UNITED NATIONS
DEVELOPMENT PROGRAMME
OFFICE FOR PROJECT SERVICES

YEMEN REPUBLIC
MINISTRY OF AGRICULTURE & WATER RESOURCES
SANA'A, SADAH AND HAJJAH
AGRICULTURAL & RURAL DEVELOPMENT AUTHORITY (SSHARDA)

NORTHERN REGION AGRICULTURAL DEVELOPMENT PROJECT
TECHNICAL ASSISTANCE FOR ENGINEERING SERVICES
YEM/87/015

LAND USE MAP OF THE NORADEP REGION
APPROACH AND METHODOLOGY

Final Report
May 1993

DHV CONSULTANTS bv
in association with
TEAM CONSULTING ENGINEERS CO. LTD
DARWISH CONSULTING ENGINEERS

TABLE OF CONTENTS

PREFACE

The NORADEP Landuse mapping has been used mainly for the assessment of land system runoff categories to be incorporated in the waterbalances of the NORADEP Sub-regions. Besides it provided an input for the preparation of the Water Management Plans and may be used in future planning exercises.

SUMMARY

The land use classification of the NORADEP project area was based on TM satellite data. Land use is very much determined by available moisture, temperature and the market price of the crop.

Rainfall and irrigation are the main sources of available moisture. The variation in mean temperature is caused by the elevation. The NORADEP project area is dominantly occupied by natural vegetation; these dry and hot areas can be used as rangeland. There is agriculture where sufficient moisture permits it. Cereals (millet, sorghum) are the main crops planted on the rainfed land. Other water sources are hill slope runoff and irrigation. Runoff plays an important role due to the limited amount of rainfall; irrigation is primarily found in the wadibeds where fruits and vegetables are grown also. High value cash crops like qat, vegetables, coffee and fruits are grown in temperate (higher elevation) areas with sufficient moisture.

Two type of land use are of particular interest in the NORADEP project area: mountain terraces and spate irrigation. Both are man-made and started at least 2000 years ago. Terraced agriculture is found on mountain slopes exposed to rain; terraces intercept the rain, runoff and eroded soil material very well. Spate irrigation is a traditional way of irrigation; dams are constructed in the wadis and flood water and fertile sediments are diverted onto the fields. At least three floods are needed to produce a good crop.

To ease the land use classification, the NORADEP project area was divided into four land regions. The land regions were based on among other criteria, geomorphology, the rainfall and elevation, and are refined into land systems: the land use. The first land region, the **Lowlands (Tihama)** has a tropical climate with a mean annual rainfall varying from nearly zero (in the west) to 500 mm (in the east). Sorghum and millet are the most important crops; with irrigation, fruits, tobacco and sesame can be grown.

The **Western Midlands and Highlands** are zones of lower temperatures. The mean annual rainfall is 900 mm in the southwest and decreases towards the northeast. Here, provided there is sufficient moisture, crops like qat, potatoes and deciduous fruits are grown. The delineation between the Lowlands and the Western Midlands and Highlands is based on the distinct boundary observed on the satellite image. The Lowlands have light coloured sands and the Western Midlands and Highlands dark coloured mountains.

The **Highland Plains and Surrounding Catchments** have an altitude of about 1800 m to 2600 m. Depressions in the gently sloping limestones and volcanic outcrops are filled with alluvial, pyroclastic and aeolian material. The mean annual rainfall ranges from 125 mm to about 250 mm.

The Highland Plains and Surrounding Catchments cover a small area but are important for agriculture because of the combination of the flat terrain, the hill slope runoff, the waterholding capacity of the sediments, the occurrence of ground water and the short distance to the market. The high altitude results in a temperate climate.

Sorghum is the main crop; if there is sufficient moisture high-value cash crops such as qat, vegetables and deciduous fruits are grown also.

The **Eastern Midlands and Highlands** are characterized by bare rocks. The mean annual rainfall in the western part of the Eastern Midlands and Highlands is about 125 mm and decreases towards the east, where the climate is hot and dry. The area has very little agricultural development and is hardly inhabited. Two different lifestyles can be found: the Bedouin with their nomadic herding, and agriculture along the wadis. Groundwater is very important for agriculture; the main crop is sorghum.

The division between the Western Midlands and Highlands and the Eastern Midlands and Highlands is based on the north/south watershed.

