APPENDIX 4 EXAMPLES OF REGULATIONS AND FORMS FOR GROUNDWATER DEVELOPMENT AND MANAGEMENT

TABLE OF CONTENTS

1. Notice of Intention to Construct a Well/Borehole (Kenya)

KENYA - Water (General) Rules

116. (1) The notice of intention to construct a well required under section 51 of the Act shall be in form No. W.A.B. 26 in the Second Schedule to these Rules, except where such well is to be situated within a conservation area notified under section 74 of the Act, or within 100 yards of any body of surface water.

(2) Such notice shall be submitted not less than one month before construction is due to commence, and shall be accompanied by a sketch map, or Land Office plan, in duplicate, on a scale of not less than one inch to one mile, on which shall be shown the boundaries of the land on which it is proposed to construct the well, the approximate position of the proposed well and, if possible, the position of the nearest body of surface water and of the nearest existing well.

(3) Notice of the date of commencement of construction of the well shall be given by letter not later than the day on which the construction commences, and such notice shall give the name of the borehole contractor constructing the well.

(4) A notice of intention to construct a well shall be acknowledged by the Water Apportionment Board, and such acknowledgement shall state the number allocated to the well; and such number shall be used in all future references to such well.

117. Where the well is to be situated within a conservation area or within 100 yards of any body of surface water, the notice of intention to construct shall be in the form of an application for a permit, and shall be in form No. W.A.B. 29[1] in the Second Schedule to these Rules.

Form W.A.B. 26
Notice of Intention to Construct a Well/Borehole

In accordance with section 51(1) of the Water Act, I hereby give notice of my intention to construct a well (borehole) as detailed below:

1. Name .....
2. Postal address .....
3. Land Reference No. of plot or farm ..... Acreage .....
4. Purpose for which water will be used .....
5. Proposed borehole contractor (if known) .....
6. Proposed date of commencement (if known) .....
7. Distance well will be from nearest existing well/borehole .....
8. Quantity of water to be taken from well daily .....

.....
Signature of Applicant or duly Authorized Agent

Date .....

NOTES

1. This form is to be used only if the well or borehole is to be situated:
   (a) outside a conservation area notified under section 74 of the Water Act; and
   (b) more than 100 yards from any body of surface water.
2. If the conditions under Note 1 are fulfilled, no authorization is needed to proceed with the work, but it will be necessary to notify the Water Apportionment Board when construction commences and, unless otherwise exempted, to submit the drilling record in form No. W.A.B. 28[1] on completion of the work, whether the well or borehole is a success or not.
3. If the well or borehole is to be situated less than one-half mile from the nearest existing well or borehole, the written authority of the Water Apportionment Board is required under section 50(2) of the Act before the construction or extension of a well or borehole is commenced.
   Except that written authority is not required where the total quantity of water to be extracted in any one day will not exceed 5,000 gallons (or such other quantity as the Water Apportionment Board may approve) and the well or borehole is to be not nearer than 250 yards from any other well or borehole.
4. This form is to be submitted not less than one month before construction of the well or borehole is due to commence, and must be accompanied by a sketch map or Land Office plan, in duplicate, on a scale of not less than one inch to the mile, on which must be shown the boundaries of the land on which it is proposed to construct the well or borehole, the approximate position of the proposed well or borehole and, if possible, the position of the nearest body of surface water and of the nearest existing well or borehole.

FOR USE OF THE WATER APPORTIONMENT BOARD ONLY

Acknowledgment issued on .....
W.A.B. Well No. allocated .....
Written authority of the W.A.B. (under Note 3) issued on .....

[1] Omitted.

2. Application for a Grant of Water Right (Ground Water) (Malawi)

MALAWI - Water Regulations, 1969

Form WRB.2

Application for a Grant of Water Right/Certificate of Existing Rights* - (Ground Water)

This form to be submitted in triplicate.

To: The Chairman of the Water Resources Board

1. Full name of applicant .....
   Postal address .....
   Occupation .....
2. Details of land on which borehole .....
   * will be/has been sunk .....
   Give Registered No. .....
3. Give details of land where .....
   water will be used if .....
   different from (2) above .....
4. Acreage .....
5. Description of borehole/well .....
   Diameter, Depth, etc. .....
6. Details of pump (where hand-operated pump is used answer only (a) and (b)
   (a) Type of pump .....
   (b) Type of driving .....
   machine and fuel used .....
   (c) Brake horse power of (b) .....
   (d) Approximate elevation of pump above sea-level
   _____feet
   (e) How pump is connected to driving machine .....
   (f) Internal diameter of suction main ..... inches
   (g) height os suction (maximum) ..... feet
   (h) Height to which water is to be lifted above pump ..... feet
   (i) Internal diameter of delivery pipe ..... inches
   (j) Length of delivery pipe ..... feet
   (k) Pumping hours per day ..... hours
   (l) Quantity of water to be pumped when plant is working .....gals. per hour

(7) Purposes for which water is required:

	Gallons per day
Domestic	_____
Public	_____
Industrial	_____
Irrigation	_____
Any other purpose (to be stated)	_____
	_____
Total quantity of water per day	= = = = = = = =

(8) Alternative source of water available to the applicant (if any).

(9) The following are the existing boreholes within one-half mile of the site to which this application refers:

Borehole No. (if known)	Name of Farm (Reg. No.)	Distance from site
_____	_____	_____
_____	_____	_____

(10) */** I enclose herewith crossed cheque/Postal Order/Money Order No. _____ for £1-0s-0d to cover the prescribed fee for this application and undertake to pay the Malawi Government on demand the cost of insertion in the Government Gazette and in at least one newspaper circulating in Malawi of a Notice requiring any person objecting to the issue of a Grant of Water Rights to lodge such a complaint with the Chairman of the Water Resources Board.

Date: _____

_____
Signature of applicant or duly authorized agent

NOTE: This form is to be accompanied by a sketch map, in duplicate on a scale of not less than one inch to one mile, on which must be shown the farm or holding boundaries, the approximate position of the proposed borehole and existing boreholes within one-half mile radius and the position of any body of surface water.

* Delete as appropriate.

** This paragraph is not applicable to applications to record an existing right under the Act.

3. Format of Permit (Western Australia)

WESTERN AUSTRALIA - Rights in Water and Irrigation (Construction and Alteration of Wells) Regulations, 1963

Form 3
License under Section 20

No. of Licence .....

Name and address and occupation of licensee .....
Location of well ..... Municipal district of the .....
Lott, Location or Lease No. .....
Position .....

Thing which may be done pursuant to this License, i.e., commence construct enlarge, deepen, alter, or draw water from a well .....

Purpose for which the licensee may utilise the water .....

Period for which the license is issued .....

Special terms, limitation and conditions (if any) upon which the license is issued .....

This license is issued upon the conditions:

(i) that the information required under regulations 9 and 10 is forwarded as required;

(ii) that the quantity of water drawn from this well and the rate of draw does not exceed the figure which the Minister may from time to time determine under section 21 of the Act.

The work described hereon, and referred to in the application and plans and descriptions and statement of the purpose for which it is proposed to utilise the water deposited by or on behalf of the abovenamed ..... as finally approved by me, is hereby declared to be a licensed work under the Rights in Water and Irrigation Act, 1914 (as amended).

This license is issued subject to and in accordance with the regulations relating to artesian and non-artesian wells, made under the Act.

Given under my hand at Perth this ..... day of .....19..

.....
Minister for Works and Water Supplies

NOTE: No alteration shall be made in connection with the well, nor shall the water from the well be used for purposes other than those authorised by this license. See regulation 11.

On expiry of term for which license is issued, application for renewal may be made on Form No. 1[1].

---

[1] Omitted.

4. Obligations of Permit Holders (South Australia)

SOUTH AUSTRALIA - Underground Waters Preservation Regulations, 1970

9. The return required by section 19 of the Act shall be in the form set out in Schedule Six hereto and shall contain all information indicated as required in the said form.

10. (1) A person engaged in operations for the drilling or construction of a well for which a permit has been issued shall keep the following records and samples and shall, within 14 days of the completion or abandonment of such work, forward the records, copies of which shall be supplied to the permit holder, and samples to the Minister, provided however, that the Minister or an authorized person may at any time inspect the records and samples or request that they be forwarded to the Minister at such other time as he may think fit:

(a) Representative samples of not less than 1/2 lb. weight taken at each change of strata observed in the well, and in any case at intervals not exceeding 10ft. of advance of the well. Such samples to be enclosed in a suitable container, and to be clearly marked so as to identify the well and depth at which the sample was taken.

(b) A representative sample of not less than 26fl. oz. weight of each water cut in the well preserved in a suitable bottle and clearly marked so as to identify the well and the depth at which the sample was taken.

(c) Records showing details of:

(i) The depth at which water was cut and the level at which water stands below ground surface.

(ii) Casing inserted in the well.

(iii) Daily progress of drilling in each calendar week.

(iv) Construction methods used.

(2) The records required to be kept pursuant to paragraph (c) of this regulation shall be in the form set out in Schedule Seven hereto.

Schedule Six - Permit Completion Advice
Schedule Seven - Weekly Record of Daily Drilling

Schedule Six
Permit Completion Advice

To: The Minister of Mines
c/o Department of Mines

Well No.
Permanent:.....
Temporary:.....

In accordance with section 19 of the above Act, I hereby advise particulars of:
*(a) The Completion
*(b) The Abandonment
of the work specified in PERMIT No. .....
* Strike out line not applicable

Name of permit holder (BLOCK letters).....
Postal address.....
Property on which the work was carried out:
Allotment No. ..... Section No. ..... Hundred of .....
Name of driller .....
Drilling commenced .....
Drilling completed .....
If abandoned before completion of permitted work, state reason .....

DETAILS OF WELL

If new well:
Final depth ..... ft.
Details of casing(s) left in well:
Length ..... ft ..... in. Diameter ..... in.
Length ..... ft ..... in. Diameter ..... in.
Particulars of sand screen .....
or slotted casing or liner .....
Particulars of cementing .....
If work on existing well:
Original depth ..... ft.
Final depth ..... ft.
Details of casing(s) in well:
Before commencement of work:
Length ..... ft ..... in. Diameter ..... in.
Length ..... ft ..... in. Diameter ..... in.
After completion of work:
Length ..... ft ..... in. Diameter ..... in.
Length ..... ft ..... in. Diameter ..... in.
Particulars of sand screen .....
or slotted casing or liner .....
Particulars of cementing .....

DETAILS OF PUMP

Particulars of pump installed by .....
(1) Type ..... (2) Depth installed .....ft.
(3) Powered by (electric, diesel, etc.) .....
(4) H.P. or watts.....
(5) Nature of discharge, (dam, trenches, sprinklers, etc.) .....
NOTE: If no pump is installed within 30 days of completion of work the "Completion Advice" must be forwarded without this information which must be supplied immediately the pump is installed.

R E M A R K S
.....
.....
Date: .....

.....
Signature of Permit Holder

Schedule Seven
Weekly Record of Daily Drilling

WEEKLY RECORD OF DAILY DRILLING FOR PERMIT NO. .....
Permitholder.....
Address .....
The following information is supplied in accordance with the provisions of Regulation 10 under the above Act.
I certify that I have:
(1) Taken and retained a sample of not less than 26 fl. oz. weight of each water cut; and
(2) Taken and retained a sample of not less than 1/2 lb. weight at each change of strata encountered or at intervals not exceeding every 10ft.

Water Struck: Usable or Saline?
(1) .....ft. .....
(2) .....ft. .....
(3) .....ft. .....
(4) .....ft. .....
(5) .....ft. .....

Level of water cut at ..... ft. below ground surface:
(1) Before development ..... ft.
(2) Before pump/bailer test ..... ft.
(3) After pump/bailer test ..... ft.

