DEM: RawDEM
  - Input Centroid: Centroid 423

- Centroidal Longest Flowpath
  - Input Subbasing: Boac_Sub
  - Input Centroid: Centroid 423

Input Longest Flow Path: Longest Flowpath423

Parameters

- Select HMS Processes
  - Input Subbasin: Boac_Sub
  - Input River: Boac_River
  - Subbasin Loss Method: SCS
  - Subbasin Transform Method: SCS
  - Subbasin Baseflow Method: Recession
River Route Method: Lag

- River Auto Name: Boac_River
- Basin Auto Name: Boac_Sub
- Add the Boac_SoilLU and cnlookup from the CN Lookup Table folder
- Under Utility tab
  - Click Generate CN Grid
  - Input Hydro DEM: Fil
  - Input Soil Landuse Polygon: Boac_SoilLU
  - Input Curve Number Lookup: cnlookup

- Back to Parameters tab menu
- Subbasin Parameters from Raster
  - Input Curve Number Grid: CN Grid
- Muskingum-Cunge and Kinematic Wave Parameters
  - Provide 0.04 value for Manning’s N

- Save map document
- Map to HMS Units
  - Click OK then Select Unit Type: SI
- Check Data: Default

- HMS Schematic: Default
- Toggle Legend > Select HMS Legend
- Add Coordinates
  - Click OK
- Prepare Data for Model Export, click OK then click Yes

- Background Shapefile: Default, click OK.
HYDROLOGIC MODELING USING HEC-HMS

Model Set-up

Note: Add New folder in the Boac Folder and Name it HMS.

1. Open HEC-HMS 3.5
2. Click File, choose New and Create New Project, navigate to your directory, create New Folder and name it HMS
3. Name the Project Boac then click Create.
4. Click File, choose Import then select Basin Model, locate the .basin file created using HEC-GeoHMS (e.g. Boac.basin)
5. Open the basin model on the watershed explorer window and the HMS schematic will appear. Then right click on the Window, select Background Layers, then add the basin shapefile of the watershed (Boac_sub) then click Select then close.
6. In the Watershed Explorer Window, locate the lowermost junction (e.g. J274) and rename it to “Junction”. This will serve as the starting point of hydrologic model.

Set Parameter Values

** All required values are provided in Boac_data excel file

From the Parameter menu, select

- Loss - SCS Curve Number. (Input Initial Abstraction)
• Sorting should be set to Alphabetic, copy Initial Abstraction from Boac_Data.xlsx under the Loss worksheet.
• Paste then set Impevious column to '0' then click Apply.
• Transform – SCS Unit Hydrograph (Input Lag Time)
• Baseflow – Recession (Initial Discharge, Recession Constant, Ratio to Peak)
• Routing – Lag (Lag Time)

Create a Meteorologic Model
1. From the Components menu, select Meteorologic Model Manager. Create a New meteorologic model and name it 100-year storm. Click Create.
2. In the watershed explorer window, expand the Meteorologic Model
3. Click the Meteorologic Model and select Frequency Storm from Precipitation
4. On the Basins tab, select Yes in the Include subbasins column.
5. On the watershed explorer, under Meteorologic Model>100-year storm, click Frequency Storm
   - Probability: 1 Percent
   - Input Type: Annual Duration
   - Intensity Duration: 5 minutes
   - Storm Duration: 1 Day
   - Intensity Position: 50%
6. Input required values (with asterisk), get values from RIDF worksheet. Click Save.

Create Control Specification
1. From the Components menu, select Control Specification Manager. Create New control specification and name it, Typhoon Ruby.
2. In the watershed explorer, expand Control Specifications folder and click Typhoon Ruby.
3. Fill Control Specifications tab with the given date in the Excel file.
4. Set Time Interval to 10 minutes.
Create Simulation Run

1. From the Compute menu option, select Create Simulation Run and name it Typhoon Ruby. Click Next until you reach Finish.

2. From the watershed explorer window, click on Compute tab menu. For Basin Model, use Boac. For Meteorologic Model, use 100-year storm. For Control Specification, use Typhoon Ruby.

3. From the Compute option menu, select Compute Run [Typhoon Ruby].

4. From the watershed explorer, select Results tab, expand Simulation Runs>Typhoon Ruby>Junction then select Time Series Table (this provide outflow values that will be used in HEC-RAS modeling).
HYDRAULIC MODELING USING HEC-RAS
Geometric Data Preparation (HEC-GeoRAS)

A. Prepare Flowpaths
1. Open Google Earth. Go to Boac Bridge (13°27'0.12"N, 121°50'49.67"E).
2. From the bridge facing downstream, click Add Path then digitize the River Banks, River Flowpaths, and Centerline from the bridge to the outlet.
3. Save the digitized path as KML.
4. Convert the saved KML to Shapefiles.