Selection of the watershed as boundary was done with a purpose: water resources play an important role in the NORADEP project.

1 CHARACTERISTICS AND AVAILABILITY OF SATELLITE DATA

The project area covers 34 522 km^2. Owing to the size, diversity and inaccessibility of the survey areas, the land use inventory made intensive use of remote sensing, the gathering and processing of information about the earth's environment, particularly its natural and agricultural resources, using photographic and related data acquired from an aircraft or satellite. DHV Consultants proposed remote sensing techniques, because they are the only way in this case to obtain accurate information economically and quickly.

Although remote sensing data interpretation makes a land use inventory easier, there are limitations that must be recognized. The degree to which categories of cover can be recognized depends on the type, quality, scale and season of the remote sensing data. A map based on remote sensing data always represent the situation during the time of the data collection. A remote sensing interpretation has to be followed by field checks. Remote sensing techniques are, therefore, used to improve and reduce field work rather than to take its place.

More information on remote sensing is provided in Annex 2.

Recent high resolution satellite data of the project area, eg. SPOT and TM, are available for the project area. The following characteristics of the high resolution satellite data have an important bearing on the resource and environmental component study.

- *Synoptic View*
  High resolution satellites cover areas of about 185 by 185 kilometres (TM) or 60 by 60 kilometres (SPOT) and have a ground resolution of 30 metres (TM) or 20 metres (SPOT). These characteristics allow for land classification surveys over a large area at a scale of 1:50 000. Important features such as the influence of climate, parent material, topography and soils on vegetation can be inferred.

- *Repetitive Coverage*
  The satellite passes over the same area every 16 days, which provides the opportunity for selection of the scene taken at the time best suited for land use classification.

- *Multispectral Capabilities*
  Satellite data are recorded in several distinct parts of the spectrum and these multispectral capabilities prove extremely useful in land classification.

- *Near-orthographic Projection*
  The almost uniform vertical projection, and the advanced geometric correction methods available, mean that satellite data can be regarded as having the specifications of 1:50 000 mapping.

  As a result high resolution satellite data is a very inexpensive tool for land use classification. The project area is covered by six TM scenes, and a much higher number of SPOT scenes. Therefore, the TM scene is to be preferred; also TM has more channels in the visible part of the spectrum than SPOT. It is the experience of DHV Consultants that TM is better than SPOT for distinguishing geophysical information.

2 MATERIALS AND METHODS

There are three steps in land use classification: data collection, data manipulation and presentation of results.

2.1 DATA COLLECTION

The emphasis here is on data acquisition and data analysis. Data were collected from existing thematic maps, reports, data files, and from remote sensing. Firstly, the existing information on land use in the project area in the form of maps and reports were gathered together. These are listed in Annex 1. This information reflects the historical land use situation. Then, recent remote sensing data (satellite data) were obtained, which provides information on relatively current land use.

DHV Consultants ordered six TM images to cover the project area. Table 2.1 shows their dates of acquisition, the location in path and row and the location of the centre point in latitude and longitude.

Table 2.1 *Details of TM Images*

NORTH

	Date	23 November 1989			
	Path/row:	167/50			
	Lat/long	N14°-27'/E43°-34'			
WEST	Date	16 October 1987	6 October 1989	18 October 1987	EAST
	Path/row:	167/49	166/49	165/49	
	Lat/long	N15°-53'/E42°-25'	N15°-54'/E43°-53'	N15°-54'/E45°-30'	
	Date	16 October 1987	30 August 1990		
	Path/row:	167/48	166/48		
	Lat/long	N17°-21'/E42°-44'	N17°-21'/E44°-13'		

SOUTH

The criteria used in the selection of acquisition dates for the TM images were that they should be cloud and haze free, good quality, optimum date for differentiating crops (September or October).

Besides the TM images, DHV Consultant also ordered six Landsat MSS images covering the project area. Table 2.2 shows the dates of acquisition, the location in path and row and the location of the centre point in latitude and longitude of the Landsat MSS images.

The criteria used in the selection of acquisition dates for the Landsat MSS images were that they should preferably be more than eight years old, of cloud and haze free, good quality and at the end of the dry period (or first rains).