Estimated quantity ..... g.p.h. Pump/bailer test ..... hours
Depth of bore ..... ft. Diameter of hole ..... in.
Casings left in bore:
Length ..... ft. Diameter ..... in.
Length ..... ft. Diameter ..... in.
Pressure cemented? (yes or no) .....
or Casing Shoe cemented? ..... } Quantity of cement used ..... bags.
Depth screen set below ground surface ..... ft.
Details of screen (or slotted casing):
Length ..... ft. Diameter ft. Opening .....

Office Use ONLY

WATER CUT as set out in following Table:

Depth in Ft. Below Ground Surface	Water Level Below Ground Surface	Galls. per hour	How Tested e.g. Bailer or pump	p.H.	Total Salts p.p.m.	Analysis No.

WEEK ENDING SATURDAY / /19

Date	Distance drilled			Depth to which casing set and diameter of casing	Depth at which change occurs		Description of Strata passed through	Drilling Conditions, e.g. hard, soft, caving, heaving, etc.
	Feet	From Feet	To Feet		From Feet	To Feet		

Date drilling commenced / /19 Date drilling completed / /19 (Required for final week only)

Date / /19 Signature of Driller: .....

5. Dealing with Existing Borehole (South Australia)

SOUTH AUSTRALIA - Underground Waters Preservation Regulations, 1970

Schedule Three
Notification of an Existing Well or Bore

To: The Minister of Mines,
c/o Department of Mines

In accordance with section 7 of the above Act, I hereby advise particulars of the undermentioned well or bore on the property owned or occupied by me within a DEFINED AREA as prescribed pursuant to section 61(a) of the above Act.

NOTE: 1. A separate advice is required for each well or bore on the property.
2. Irrespective of whether the construction of the well or bore is complete or not an advice must be forwarded.

Name of owner (BLOCK letters) .....
Postal address .....
Name of occupier (BLOCK letters) .....
Postal address .....
Property on which bore is located:
Allotment No. ..... Section No. ..... Hundred .....
If freehold: L.T.O. plan No..... Certificate of Title Vol. ..... Fol. .....
If Crown lease: Block No. ..... Type of lease and No. .....
What is area of property? ..... acres .....roods.
Does this notification refer to a well, a bore, or a combined well and bore?
(State which) .....
Is the construction of the well or bore complete or incomplete? .....
How many other wells or bores are on the property? .....

DETAILS OF WELL OR BORE

Depth of well or bore ..... ft.
Depth at which water stands below ground surface ..... ft.
Details of casing(s) or lining(s): Length ..... ft. Diam ..... ft.
Length ..... ft. Diam ..... ft.
Materials used as casing(s) or lining(s) .....
Type of screen installed (if any) .....Length.....ft. Diam ..... in.
If used for Water Supply, is it for:
(a) Domestic purposes? .....
(b) Stock watering? .....
(c) Irrigation? .....
or
(d) Industrial purposes? .....
If used for Irrigation, state acreage of usual crops irrigated annually:
..... acres
..... acres
..... acres
..... acres
State salinity of water, if known:
(a) ..... grains per gallon
or
(b) ..... parts per million
If used for Drainage, what is type?:
(a) Domestic sullage .....
(b) Septic tank effluent .....
or
(c) Industrial wastes .....
If used for Industrial Waste, what is:
(a) Nature of waste? .....
and
(b) Quantity drained? ..... gall. per day.
If waste contains poisonous or toxic substances give details .....
.....

DETAILS OF DRILLING OF WELL OR BORE (IF KNOWN)

Name of person or company who drilled the well or bore .....

.....

Year in which well or bore was drilled .....

Any information you may have concerning the nature and thickness of soils, rocks, etc., penetrated by bore should be attached. If complete log of bore is available, please attach copy.

DETAILS OF PUMPING FROM WELL OR BORE

State average number of hours per week well or bore is pumped ..... hours

State average number of weeks per year well or bore is pumped .....weeks

State rate of pumping in gallons per hour:

(a) Normal ..... gall.

(b) Maximum ..... gall.

State:

(a) Type of pump used ..... Depth pump set ..... ft.

(b) Diameter of bowls ..... No. of stages .....

State:

(a) Type of power used on pump (electric, diesel, petrol, windmill, etc.) .....

(b) Horsepower or watts of engine .....

State nature of discharge (dam, trenches, sprinklers, etc.) .....

North

Draw sketch showing position of this well or bore in relation to property boundaries.

Date: ..... Signature of Owner or Occupier: .....

6. Application for Well Driller's Licence (South Australia)

SOUTH AUSTRALIA - Underground Waters Preservation Regulations, 1970

Schedule Eight
Application for Well Driller's Licence

OFFICE USE ONLY
Appln. No. .....
Date of Receipt
of Fee: .....

To: The Minister of Mines,
c/o Department of Mines

I, ... (Full name)
of ..... (Postal Address)
born ....., 19 , at ..... in .....
(Date of Birth) (Town) (Country)
resident in Australia since 19 , hereby apply for a WELL DRILLER'S LICENCE in the State of South Australia. I enclose the prescribed fee of $10 and submit hereunder statements setting out my practical experience. (*Details to be filled out by the applicant personally*).

RECORD OF EXPERIENCE OF WATER WELL DRILLING

(1) Number of years of drilling experience:
  (a) As assistant to driller ..... years.
    Employer: .....
    Address: .....
  (b) As driller:
    (i) employed ..... years.
      Employer: .....
      Address: .....
    (ii) on own account ..... years.
(2) Approximate number of wells drilled in past five years .....
(3) In what districts has drilling been carried out? (See map overleaf[1] and state zone numbers) .....
(4) (a) Maximum depth drilled by you ..... ft.
    Where? .....
    Client .....
    Address .....
  (b) Approximate water supply obtained from this well ..... g.p.h.
(5) Have you personally:
  (a) Installed sand screens? .....
  (b) Set packers? .....
  (c) Pressure cemented casing? .....
  (d) Cemented casing by dump bailing methods? .....
  (e) Installed pumps? .....
  (f) Conducted pump tests .....
  (g) Set several casing sizes in one hole? .....
  (h) Straightened holes? .....
  (i) Plugged wells? .....

Particulars of the above together with names and address of clients must be produced at interview or examination.

[1] Omitted.

DESCRIPTION OF EQUIPMENT USED

(6) State types of rigs and engines used:

	1	2	3
Type of rig			
Capacity of rig			
Type and h.p. of engine			

GENERAL INFORMATION

(7) Do you hold, or have you held, a Driller's Licence for another State or Country? If so:

(a) What State or Country? .....

(b) What type of Licence? .....

(c) How long held? .....

(d) If no longer held state why cancelled .....

.....

All the information contained in this application has been filled out by me and carefully checked and is correct in every particular: AND I make this solemn declaration conscientiously believing the same to be true, and by virtue of the provisions of the Oaths Act, 1936.

Signature of Applicant .....

Declared and subscribed at ..... in the State of South Australia, this ..... day of ..... on thousand nine hundred and .....

Before me: .....

10 cents stamp duty *A Justice of the Peace in and for the State of South Australia*

7. General Obligation of Licence Holders (Australia-Northern Territory)

I - AUSTRALIA - NORTHERN TERRITORY - Control of Waters Regulations

8. (1) The holder of a certificate of registration as a driller shall comply with the requirements of sub-section (11) of section sixteen H of the Ordinance by supplying to the Director of Water Resources, Darwin:

(a) a written statement in accordance with the Fourth Schedule;

(b) a sample of not less than four ounces in weight of each stratum encountered during the drilling; and

(c) a sample of not less than twenty-six fluid ounces of each water supply encountered during the drilling.

(2) All samples required to be supplied under the last preceding sub-regulation shall be clearly labelled with:

(a) the depth from which the sample was obtained;

(b) the name of the driller;

(c) the name of the property on which the bore was drilled; and

(d) the name or number of the bore, or if the bore has no name or number, such other information as is sufficient to identify the bore.

Fourth Schedule - Final Statement of Bore

Fourth Schedule
Final Statement of Bore

From	To	Description of Strata	Name of Bore:
			Name of Property:
			Description of Property:
			Name of Owner:
			Name of Contractor:
			Name of Driller:

LOCATION OF BORE: (or supply sketch on back hereof)

.... Miles (a) | N NE / S SE / E NW / W SW | of (b) ....

(a) Circle appropriate direction.
(b) Use known point such as existing bore, homestead, outstation, &c.

Date of Commencement:

Date of Completion:

Total Depth:

Particulars of Casing:

Particulars of Perforations or Screens:

ADDITIONAL INFORMATION OF INTEREST ABOUT THE BORE

Samples of Strata and Water supplies have been*
will be*
left at the following Trading Place:
.....

.....
Signature

WATER	1st Supply	2nd Supply	3rd Supply
Struck at			
Standing water level			
Pumping supply G.P.H.			
Duration of Pump Test			
Water level during test			
Quality: good, fair or bad			

* *Delete as necessary*

JAPAN INTERNATIONAL COOPERATION AGENCY

REPUBLIC OF ZAMBIA
MINISTRY OD ENERGY NS WATER DEVELOPMENT

THE STUDY

ON

THE NATIONAL WATER RESOURCES MASTER PLAN

IN

THE REPUBLIC OF ZAMBIA

FINAL REPORT

SUPPORTING REPORT [S]

LANDSAT SATELLITE IMAGERY ANALYSIS

OCTOBER, 1995

YACHIYO ENGINEERING CO., LTD.
(YEC)

THE STUDY ON NATIONAL WATER RESOURCES MASTER PLAN
IN THE REPUBLIC OF ZAMBIA

SUPPORTING REPORT (S)
LANDSAT SATELLITE IMAGERY ANALYSIS

Table of Contents

List of Abbreviation

ARC/INFO Computer Software Package for Geographic Information System developed by Environmental Systems Research Institute, USA.

ELIMINATE/FREQUENCY/GRIDPOLY/UNION is a command of ARC/INFO.

CCT Computer Compatible Type.

EOSAT Earth Observation Satellite Company - the Commercial Operator for the Landsat Programme.

ERDAS Computer Software for Satellite Data Processing developed by ERDAS INC. USA.

DIPS/EDIT/GISMO/ISOCLASS/TRAIN is a command of ERDAS.

NASA National Aeronautics & Space Administration, USA.

NOAA National Oceanic & Atmospheric Administration, USA.

NWRMP National Water Resources Master Plan.

Pexel Picture Cell - the Minimum unit of Satellite Data.

TM Thematic Mapper - Name of Sensor carried on Landsat 4 & 5.

UTM Projection Method of Map - Universal Transverse Mercator.

List of Tables and Figures

List of Products (in separate volumes)

COLOR INFRARED MOSAIC	: Sheet 1-7, Scale 1:500,000 (Photo Print)
WATERSHEDS MAP	: Sheet 1-7, Scale 1:500,000 (Polyestel Base)
GEOLOGY MAP	: Sheet 1-7, Scale 1:500,000 (Polyestel Base)
GEOMORPHOLOGY MAP	: Sheet 1-7, Scale 1:500,000 (Polyestel Base)
LAND COVER MAP	: Sheet 1-7, Scale 1:500,000 (Polyestel Base)
WATERSHEDS MAP	: Sheet 1-4, Scale 1:1,000,000 (Color Paper)
GEOLOGY MAP	: Sheet 1-4, Scale 1:1,000,000 (Color Paper)
GEOMORPHOLOGY MAP	: Sheet 1-4, Scale 1:1,000,000 (Color Paper)
LAND COVER MAP	: Sheet 1-4, Scale 1:1,000,000 (Color Paper)

CHAPTER 1 INTRODUCTION

This report describes the use of Landsat Thematic Mapper (TM) data to create geology, geomorphology, drainage, and land cover data bases to support "The Study On The National Water Resources Master Plan In The Republic Of Zambia", hereinafter referred to as NWRMP. The analysis was conducted over the period of May 1994 through March 1995 and produced the following:

1) Forty-five colour-infrared Landsat TM images covering all of Zambia at 1:200,000 scale. These images were used for ground truth analysis in Zambia.