B. Prepare Geometric Data
1. Open ArcGIS
2. Under ArcMap, Install GeoRAS Extension
   - Customize>Extension
   - Check the following: 3D Analyst, Network Analyst, Spatial Analyst
   - Customize>Toolbars>HEC-GeoRAS
3. Save the ArcMap project. File>Save as>Save project .mxd
4. Click Add Data then load DEM and shapefiles (centerline, flowpaths, and banks).
5. Convert the raster DEM of Boac into floating raster (.flt). Open Toolbox, Select Conversion Tools>From Raster>Raster to Float
   - Name it Boac_float
   
   **this float (.dem) will be used in HEC-RAS**

6. On the GeoRAS toolbar, under RAS Geometry
   - click Layer Setup
     - Required Surface>Single>GRID>Select Boac_DEM file>OK
     
     - click Create RAS Layer>All>OK
     
     - click Create RAS Layer>All>OK
Delete all created RAS Layers except:

- River
- Banks
- Flowpaths
- XSCutlines

**Copying River Shapefiles to RAS Layers**

1. On the table of contents, click River > Edit Features > Start Editing
2. On the Window explorer:
   - click centerline > Right click > Copy
   - Click anywhere on the Window > Right click > Paste
   - Select Target: River
**Do the same for the banks and flowpaths**

**Include centreline of the flowpaths**

3. Click Assign River Code and Reach Code to River Button
   - Click River centreline
     - River Name: Boac River
     - Reach Name: Boac

4. Click Assign Line Type Attributes button
   - Click Left flowpath
     - Line Type: Left
   - Click Right flowpath
     - Line Type: Right
   - Click River
     - Line Type: Channel
5. Under RAS Geometry
   - Select Stream Centerline Attributes>Click All
     o Stream Centerline: River
     o Terrain: Boac_DEM
     o Stream Profiles: River 3D

6. Click Construc XS Cutlines
   - XS Cutlines: XSCutlines
   - Stream Centerline: River
   - Interval: 800 meters
   - Width: 1000 meters

7. Right click XSCutlines> Edit Features> Start Editing
   - Start editing cross-sections
   - Save Edits
Notes: There should be no intersection between cross-section lines. Cross-section lines and Centerline must have perpendicular intersection.

8. Under RAS Geometry
   - Select XSCutlines Attribute
     - Choose All> Click Okay

   - Click Layer Setup>Required Layers
     - Stream Centerline: River
     - XS Cutlines: XSCutlines
o XS Cutlines Profiles: XSCutlines3D

- Under Optional Layers
  o Banklines: Banks
  o Flowpath: Flowpaths
  o Stream Profiles: River3D
  o Other option: Null

9. Under RAS Geometry
   - Click Export RAS Data
• Click the folder icon> go to Boac> HECRAS Folder> Create New folder, name It Geometric Data> Save the file and name it GIS2RAS

Hydraulic Modeling Using HEC-RAS

1. Open HEC-RAS 4.1.0
• Click File>Save Project as> Go to your Boac Folder> Save the project inside HECRAS folder> create new folder> name it BoacRASand name it as BoacRAS> Save the Project, name it BoacRAS> Click Okay

2. Under Edit menu option, Select Geometric Data; geometric data interface will appear
3. Under Geometric Data Interface
• File>Import Geometric Data>GIS Format>Choose the .sdf file (file created in ArcGIS)>Click OK
• Import Geometric Data dialog box will appear>Click SI(Metric Units)>Click Finish Import Data
4. Under Geometric Data interface
   - Click Tables > Edit Manning's n or k values
     - n#1: 0.05
     - n#2: 0.03
     - n#3: 0.05
   - Click Tools > Cross Section Points Filter > Multiple Locations > All RS > Minimal Area Change
     - Number of Points to trim cross section down to: 480
     - Click Filter Points on Selected XS
Click OK

- Click File>Save Geometric Data As>Save Geometric Data inside C:\FMBTraining\Flood Modeling\Boac\HECRAS\GeometricData and name it Boac_Geo

5. Under main interface
- Click Edit>Unsteady Flow Data

- For the upstream cross section: Flow Hydrograph
  - Data time interval: 10 minutes
  - No. of Ordinates: 145 (depends on the number of discharge values of the given data)
  - Fixed Start time: 23Dec2014, 17:00
Copy Discharge data to the Flow Hydrograph (generated using HEC-HMS)

Click Plot Data

- For the downstream cross-section: Normal Depth
  - Friction Slope: 0.01
  - Click Ok

6. Click File> Save Unsteady Flow Data As
   - Create new folder inside the HECRAS folder > name it as FlowData
7. Under the main interface:
   - Click Run> Unsteady Flow Analysis
   - Enter Simulation Date and Time
   - Computation Interval, Hydrograph Output Interval, Detailed Interval: 10 minutes
   - Click File>Save Plan As>Save Plan in BoacRAS folder> name it Boac_UnsteadyAnalysis
   - Compute
8. Under the main interface
   - Click View> X-Y-Z Perspective Plots
   - Click the Animate the simulation results button

9. Under the main interface
   - Click GIS Tools> RAS Mapper
   - Under RAS Mapper
     - Click Tools> Floodplain Mapping

10. Under Floodplain Mapping Window
    - Under Ground Surface
      - Terrain Layer> Click New Terrain> Load Boac_float
    - Under Layers to Generate Category
- Profiles: Check Max WS only
- Variables: Water Surface Elevation
- Click Generate Layers

- New Layer will be Generated
REFERENCES