Table 2.2 *Details of Landsat MSS Images*

NORTH

	Date	23 April 1984			
	Path/row:	167/50			
	Lat/long	N14°-27'/E43°-38'			
WEST	Date	16 March 1985	5 February 1985	1 February 1986	EAST
	Path/row:	167/49	166/49	165/49	
	Lat/long	N15°-53'/E42°-23'	N15°-54'/E43°-56'	N15°-54'/E45°-27'	
	Date	30 April 1984	24 February 1985		
	Path/row:	167/48	166/48		
	Lat/long	N17°-21'/E42°-47'	N17°-21'/E44°-15'		

SOUTH

A multi-temporal analysis of the two dates helps in the land use classification to better differentiate irrigated land.

Positive transparencies (optroniks) at a scale of 1:1000 000 of the satellite data were ordered, which were used to make 1:250 000 photographic enlargements.

2.2 DATA MANIPULATION

After data collection, consideration was given to the destination of the information gathered: either to be used as an input to further data manipulation or to be presented in a graphical form. (Data manipulation is defined as the management and analysis of spatially referenced information in a problem solving synthesis).

A hierarchical system approach called land system classification was used for the NORADEP project area. Land system classification was developed to divide land into units that integrate environmental data related to biological productivity and engineering requirements for planning, development and management. Emphasis is placed on the relationships existing between landforms and vegetation in deriving the hierarchy of land units suited to cover extensive land areas.

The approach is based on a multiphase survey of three levels: the highest is at an exploratory (1:1000 000) scale; in the next two levels the degree of detail is progressively refined to reconnaissance scale (1:250 000) to meet the requirements of the survey.

For more detailed information such as natural vegetation and crop practices, the reader is referred to the following reports: The Vegetation of the Republic of Yemen, Western Part, DHV 1991; Socio-economic Study, NORADEP Project, DHV 1992.

The Consultant used the Landsat TM data for the highest level; the interpretation of the Landsat imagery was based on the recognition and delineation of broad surface landforms that have properties expressive of vegetation, precipitation, topography or lithological units, or of close lithological association having everywhere undergone comparable geomorphic evolution.

The following land regions were distinguished:

- Lowlands (Tihama).
- Western Midlands and Highlands.
- Highland Plains and Surrounding Catchments.
- Eastern Midlands and Highlands.

The land region classification and the delineation of the units were based on the requirements of the NORADEP project. For instance, the boundary between the Western Midlands and Highlands and the Eastern Midlands and Highlands is the watershed. These agree approximately with the other existing land use classifications in Yemen: Natural Regions of Yemen, Japan International Cooperation Agency, and the classification by Cornell University of 1983.

The classification units used by Cornell university were:

- Tihama Coastal Lowlands.
- Foothills and Middle Heights of the Western Slopes.
- Central Highlands.
- Eastern Semi-Desert Plateau.

The second level is the land system. Differentiation of land systems is based predominantly on land use; other important items are uniform geology, uniform vegetation, water source (rainfall, irrigation type), and geomorphic history. The scale of this survey was 1: 250 000. TM satellite data were used and identification of the land systems was based on the correspondence between the colours, shapes, shades and texture of the land systems and the reflectance of these land systems on the ground. More information on this subject is provided in Annex 3.

Some land systems can be identified intuitively, depending on the interpreter's background information on the situation in Yemen. Others are derived from the literature. Selected areas in the NORADEP project area had to be field checked (level 3). Next the land systems are identified within the four land regions. Table 2.3 shows the land regions with their land system (land use) classifications.

The third level was based on the ground-truth survey which was carried out at selected important sites in the NORADEP project area. The program of the land use survey is given in Annex 4.

Field information was obtained on land use, and other relevant characteristics such as crop type and available water, and matched with the image to meet the requirements of the survey. Ground truth was also obtained from literature, maps and discussions with project team members. The assistance provided by SSHARDA was very useful. During the field visit their knowledge of the land use in Yemen and the interactions with the farmers were of great help.