2) Seven colour-infrared, geocoded, image maps covering all of Zambia at 1:500,000 scale. These image maps were created from a digital mosaic of the 45 Landsat TM scenes.

3) Seven black-and-white geology maps of Zambia at 1:500,000 scale. These maps were derived from the visual interpretation of the Landsat TM image maps and information derived from the 1:1,000,000-scale Geological Map of the Republic of Zambia (Edition 2) compiled and published by the Geological Survey Department of Zambia in 1981. The interpretations were digitised to create a vector data base.

4) Seven black-and-white geomorphology maps of Zambia at 1:500,000 scale. These maps were derived from the visual interpretation of the Landsat TM image maps and information derived from the 1:2,000,000-scale Republic of Zambia Preliminary Geomorphic Map compiled and published by the Soil Survey Unit of the Department of Agriculture of Zambia in 1985 (Technical Guide No. 15). The interpretations were digitised to create a vector data base.

5) Seven black-and-white drainage channel and watershed boundary maps of Zambia at 1:500,000 scale. These maps were derived from the visual interpretation of the Landsat TM image maps and the interpretations were digitised to create a vector data base.

6) Seven black-and-white land cover maps of Zambia at 1:500,000 scale. These maps were derived from digitally processing the Landsat TM data. The raster classification was converted to vectors to create a vector data base.

7) Four quadrant colour geology maps of Zambia at 1:1,000,000 scale.

8) Four quadrant colour geomorphology maps of Zambia at 1:1,000,000 scale.

9) Four quadrant colour land cover maps of Zambia at 1:1,000,000 scale.

10) Four quadrant colour drainage channel and watershed boundary maps of Zambia at 1:1,000,000 scale.

11) Four quadrant black-and-white administrative boundary maps of Zambia at 1:1,000,000 scale.

12) Calculation of area statistics for geology, geomorphology, and land cover by administrative boundary.

13) Calculation of area statistics for geology, geomorphology, and land cover by watershed boundary.

14) This report which deals with the use of Landsat TM data to derive the above products.

CHAPTER 2 LANDSAT SYSTEM CHARACTERISTICS AND IMAGE PRODUCTS

2.1 Characteristics of Landsat System

The Landsat satellite (formerly called ERTS, Earth Resources Technology Satellite) is a land remote sensing satellite system, which began as an experimental programme conducted by the U.S. National Aeronautics and Space Administration (NASA). Landsat 1, launched on July 23, 1972, was expected to function for about 1 year but continued to operate flawlessly until 1978 when it was decommissioned after nearly 5 years of continuous operation. During that time, it returned digital data for roughly 300,000 images of the earth's surface. Landsat 1 was so successful that four other Landsat satellites (Landsat 2, 3, 4, and 5) were launched. Landsat 2 was launched on January 22, 1975 and was decommissioned in July, 1983; Landsat 3 was launched on March 5, 1978 and was decommissioned in September, 1983; Landsat 4 was launched on July 16, 1982 and Landsat 5 was launched on March 1, 1984. The Landsat system was declared an operational system in 1983 and turned over to the U.S. Commerce Department's National Oceanic and Atmospheric Administration (NOAA). In 1984, the Land Remote Sensing Commercialisation Act (Landsat Act) was established to transfer the commercial operation of the Landsat programme to the private sector. Earth Observation Satellite Company (EOSAT) was selected as the commercial operator for the Landsat programme.

Landsat 1, Landsat 2, and Landsat 3 carried two earth imaging sensors. The Return-Beam Vidicon (RBV) sensor, which is similar to a television camera, recorded red, green, and infrared energy reflected from the surface of the Earth in one broad panchromatic band with a resolution of 35 metres. However, the RBV was only successful on Landsat 3. The Multispectral Scanner (MSS) was the primary earth imaging instrument carried on Landsat 1, 2, and 3 and it is still operating on Landsat 4 and 5. The MSS sensor collects data by scanning the earth from west to east with an oscillating mirror. Radiation from four different spectral bands (green, red, and two in the near infrared) is recorded. The radiation is transferred by fiber optics to filters that permit only certain wavelengths of radiation to strike the sensor's detectors. The picture element (pixel) sampled by the MSS is about 79 X 56 m (the size of a football field). Landsat 1, 2, and 3 orbited the earth at an altitude of approximately 900 km and provided repetitive coverage for any location on earth every 18 days.

As mentioned above, the Landsat 4 and 5 satellites were launched in 1982 and 1984, respectively. Landsat 4 is used sparingly because of an electrical problem that developed shortly after its launch. As of March 1995, Landsat 5 is still operating. Landsat 4 and 5 circle the Earth every 98.9 minutes in a near polar orbit of approximately 700 km. Each satellite provides repetitive coverage for any area every 16 days, at the same local time of day. Landsat 4 and 5 each weigh nearly 2,000 kg and carry the MSS sensor and the Thematic Mapper (TM) sensor. The TM sensor has excellent capabilities for meeting the data needs of many GIS applications for large regions. Along each orbital path, the TM and MSS sensors can continually scan a swath 185 km wide. The scanned data are systematically divided into an area termed a "Landsat Scene," which encompasses approximately 185 km by 170 km. Each scene covers approximately 3.2 million ha. Users of Landsat data can purchase data from an existing archive maintained by EOSAT or can schedule the collection of data for any site. The images from the TM sensor on Landsat 4 and 5 have significantly better geometric

quality than images from sensors on earlier Landsat missions due to engineering enhancements to the spacecraft. This has facilitated geodetic-rectifications of the images to the accuracy standards for 1:24,000-scale map products (Welch et al. 1985).

The TM sensor provides significant improvements in spatial, spectral, and radiometric resolution compared to the MSS. The instantaneous-field-of-view (IFOV) of the TM is square and results in a ground resolution cell and image pixel of approximately 30 m on a side. The TM measures the intensity of reflected radiation in six spectral bands: three in the visible wavelengths, blue (0.45-0.52 µm), green/yellow (0.52-0.60 µm), red (0.63-0.69 µm), one in the near infrared (0.76-0.90 µm), and two in the shortwave infrared (1.55-1.75, 2.08-2.35 µm). The TM also measures emitted thermal radiation (10.4-12.5 µm) although the IFOV for this spectral band is 120 m on a side. The greater radiometric resolution is achieved by the analog-to-digital conversion of the electrical signal to 8 bits or 256 gray levels compared to the 64 gray levels of the MSS on the first three Landsat satellites.

Overpass time for all of the Landsat satellites is approximately 9:45 a.m. local time, although perturbations in the orbit have caused small variations in the time. An early morning sun-synchronous orbit was selected to take advantage of clear morning skies and to ensure repeatable illumination. Consistency in illumination is important for constructing image mosaics and in comparing changes through time. In addition, the moderately low sun angle at the time of overpass, particularly in the higher latitudes and during the winter months, enhances detail caused by relief differences.

2.2 Computer Processing of Landsat TM Data

The Landsat TM data is delivered on magnetic tapes called CCTs (Computer Compatible Tapes). From these data tapes, Landsat images are produced by a assigning various combinations of bands to the colours of blue, green, and red. An interactive computer system is used for viewing and selecting the various bands for processing. The algorithms within the processing package can be divided into two broad types: "pre-processing" and "image processing".

2.3 Pre-processing

The Landsat TM data contains some noise and distortions (such as pixel dropouts). Therefore, pre-processing of the data is necessary before the images can be created. The pre-processing consisted of:

1) Viewing the images and replacing any dropped pixels or lines.
2) Geocoding the image to insure that the imagery will register to published maps.
3) Histogram matching the imagery with adjacent scenes to reduce the variation between consecutive scenes in an image mosaic.
4) Mosaicking all satellite scenes required to cover each map sheet. 5 ~ 7 Landsat scenes are required to cover one full 1:500,000 map sheet.

2.4 Color-Infrared Composite Image

The color-infrared composite images for the seven map sheets were created by recording to film bands 2, 5, and 4 to the colours of blue, green, and red, respectively. Various band

combinations were examined interactively on a display screen, but this combination of bands produced the best images throughout all of Zambia. From this band combination, geology, geomorphology, drainage, land cover, and cultural features could readily be interpreted.

Each of the seven map sheets covers approximately 4.5 degrees of longitude and 3.5 degrees of latitude. Printing these images at a scale of 1:500,000, the resultant image maps measure approximately 391/2 inches by 531/2 inches. The map number, latitude and longitude extent, and the map name for the seven 1:500,000-scale image maps covering all of Zambia are shown in Table 2-1.

Table 2-1 Map Contents for the seven 1:500,000-scale image maps

MAPSHEET # / MAPSHEET NAME	UPPER LEFT LONGITUDE	UPPER LEFT LATITUDE	LOWER RIGHT LONGITUDE	LOWER RIGHT LATITUDE
Sheet #1 / NORTH	26°00' E	8°00' S	30°30' E	11°30' S
Sheet #2 / NORTHEAST	30°30' E	8°00' S	35°00' E	11°30' S
Sheet #3 / WEST	21°45' E	10°45'S	26°00' E	14°30' S
Sheet #4 / CENTRAL	26°00' E	11°00' S	30°30' E	14°30' S
Sheet #5 / EAST	30°30' E	11°30' S	35°00' E	15°00' S
Sheet #6 / SOUTHWEST	21°45' E	14°30' S	26°00' E	18°10' S
Sheet #7 / SOUTHEAST	26°00' E	14°30' S	30°30' E	18°10' S

These images were registered to the Transverse Mercator projection using UTM Zone 35 (South), the ARC 1950 horizontal datum, and the Clark 1880 spheroid. The administrative district boundaries and their names are displayed on the image maps.

CHAPTER 3 LANDSAT DATA ANALYSIS

The purpose of the Landsat data analysis for this project was to produce Landsat image maps, geology, geomorphology, drainage channel/watershed boundary, and land cover maps and vector data bases. All data was either digitised in vectors directly from visual interpretation of the Landsat image maps with various ancillary data or were created from classifying the data and converting the raster data to vectors. All data bases were maintained as a nation-wide coverage in ARC/INFO. Maps were produced at four scales: seven 1:500,000 scale maps, four 1:1,000,000 scale maps.

3.1 Selection and Purchase of Landsat Data

Landsat data used for this project were selected using the following criteria:

1) Landsat scenes that would cover all of Zambia. The area covered by Landsat data are defined by Path (East-West) and Row (North-South) numbers.

2) Most recent data available (from the latest observation dates), but within the same season. Dates of the scenes ranged from 1992 to 1993 (except for the small north-west corner of P172/R73 acquired in 1984). All the data came from the months of September or October except for P169/R68 and P172/R73 which were June scenes.

3) Good quality data with minimum amount of cloud cover. Cloud cover of more than 30 percent make the data impractical for interpretation because of the limited view of the land surface. All of the data for Zambia was cloud free except for four quadrants where the maximum cloud coverage was only 10%.

By considering these factors, a total of 45 scenes were acquired. All but two were acquired from the same season (1 September through 14 October), and over a two year period (September 3, 1992 through October 14, 1993). All of the 45 scenes covering Zambia were cloud free with the exception of a small patch of scattered clouds located north-northwest of Luwingu and another small patch northeast of Isoka.

3.2 Production of Color-Infrared Mosaics

By pre-processing the acquired Landsat imagery as discussed above, color-infrared mosaics for the seven 1:500,000 scale map sheets were produced and were the primary data source for the geomorphology, geology, and drainage channel/water basin boundary interpretations. Band 2 was imaged as 256 intensities of blue, band 5 was imaged as 256 intensities of green, and band 4 was imaged as 256 intensities of red. Histogram matching techniques allowed adjacent scenes from different dates to match colouration reasonable well.