Table 2.3 *Land Regions and Systems*

Land Region: Lowlands (Tihama)
Land system/use: - dunes and sandy plains (not cultivable) - natural vegetation/rangeland - rainfed agriculture - irrigated land (groundwater) - irrigated land (rainfed, with hill slope runoff and/or groundwater) - irrigated (spate irrigation)
Land Region: Western Midlands and Highlands
Land system/use: - natural vegetation/rangeland - rainfed, hill slope runoff agriculture - irrigated land (spate and groundwater, mainly wadibeds) - terraced agriculture (mainly rainfed with hill slope runoff)
Land Region: Highland Plains and Surrounding Catchments
Land system/use: - natural vegetation/rangeland - irrigated land (groundwater, mainly plains) - irrigated land (spate and groundwater, mainly wadibeds)
Land Region: Eastern Midlands and Highlands
Land system/use: - bare rocks with isolated shrubs - shrubs in wadibeds - natural vegetation/rangeland - rainfed, hill slope runoff agriculture - irrigated land (spate and groundwater, mainly wadibeds)

2.3 PRESENTATION OF RESULTS

Presentation of the results is mainly in the form of cartography which has two major stages:

- Collecting and selecting the data for mapping.
- Manipulating, generalizing and enhancing the data, designing and constructing a map.

It should be realized that throughout the activities that precede map production, the aims and requirements must be constantly borne in mind. The quality of the data collected and of the data manipulations have consequences for the message presented in the resultant map. Also, it should be recognized that the map represents the situation at a given moment. The degree to which land use can be recognized depends on the date (season) of the remote sensing data. A large part of the project area is covered by a satellite image of October 6th, 1989 and the interpretation represents the situation of the land use on that date.

Table 2.4 *Mapping and Land Use Classification Units*

Mapping Unit	Land Use Classification Unit	Area (km^2)	% of total Area
	Land Region: Lowlands (Tihama)		
T1	Dunes and sandy plains (not cultivable)	173.3	0.5
T2	Natural vegetation/range land	1 504.3	4.4
T3	Rainfed agriculture	1 161.8	3.4
T4	Irrigated land (groundwater)	248.3	0.7
T5	Irrigated land (rainfed, with hill slope and/or groundwater	433.5	1.3
T6	Irrigated (spate irrigation)	230.0	0.7
	Sub-total Lowlands (Tihama)	3 751.2	11.0
	Land Region: Western Midlands and Highlands		
W1	Natural vegetation/rangeland	11 312.3	32.7
W2	Rainfed, hill slope runoff agriculture	576.3	1.7
W3	Irrigated land (spate and groundwater, mainly wadibeds)	259.0	0.8
W4	Terraced agriculture (mainly rainfed with hill slope runoff)	970.0	2.8
	Sub-total Western Midlands and Highlands	13 117.6	38.0
	Land Region: Highland Plains and Surrounding Catchments		
E1	Natural vegetation/rangeland	278.0	0.8
E2	Irrigated land (groundwater, mainly plains)	303.3	0.9
E3	Irrigated land (spate and groundwater, mainly wadibeds)	138.3	0.4
	Sub-total Highland Plains	719.6	2.1
	Land Region: Eastern Midlands and Highlands		
P1	Bare rocks with isolated shrubs	13 975.5	40.4
P2	Shrubs in wadibeds	51.8	0.1
P3	Natural vegetation/rangeland	2 262.5	6.6
P4	Rainfed, hill slope, runoff agriculture	144.5	0.4
P5	Irrigated land (spate and groundwater, mainly wadibeds)	499.5	1.4
	Sub-total Eastern Midlands and Highlands	16 933.8	48.9
	Total NORADEP Project Area	34 522 km^2	

The mapping units assigned to the various land use classification units are shown in Table 2.4, which also shows the area each mapping unit occupies and the percentage of the total NORADEP project area each mapping unit represents.

2.4 LAND USE MAP

The map shows the following topographic information: International Boundary

- Provincial Boundaries,
- Project Region Boundary,
- Paved Roads,
- Gravel Roads,
- Tracks,
- Rivers and Streams,
- Cities,
- Major Towns.

The information on roads, tracks, rivers and streams, cities and major towns was obtained from the existing topographic maps. However, some features on the existing topographic map were outdated and satellite data were used to update these. At the request of the NORADEP Project special attention was paid to the rivers and streams.

The land use interpretation scale 1:250 000 was reduced to a map scale of 1:500 000. On the map the satellite data were printed as a grey background. This special feature gives the user additional information on landforms.

The Land Regions are printed in different hues. The landuse classification units within the Land Regions have different intensities, selected so that an increase in intensity indicates an increase in vegetation density.