3.3 Classification of Nation-Wide Land Cover

Land cover information was digitally extracted from each of the 45 Landsat TM scenes. This involved a three step process: the preprocessing stage, the grouping and editing stage, and the postprocessing stage.

The preprocessing stage includes preparing the scene, geocoding the scene, and classifying the scene. Upon receiving a scene, six bands (band 6, the thermal band was not processed)

were loaded onto disk. This six-band data set of the entire scene required approximately 250 megabytes of disk storage for each of the 45 scenes. The entire scene is reviewed for data errors. The analyst is looking for band registration errors, band dropouts, and salt and pepper data errors (erroneous high and low data values) and these errors are corrected using values for adjacent areas or, if errors were too significant, a new scene would be ordered. Once the raw data were reviewed and errors corrected, the image was geocoded. The data was geocoded using a cell size of 30 metres.

The final step in the preprocessing of land cover information is to create the classified file. The classification approach used ISOCLASS in the ERDAS image processing system to created 240 spectral classes for each of the Landsat TM images. ERDAS's MAXCLAS routine was used to assign one of the 240 spectral classes to each of the pixels of the TM scene. The 240 spectral classes well represent the spectral information contained in the six bands processed. A pseudo color table was produced to display the classified file in color. This pseudo color table emulates a 3-band color composite of bands 4, 5, and 3 displayed in red, green, and blue.

DISP/TRAIN/EDIT modules were used to display the classified data, assign the spectral classes to the desired informational classes, and to edit the scene to reduce all interpretable omission and commission errors. DISP/TRAIN/EDIT modules allow one spectral class to represent one informational class in one region and another informational class in another region. By visually examining the classified file, the image interpreter can assign the spectral classes to informational classes and efficiently edit the image to improve classification accuracy.

DISP facilitates viewing the image by the image interpreter. The image interpreter can select an area for view by UTM or latitude and longitude coordinates or map sheet name. In addition, adjacent areas can be viewed by entering commands to view the next screen north, south, east, or west of the current screen. With TRAIN, the image interpreter has a wide variety of commands to help ascertain which spectral classes represent various informational classes. EDIT is used by the image interpreter to remove omission or commission errors that are readily detected by viewing the scene. Using these procedures, the classification for each pixel of the entire scene is reviewed.

The DISP/TRAIN/EDIT procedures were used to extract the following informational classes from all 45 Landsat TM scenes covering all of Zambia:

Forest
Savanna
Grassland
Agriculture
Barren
Urban
Wetland
Water

The image interpreter used the following definitions of land cover for creating the Zambia land cover classification:

- Forests include areas with moderate/dense overstory vegetation. Forests often appear as dark red or brown areas on the images.

- Savannas are spectrally similar to grasslands and forests depending upon the density of the overstory vegetation. The redder areas of savanna as seen on the images have denser overstory vegetation.

- Grasslands are dominated by grasses with only sparse overstory vegetation. Burned areas, which appear as dark blue or black areas in the images were also classified as grasslands. In the images, grasslands were medium to light pinks and greens.

- Agriculture occurs throughout the entire country including large commercial areas often associated with flood plains and smaller commercial or subsistence agriculture occurring in cleared areas of forest, savanna, and flood plains. In the images, agricultural areas appear as light to medium reds and pinks, often showing a very heterogeneous spectral patterning. In more heavily vegetated savanna and forest zones, cleared areas showed significantly higher contrast.

- Barren land cover includes non-vegetated areas in the mountains/hills, savanna, bare rock, and sand or mud flats associated with rivers and lakes. Barren areas have high reflectance and appear as white and light green areas on the images. Rock outcrops without vegetation appear as dark green and were classified as barren.

- Urban land cover contains cities and villages that are visible on the images. These areas of human activity are often light in color on the images. Plots of all villages and urban areas were produced using the data from Digital Chart of the World. All urban areas that were plotted from Digital Chart of the World and that were visible on the images were included in this classification.

- Wetlands typically have a bright red color associated with the heavily vegetated areas. The wetland are typically associated with lakes, rivers, or depressions.

- Water included open water bodies such as large rivers and lakes that appear as dark blue or black areas on the images.

The postprocessing steps include all steps required to mosaic the grouped and edit classification files, convert the data to vectors, plot the land cover maps, and generate statistical analyses by watersheds, administrative units, geomorphology, and geology (lithology).

To mosaic the grouped and edited files, Arc/Info's MERGE module was used to create a raster file of land cover for all of Zambia. ERDAS's DISPLAY module was then used to view the entire raster image of land cover and ERDAS's GISEDIT module was used to correct any inconsistencies in the classification between scenes within the mosaic.

The next step was to convert the raster data to vectors. The GRIDPOLY command in ARC/INFO was used to create the vectors. Unfortunately, ARC/INFO Version 6 will only allow a polygon to contain 10,000 arcs. The small polygons created from a small number of raster cells inherent in raster data created many interior polygons, resulting in many polygons have more than 10,000 arcs. A series of filters were used (five separate filtering steps) to

reduce the frequency of these small interior polygons. However, even after extensive filtering of the data the land cover raster file was still too complex to vectorise using Arc/Info Version 6. This complex raster file was vectorised using Arc/Info Version 7, which does not have the limitation of 10,000 arcs per polygon. After the vectorisation was completed, a fishnet vector coverage was generated and intersected with the vector land coverage. This technique allows the coverage to be processed in Arc/Info Version 6.

After the land cover vectors for the entire country were created, ARC/INFO's ELIMINATE command was used remove small polygons from the coverage. Various thresholds ranging from 25 hectares to 250 hectares as the minimum polygon size were tested. The best threshold was 50 hectares. Thresholds set smaller than 50 hectares created maps that were very noisy. Thresholds larger than 50 hectares created maps that seemed too generalised, and features such as rivers, urban areas, and small agricultural areas were too frequently eliminated when the thresholds larger than 50 hectares were tested.

The final polygon coverage for land cover for all of Zambia created with a threshold value of 50 hectares contains over 300,000 polygons.

This data base was then used to create the 1:500,000- and 1:1,000,000- land cover maps. Land cover statistics by watersheds, administrative units, geomorphology, and geology (lithology) were created by creating a union of the land cover database with these four other databases using Arc/Info's UNION command. Arc/Info's FREQUENCY command was then used to report these land cover statistics. The land cover statistics are shown in Appendices C, and F.

Zambia

Land Cover

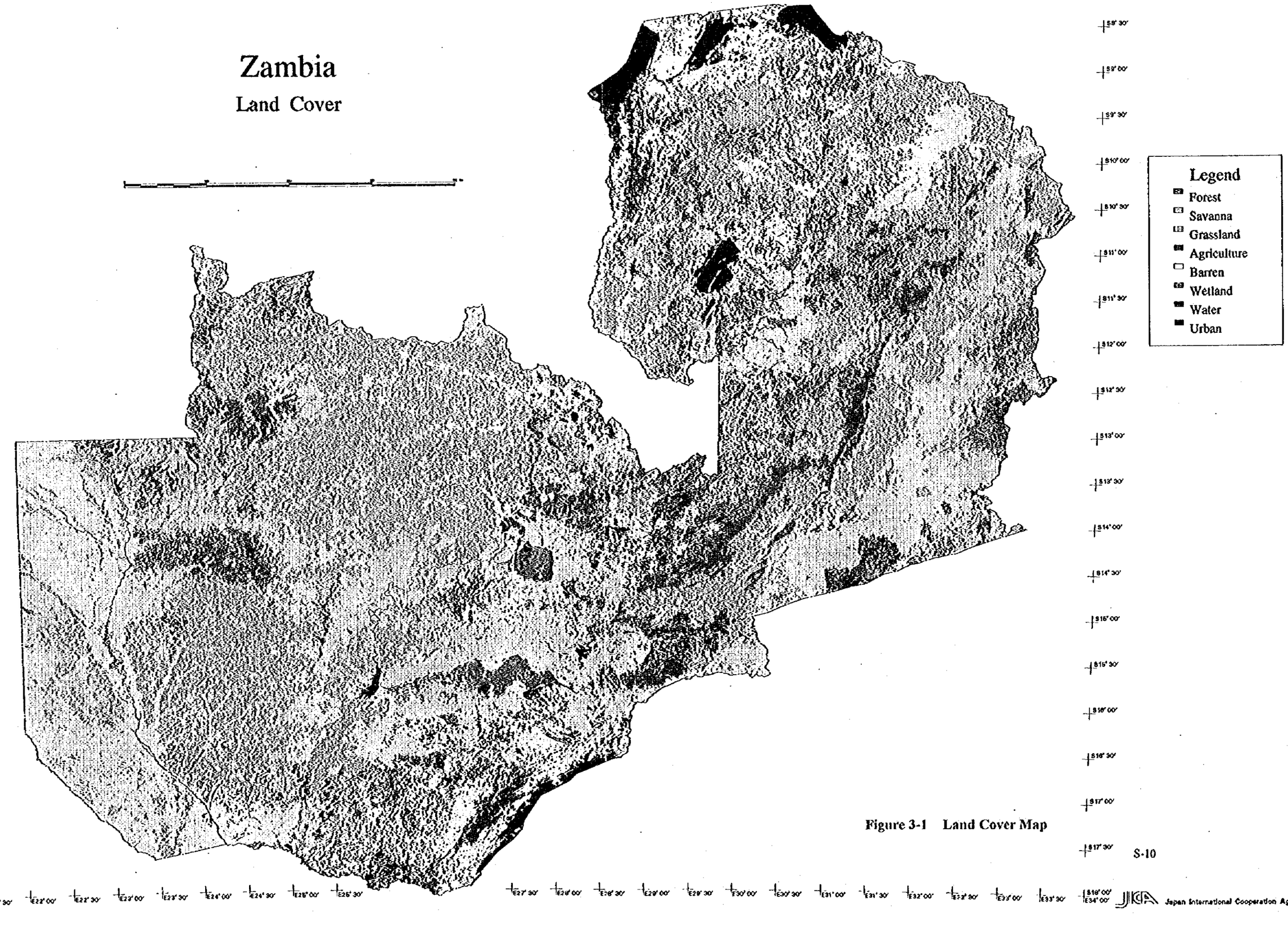


Figure 3-1 Land Cover Map

3.4 Interpretation of Nation-Wide Geology

The geological mapping in Zambia involved the mapping of lithologies, structure (including faults, folds, domes, and lineaments), and foliation. The surface exposures of rocks in the country are nearly equally divided between sedimentary and igneous/metamorphic basement types. The sedimentary rocks are located primarily in the western Northwestern Province, the Western Province, and in the rift valleys of the Southern, Lusaka, Eastern, and Northern provinces (light pale yellow, tan, and green colours). The igneous and metamorphic basement rocks are located primarily in the eastern Northwestern Province, the Copperbelt Province, the Central Province, the Luapula Province, and the non-rift valley portions of the Southern, Lusaka, Eastern, and Northern provinces (blue, pink, red, and purple colours).

The igneous/metamorphic rocks are normally highly weathered and outcrops are rarely continuous over large distances. The metamorphic rocks, with the exception of the quartzites, tend to weather rapidly and produce subdued landscapes where contacts between units are very difficult to map from the satellite imagery. Some units, however, are resistant enough to permit the identification on the satellite imagery of the regional foliation patterns. Isolated masses of granite often core the large domes of the country and the onlapping rocks help to define the extent of these granite cores.

The differentiation of the various Precambrian basement and Muva metamorphic rocks is also difficult. Using the 1:1,000,000 scale Geological Map of Zambia as a guide, certain textural characteristics of various rock groupings were tentatively identified on the Landsat imagery and attempts were made to carry these "signatures" into adjacent areas. Invariably, polygons delineated based on the signatures identified on the imagery were not identical to the published map. In fact, there were places where the continuity of the characteristics of a rock mass as depicted on the imagery were good enough to bring doubt upon the accuracy of the published map. In these cases polygon boundaries were modified from those of the published map. In most areas, however, there was inadequate diagnostic information on the imagery to make judgments as to the specific rock type of these older rocks. In these instances the published map was given precedence and the extent of the rock unit was traced from the published map.

The sedimentary rocks are more realistically mappable, particularly in the Luangwa rift valley and immediately northwest of Lake Kariba. The quality and detail of the Landsat imagery is quite exceptional in these areas and numerous previously unmapped faults and folds have been delineated. North of Lake Kariba, in areas where topographic expression is good, the sedimentary boundaries are mappable in considerable detail. In the western portion of the country, where the Kalahari Sands have blanketed the landscape with thick deposits of unconsolidated sediment, the published map was the guide to the underlying rock subcrop.

Structural deformation in the sedimentary section is relatively gentle except locally in beds associated with strike-slip fault movement or rift-flank uplift. Here beds have been deformed into pronounced folds and have been highly faulted. Were mappable, fold axes are shown with traditional anticline and syncline symbols. Faults are mapped with a bold solid line and, where observable, the sense of offset has been demarcated. Foliation is shown as a line of small, interconnected, solid dots ("string-of-pearls" symbol). Lineaments are thin solid lines, and lithological boundaries are even thinner lines.

The procedure for interpreting the geology was to affix clear mylar film to the 1:500,000 scale Landsat image maps and interpret the geologic structure and lithologic boundaries directly from these images using the Geologic Map of the Republic of Zambia (Edition 2, 1981) as control and standard photogeologic interpretation techniques. As noted above, modifications of the existing geologic map were made based upon the Landsat imagery. Lithologic units were identified and labeled with numbers corresponding to the legend found on the Geologic Map of the Republic of Zambia and reproduced in the legend.

The geological interpretation was drawn on the mylar overlay and these overlays were then hand digitised and the vector files were annotated using ARC/INFO. Plots of the hand-digitised interpretations were then edited and the ARC/INFO vector files were modified appropriately. For the color maps, look-up tables (LUT's) were created for the various rock units using colours and patterns that most closely resembled the shades of the Geologic Map of the Republic of Zambia. The color maps was plotted at 1:1,000,000 scale (in 4 quadrants). For the black-and-white maps, only the numbers of the various rock units were used to designate lithologic type.

Geology area statistics by administrative boundary and by watershed boundary were created in ARC/INFO by uniting the geology database with the administrative and watershed boundary databases using ARC/INFO's UNION command. ARC/INFO's FREQUENCY command was then used to report these geology statistics. The geology statistics are shown in Appendix A and Appendix D.

Zambia

Geology

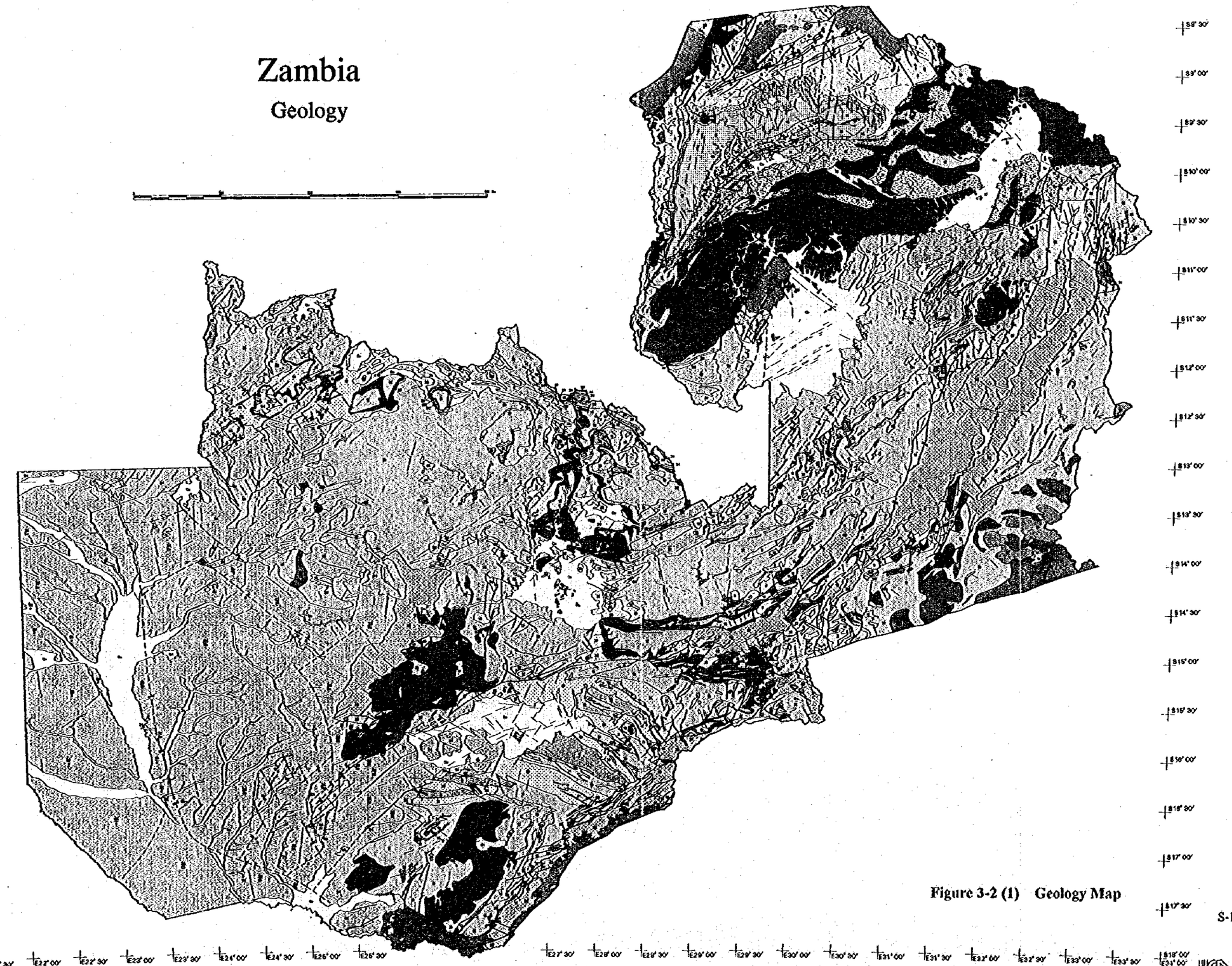


Figure 3-2 (1) Geology Map

Zambia

Geology

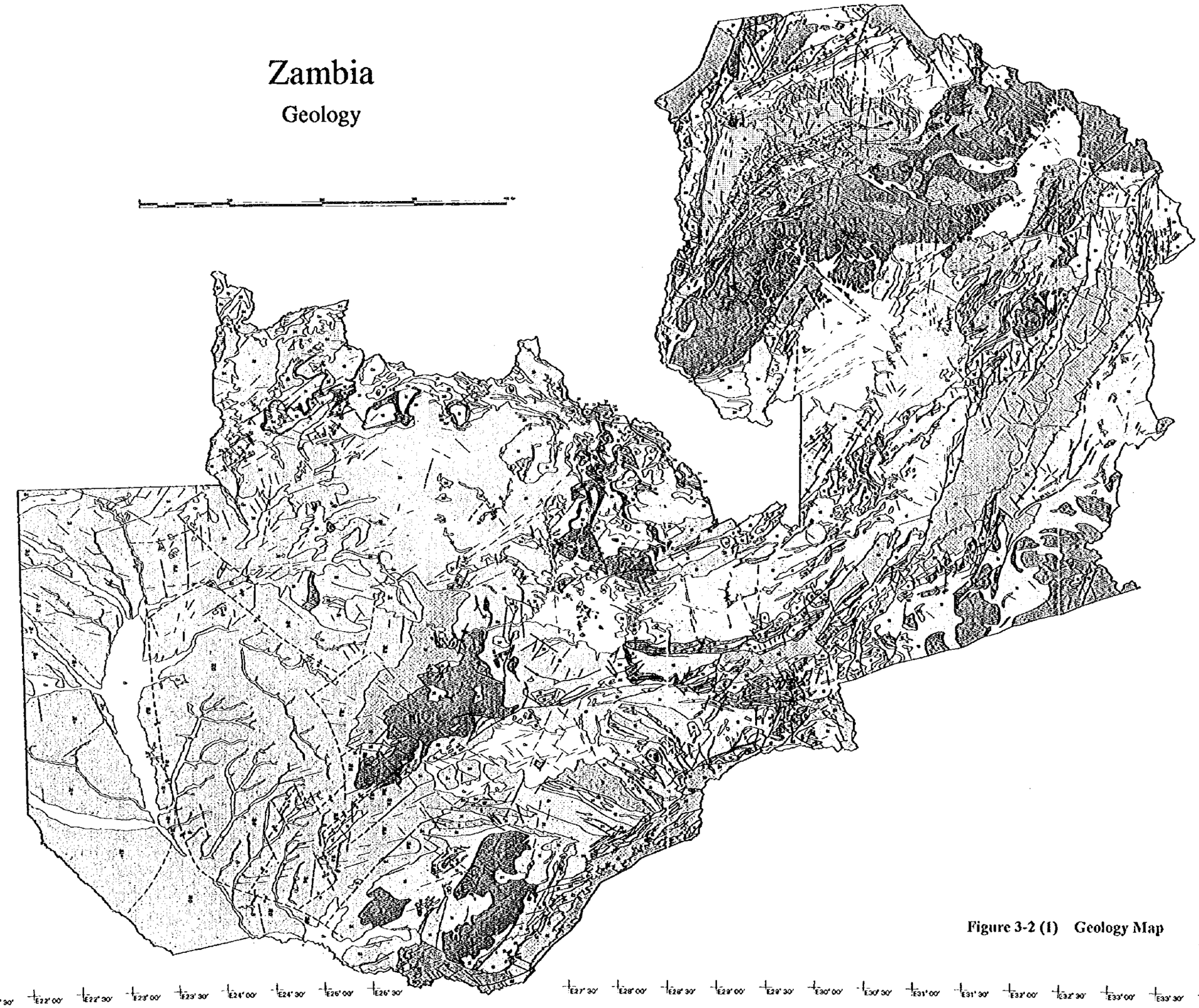


Figure 3-2 (1) Geology Map

Zambia

Geology

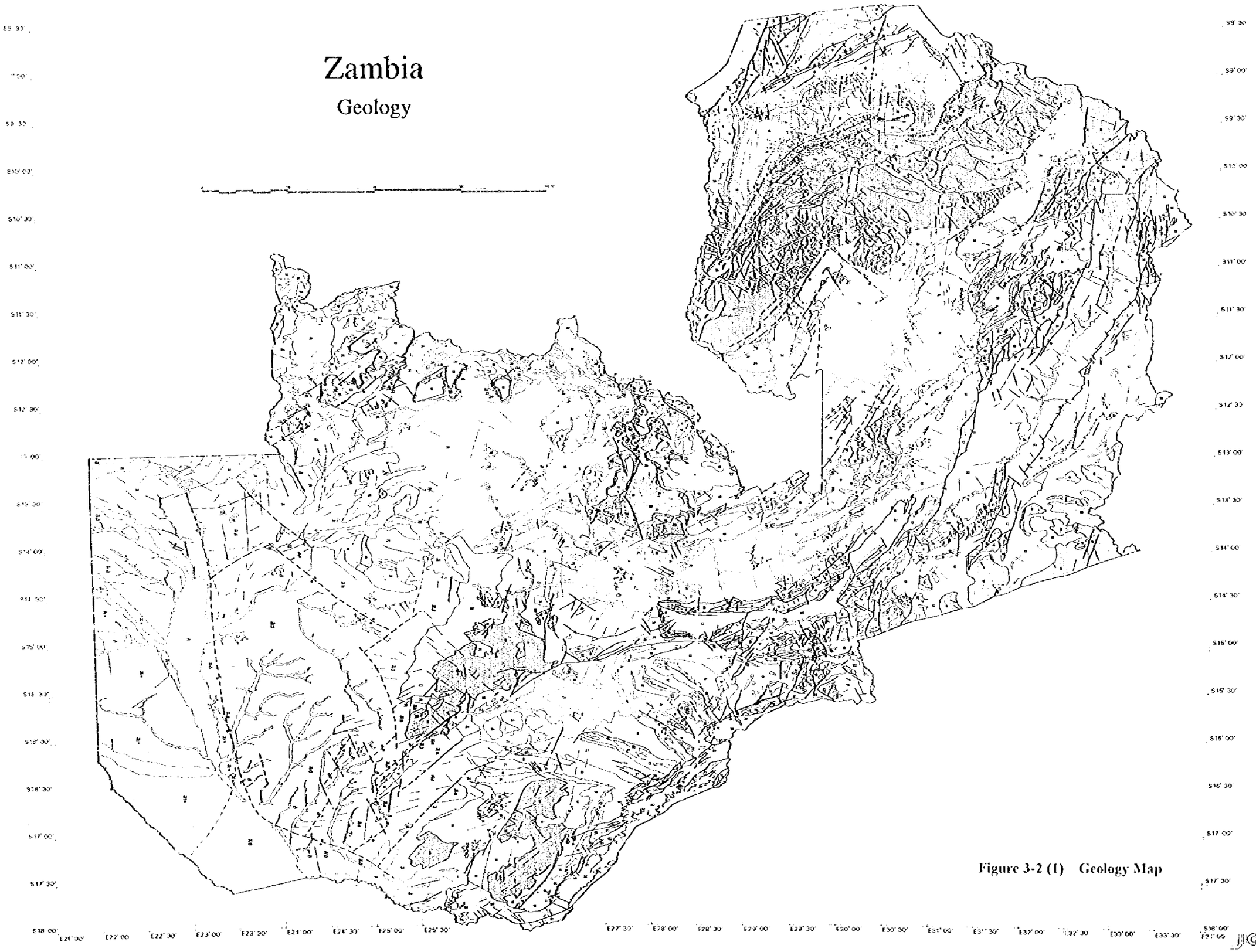
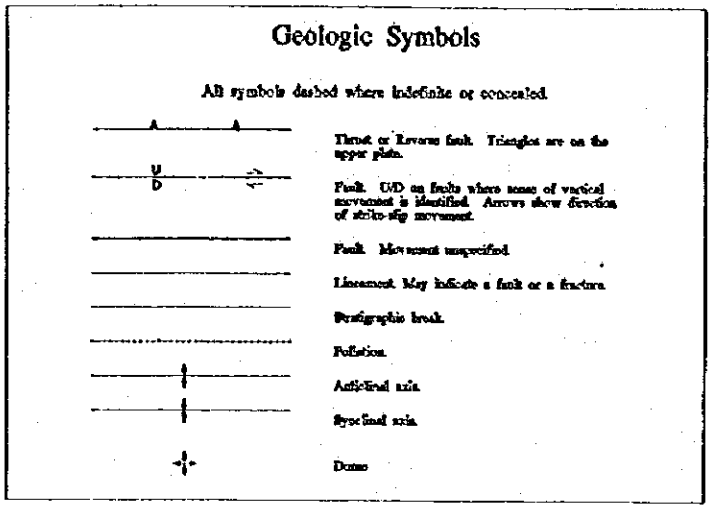


Figure 3-2 (1) Geology Map



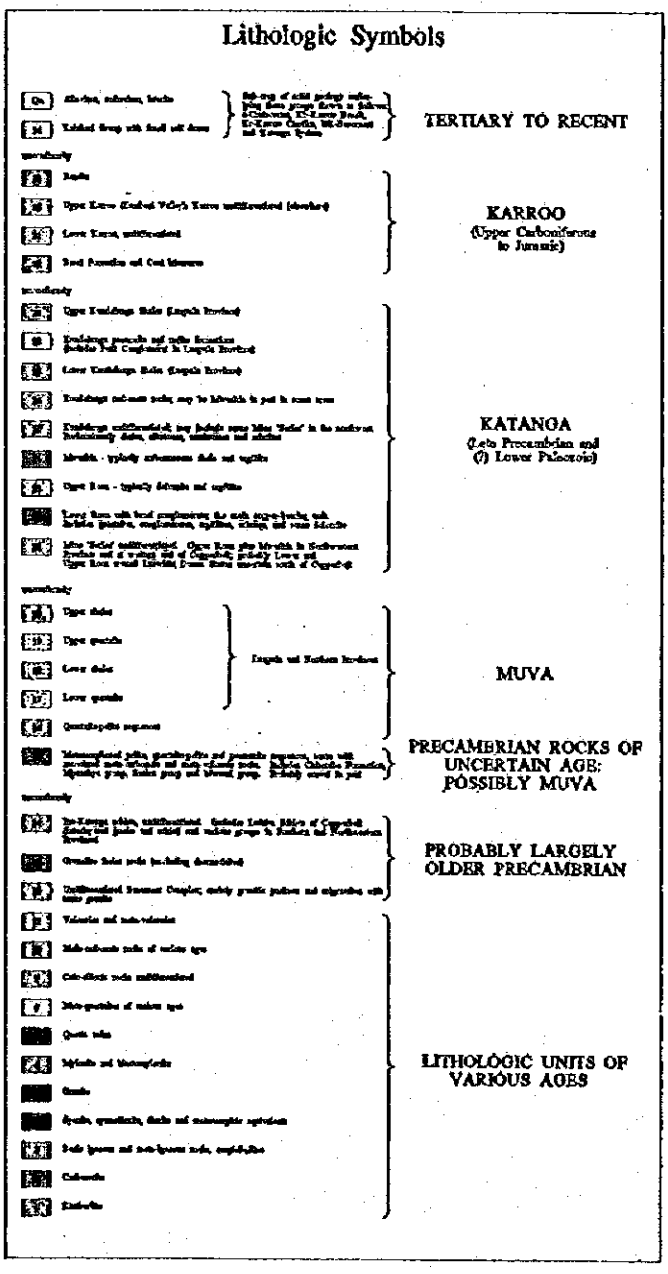


Figure 3-2 (2) Legend of Geology Map

3.5 Interpretation of Nation-Wide Geomorphology

The geomorphic analysis was based upon a photointerpretation of the seven 1:500,000 scale Landsat map sheets described previously, and followed standard analysis conventions using a combination of tonal and textural indicators. This photogeomorphic analysis was aided by reference to previous land use, soil, geomorphic and geologic mapping of Zambia and followed the three-tiered approach and legend developed for the 1:2,000,000 scale Republic of Zambia Preliminary Geomorphic Map (Technical Guide No. 15, Soils Survey Unit of the Department of Agriculture of Zambia, 1985). The lateral extent of all of the geomorphic units mapped was based solely upon interpretation of the Landsat data; the Republic of Zambia Preliminary Geomorphic Map was used only for identification of a given geomorphic unit. As such, the geomorphic analysis presented constitutes a 1:500,000 scale Landsat-based photogeomorphic revision of the Republic of Zambia Preliminary Geomorphic Map. All of the units mapped on the Republic of Zambia Preliminary Geomorphic Map were recognised on and modified according to the Landsat data except for units 2A8 (Major Dambos), 2B6 (Aggraded Plateau Terraces), and 4B2 (Flat Trough Floor Terraces). These units are generally not observable on dry-season Landsat imagery and consequently were not mapped.

The geomorphic interpretations were drawn directly on clearfilm mylar overlays to the 1:500,000-scale map sheets with permanent ink pens. These interpretations were then hand digitised into an ARC/INFO system and test plots were generated to check for inaccuracies. These edited test plots were then used to make the necessary corrections and final plots were produced. As with the other color map products, look-up tables (LUT's) were created to assign specific colours to the various geomorphic units.

The classification of the terrain follows the units defined in Technical Guide No. 15, "A Geomorphic Legend For Zambia", Soil Survey Unit, Department of Agriculture of Zambia, 1985 and consists of the following:

1A1 - Montane Plateau: Those parts of the Montane zone, usually at an elevation in excess of 2000 m (c. 6500 ft.) which are characterised mainly by rolling open grasslands and by deeply incised stream valleys, with patches of relict montane forest, and seasonal swamps in low lying areas. Slopes vary between 0 - 40%, but are 0 - 5% on the higher peaks of the Nyika plateau, and on the narrow summits of the Mafinga Hills and Makutu Mountains which are included in this unit. Granitic outcrops, particularly tors, are common.

1A2 - Montane Escarpment: The steep slopes marking the western margin of the Nyika Plateau and the precipitous flanks of the Mafinga Hills and Makutu Mountains, all of which are dissected by deep ravines. The elevation of the foot of these escarpment areas is variable and in some places falls to around 1500m (c. 5000 ft).

2A - Degraded Plateau: Those parts of the Central African Plateau where planation has been and remains the dominant landforming influence. These areas are traversed by a network of rivers, streams and dambos of varying drainage density. Relief is level to gently undulating where drainage density is low, and more pronounced where drainage density is high. Included in this unit are the isolated hills and ridges of the more resistant rocks (usually quartzitic) which rise above the general plateau surface,

minor escarpments (not associated with rift troughs), swamps and lakes which occupy depressions, and floodplains.

2A1 - Level to Undulating Plateau: Those parts of the Degraded Plateau surface characterised by level to undulating topography, usually having a dentritic drainage pattern of dambos and streams separated by level or broadly convex interfluves. Slopes rarely exceed 5% in level to gently undulating plateau areas, but may range between 3/5 - 8/12% in undulating areas where streams are more incised. Included in this unit are the footslopes (often comprising colluvial material) found at the foot of hills and ridges (slopes normally between 5 - 12%).

2A2 - Dissected Plateau: Those parts of the Degraded Plateau surface characterised by strongly dissected topography, having a dense drainage pattern with incised, relatively steep-sided stream valleys. Broad-head dambos are mainly absent. Interfluves are generally narrow and often shallow, gravelly or rocky. This unit often occurs towards the margin of the Central African Plateau where it is transitional to the Escarpment Zone.

2A3 - Hills, Ridges, and Minor Escarpments: This unit comprises isolated hills (including domed inselbergs and large tors), linear ridges and hill ranges standing above the adjacent land surface and normally comprising resistant rocks with steep slopes (25 - 100%) covered with shallow, loose (often sandy) soils, stones and rock outcrops. At the foot of the hills or ridges there is usually a zone where colluvial material has accumulated (examples: Chainama Hills near Lusaka, Mphangwe Hill near Katete). Also included in this unit are minor escarpments (not associated with rift troughs) on the plateau surface (e.g. at Solwezi State Farm).

2A4 - Swamps: Large flat depressions (usually at least 10 sq km in extent) in which the surface is permanently saturated with water and is usually overgrown with vegetation (papyrus and reeds). (Examples: Bangweulu, Lukanga and Busanga swamps).

2A5 - Lakes: Large (at least 10 sq km) permanent bodies of water, entirely surrounded by land, the depth of water away from the shore normally exceeding 2 m (e.g. Lake Bangweulu). Lakes included in this unit may be man-made (e.g. Mulungushi, Mita Hills and Iteshi Teshi dams).

2A6 - Floodplains: Low-lying, level areas adjacent to rivers or swamps which are seasonally flooded due to a rise in river level or to impeded run-off. Included in this unit are oxbow lakes, flood channels, abandoned channels, and fluvial deposits such as levees, point bar deposits, back plains and sand bars. (Examples: Kafue Flats, Chambeshi floodplain).

2B - Aggraded Plateau: That part of the Central African Plateau comprising semi-consolidated or unconsolidated deep sands (Kalahari sands). This surface is characterised by extensive, level to very gently undulating plains with generally widely spaced drainage lines, and areas where complexes of dunes and pans (some containing small lakes) predominate. This surface is restricted to Western Province and parts of North Western Province. Also included in this unit are the floodplains

and associated terraces of the upper Zambezi river, and the associated tributary alluviated valleys.

2B1 - Linear Dune Complex: Those parts of the Aggraded Plateau Surface found mainly to the west of the Zembezi river and characterised by parallel dunes (mainly in an ESE - WNW direction) extending for distances up to 50 km (Williams, 1982) and separated by inter-dune depressions. The dunes are generally 1.5 - 2 km wide and the inter-crestal spacing is approximately 3 km (Williams, op. cit.). Relative relief is 0 - 5 m.

2B2 - Pan Complex: Those parts of the Aggraded Plateau, predominantly (although not entirely) restricted to the eastern side of the Zambezi river, and characterised by numerous depressions, often circular or elliptical, occurring on the interfluves. The depressions may be permanently or seasonally flooded. The size of the pan depressions varies between 2 - 20 sq km and some (particularly near Mongu) are interconnected and integrated into the drainage pattern (Williams, 1982).

2B3 - Dilungus: Large (usually at least 10 sq km) non linear, mainly treeless, seasonally waterlogged areas found in the northern part of Mwinilunga District. Two main types are distinguished:
(A) Those dilungus having low relief, commonly traversed by perennial streams. Some of the larger ones contain east-west aligned dunes.
(B) Those Dilungus which occur either on (flat) interfluves not surrounded by Kalahari sands, or extending between drainage lines and interfluve upper slopes (0 - 5% slopes).

2B4 - Slightly Dissected Plateau: Those parts of the Aggraded Plateau with a sub-dendritic to sub-parallel drainage pattern, with level to slightly convex interfluves, and a relative relief of 5 - 50 m (c. 15 - 150 ft). Slopes vary between 0 - 8% but are mainly less than 1%. Drainage lines comprise both narrow valley dambos and broader flat-bottomed valleys. Also included are minor escarpments bordering floodplains, isolated dunes and isolated pans.

2B5 - Floodplains: Low-lying, mainly level areas adjacent to rivers which are seasonally flooded due to a rise in river level. Included in this unit are river courses, oxbow lakes, flood channels, and fluvial deposits such as levees, point bar deposits, back plains and sand bars. (Examples: Zambezi floodplain; Luana Flats).

2B7 - Alluviated Valleys: Incised valleys, filled with alluvial sediments. They are characteristically flat bottomed and do not flood annually. They are located exclusively to the east of the Zambezi river in areas lacking linear dunes.

3A - Escarpment: A linear, abrupt, steep slope terminating the elevated surface of the Central African Plateau, formed mainly (in Zambia) by major faulting and modified by subsequent erosional processes. (Example: Muchinga escarpment).

3B - Escarpment Complex: A broad zone comprising deeply dissected rocky hill land, v-shaped valleys and gorges, forming a complex descent from plateau to rift trough. The whole zone is one of active erosion and is cut by perennial and ephemeral

streams and rivers. (Example: The area between Chipata and the Luangwa Valley). It is possible to distinguish between those areas of Escarpment Complex which are characterised by a relatively high degree of dissection and those which have a low degree of dissection.

4A1 - Isolated Large Hills: Outlying hills of the Central African Plateau which rise to an elevation normally in excess of 700 m (C. 3000 ft) and have a relative relief of 200 - 300 m (C. 650 - 1000 ft.). (Examples: Kililangoma and Kasafu hills in Luano valley).

4A2 - Dissected Hilly Land: Areas underlain mainly by relatively soft Karroo sediments with generally moderate relief (30 - 120 m; 100 - 400 ft) and comprising a complex of cuestas, homoclinal ridges and hills (some isolated), together with some flat plateau areas, dambos, footslopes and fans along the base of the escarpments. Davison (1981) describes this unit as being characterised by many ephemeral streams and by shallow stony or rocky soils, and represents areas where active erosion of Karroo sediments is still taking place. It usually commences at the foot of the escarpments and extends towards the trough centres to varying extents.

4B1 - Floodplain: A strip of relatively flat land adjacent to a river channel, formed from river sediments and subject to frequent (usually annual) flooding. Included in this unit are river courses, oxbow lakes, flood channels, abandoned channels, backplains and sand bars.

4B3 - Gently Undulating Land: Those areas of the Flat Trough Floor underlain by Karroo sediments and which are non-dissected or very weakly dissected. They are characterised by very gently undulating topography with both low and convex interfluves, river and stream channels, shallow (concave or flat) valleys and dambos.

4B4 - Swamps: Large flat depressions (usually at least 10 sq km in extent) in which the surface is permanently saturated with water and is usually overgrown with vegetation (papyrus and reeds). (Example: Mweru Wantipa swamp).

4B5 - Lakes: Large (at least 100 sq km) permanent bodies of water, entirely surrounded by land. (Examples: L Tanganyika, L. Mweru Wantipa, L. Kariba [manmade]).

As with the geology statistics, geomorphology area statistics by administrative boundary and by watershed boundary were created in ARC/INFO using ARC/INFO's UNION command. ARC/INFO's FREQUENCY command was then used to report these geomorphology statistics. The geomorphology statistics are shown in Appendix B and Appendix E.

Zambia

Geomorphology

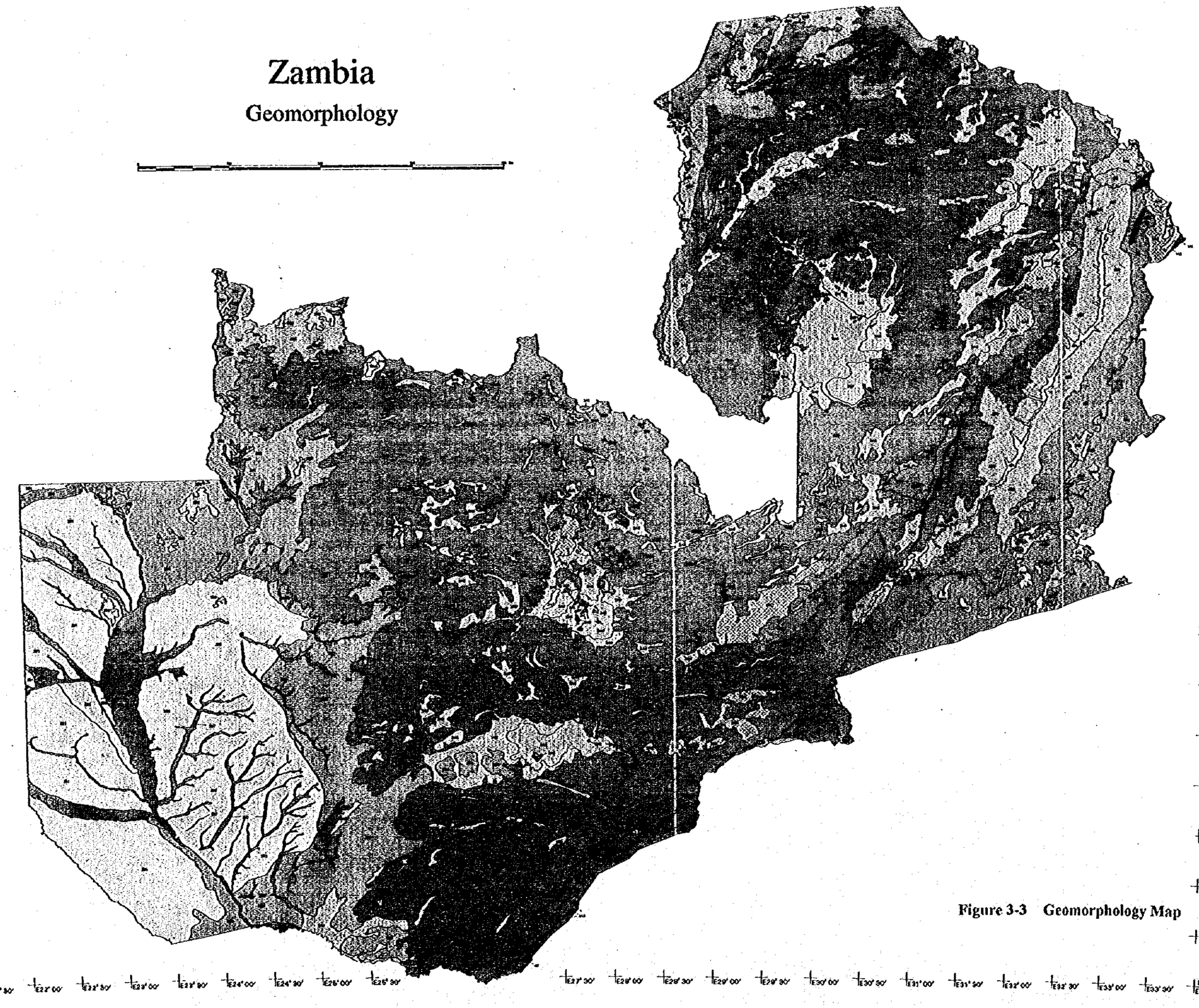
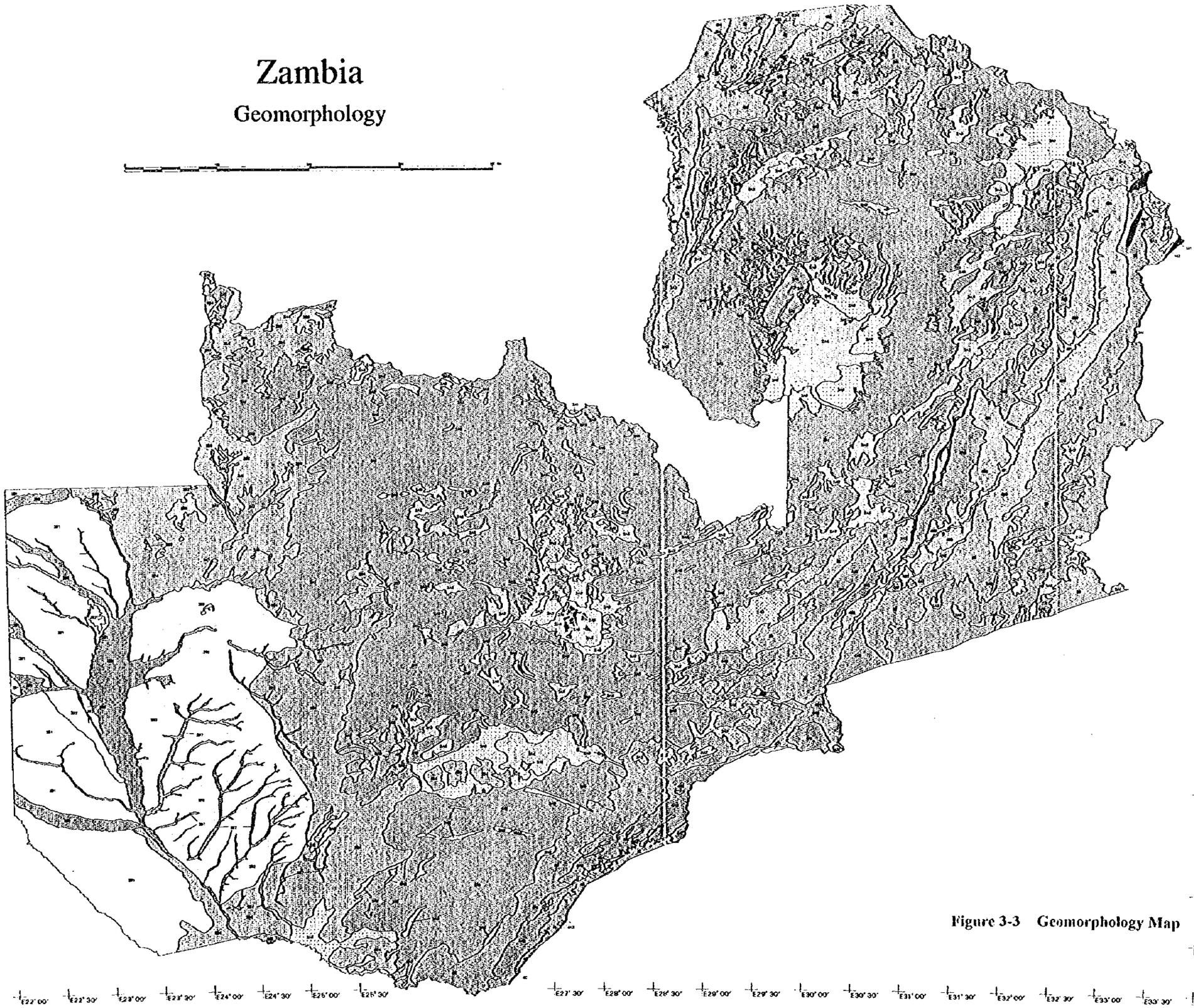


Figure 3-3 Geomorphology Map

Zambia

Geomorphology



Geomorphology

Figure 3-3 Geomorphology Map

Zambia

Geomorphology

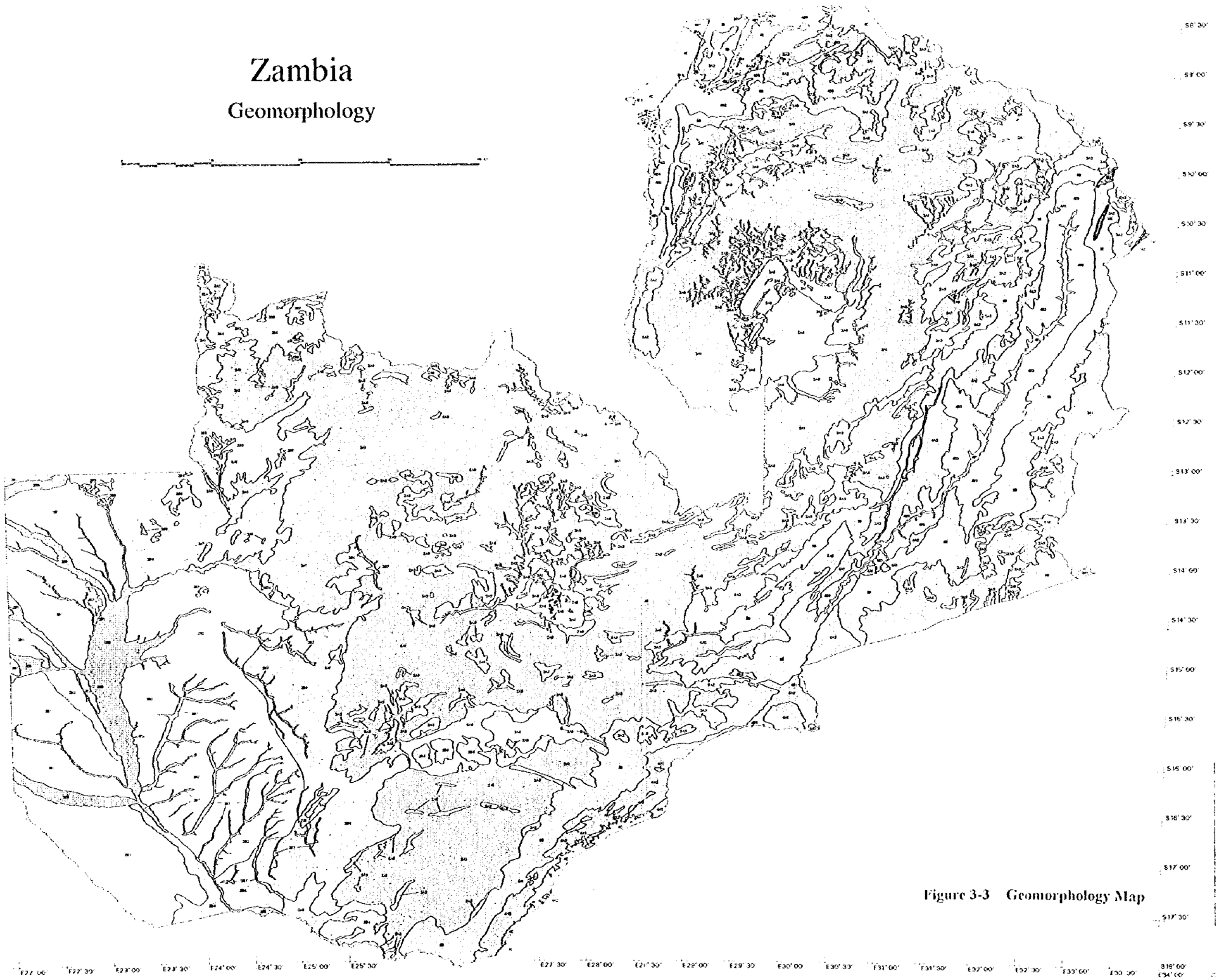


Figure 3-3 Geomorphology Map

3.6 Interpretation of Nation-Wide Drainage and Water Basin Delineation

The previously existing drainage basin delineations (or watershed boundaries) were modified based upon a thorough drainage analysis of the 1:500,000 scale Landsat image maps. The previously existing drainage basin delineations were based upon maps of various scales and where base map detail was erroneous, modifications were made. All drainage basin area calculations are based upon the new watershed boundaries derived from this nation-wide drainage analysis.

Control points depicted on various maps and described in documents provided were transferred to this drainage analysis and are shown as small triangles on the drainage maps. Various levels of detail and drainage intricacy are observable on the drainage analysis. In part this is due to the type of lithology on which the drainages have been formed. It is also due to the quality of, or amount of detail observable on, the imagery in some areas.

In addition to the unions of geology, geomorphology, and land cover by watershed boundary, the statistics for river density by geomorphology and river density by geology were also created in ARC/INFO. River density by geomorphology is presented in Appendix G and river density by geology can be found in Appendix H.

Zambia

Drainage

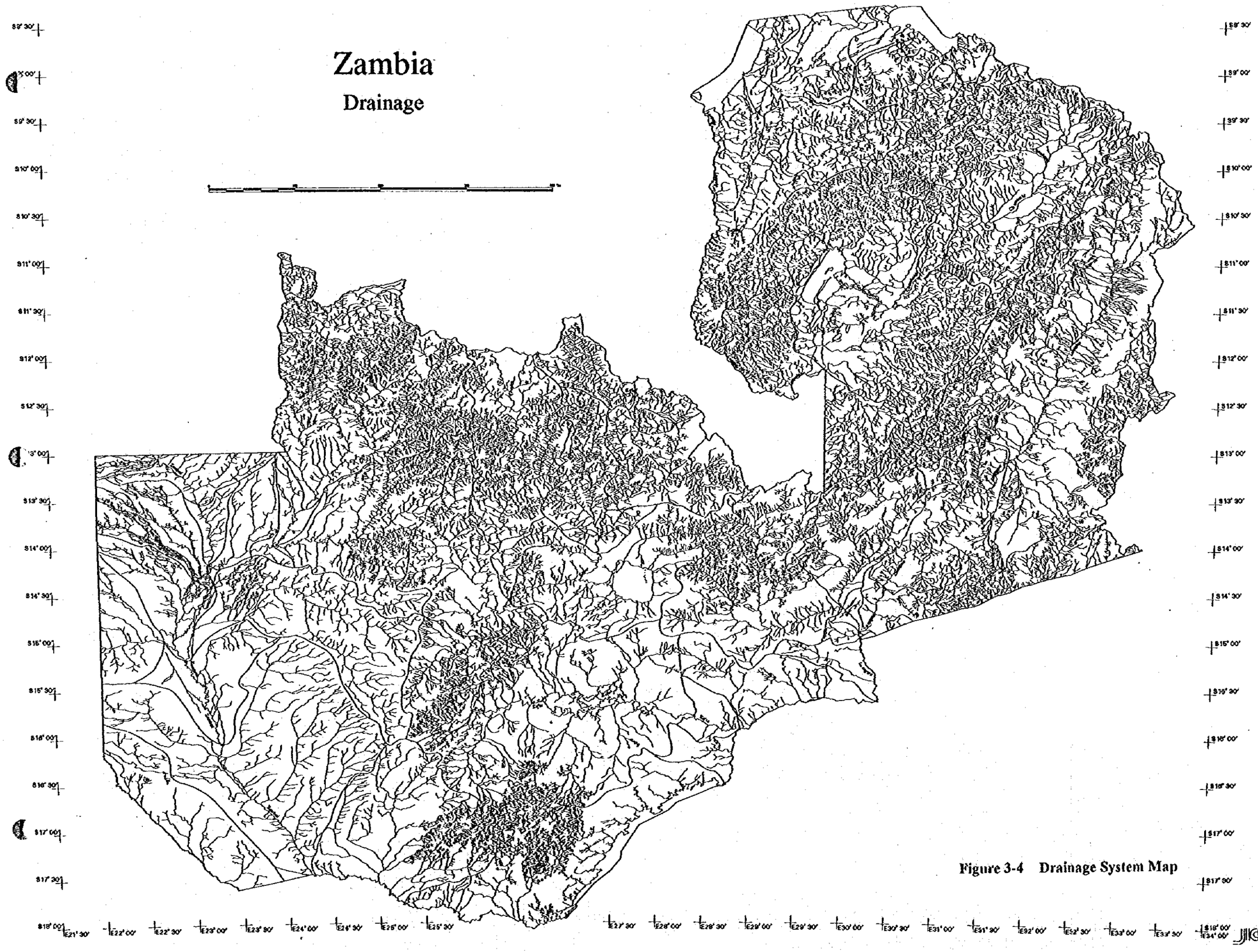


Figure 3-4 Drainage System Map

3.7 Area Calculation

Hectares of geomorphology, geology, and land cover by watershed boundary and by administrative boundary, and river density by geomorphology and by geology were calculated in ARC/INFO. Unions of these databases were made with ARC/INFO's UNION command and ARC/INFO's FREQUENCY command was used to report these statistics. The ARC/INFO output was reformatted and appears as APPENDIX A through APPENDIX H in this report.

3.8 Explanation of Products

All 1:500,000-scale map products are bound into a 35-map portfolio. The portfolio contains 5 maps for each of the seven 1:500,000-scale maps required to cover all of Zambia. The first map is the Geology transparent overlay for map sheet 1. The second map is Geomorphology transparent overlay for map sheet 1. The third map is the Drainage Channel and Watershed Boundary transparent overlay for map sheet 1. The fourth map is the Land Cover transparent overlay for map sheet 1. The fifth map is the Landsat TM Mosaic Image map. The five maps for map sheet 2 follow the products for map sheet 1. The last set of five maps in the portfolio are for map sheet 7. The portfolios are bound on the western edge of the map and are covered with a clear mylar cover. The portfolios are inserted into a 4 inch tube for storage.

The second, third, and fourth sets of map products was produced at scales of 1:1,000,000 (4 quadrants per theme). These products were produced on a color electrostatic plotter. The five series of maps at these scales include Administrative Boundary, Geology, Geomorphology, Land Cover, and Drainage/Watershed Boundary.