3 LAND REGIONS, LAND SYSTEMS AND LAND USE

3.1 LOWLANDS (TIHAMA)

3.1.1 Topography and Landscape

The Tihama is a 30 km wide by 60 km long strip, bordered in the west by the Red Sea. In the east the natural border consists of the foothills and the Western Midlands. This boundary is clear on the satellite images: the light coloured sand of the lowlands contrasts with the dark coloured mountains of the Western Midlands. The lowlands are flat to slightly undulating, predominantly barren, with incidental cacti, succulents, dry grasses and thorn bushes.

The landscape is geologically relatively young, formed by the continuous flow of sediments, and is a good example of a pediplain. Very large wadis flow from the mountains into the Tihama carrying sediments varying from silts and sands to gravel and boulders. At the foot of the mountains there is a sharp decrease in slope, which causes the flow of water to slow down and sediment to be deposited; alluvial fans in the form of vast plains are created.

At the foot of the mountains coarse material is dropped and sediments in the fans grade progressively to the fine materials of the alluvial plains. The lack of vegetation and the dryness allow the wind to carry away the finer sand particles which are deposited in the form of dunes. The shape of the dunes -Barchans and longitudinal-suggests that there is a limited sand supply for their formation.

The wadis channel most of the water for agriculture in the Tihama. The wide and wild wadis sometimes cause severe floods, but hardly ever reach the sea. Some of the water penetrates into the soil, to aquifers, or to flow into the sea. The infiltrated water can be used for irrigation.

Along the coast, currents deposit material in some locations and erode the coast at others.

3.1.2 Climate

The rainfall in the Tihama shows a strong east-west trend. It ranges from almost nil along the coast to about 500 mm in the eastern part. Landuse is strongly determined by the available moisture; rainfed agriculture is found in the east. The rains fall in the spring (Rabi'a), late summer (Sayf) and autumn (Kharif). Most rain falls in the Sayf and Kharif. The average annual temperature is around 30 degrees Celsius, annual temperature range is small. The air humidity is high, averaging 80%.

3.1.3 Landuse Classification Units

Dunes and Sandy Plains
A zone with beaches, bare and vegetated sebkhas and coastal dunes is found along the coast.

Rangelands

The vast, flat rangelands are to the east of the coastal zone. Their type and quality is very much determined by the rainfall. In the west they are almost bare but transform slowly in eastwards, with the increase in rainfall, into open scrubland.

Rainfed Agriculture

This is found near almost every village if the farmers judge that there is enough rainfall to have a crop, and it is also practised on the sandy plains and dunes. The natural vegetation is removed, except perhaps for some trees, and the area is cultivated with mainly millet. Enormous areas are seeded in years with good summer and autumn rains; in years with mediocre rainfall the cultivated area is small.

Irrigated Land (Groundwater)

Diesel pumps have transformed formally marginal agricultural land into important cash crop producing areas. The number of irrigated plots has increased enormously during the two decades since 1970. The cash crops are perennial fruit trees such as papaya, banana and mango; vegetables such as okra, tomatoes, water melon, peppers and cucumber; sesame and cotton.

In the west of the Tihama date palms are found. Traditionally this crop was irrigated with shallow groundwater, but the increase in pumps has led to groundwater mining and to a lowering of the ground water table. Nowadays the date palms have to be supported with irrigation water from the diesel pumps. The date palms are intercropped with annual crops such as sorghum, alfalfa and vegetables.

Irrigated Land Rainfed with Hill Slope Runoff and/or Groundwater

This is found in the eastern part of the Tihama where the land receives rainfall, runoff water from the nearby mountain slopes and pumped groundwater. Sorghum is the main crop. Because of the different water sources, farmers in these areas have a much better chance of a successful crop than those in the rainfed areas.

Spate Irrigation

Spate is a traditional method of irrigation. Dams are constructed in the wadis and flood water and (fertile) sediments are diverted onto the fields. The crops grown in spate irrigated areas are mainly cereals (sorghum and maize) and alfalfa. A sorghum crop needs at least three floods to produce a good yield. This type of irrigation is found in nearly all wadis.

Because of the scale of the map and the date of satellite images only the larger areas under spate irrigation are indicated on the map.

3.2 WESTERN MIDLANDS AND HIGHLANDS

The Western Midlands and Highlands have natural boundaries with the Lowlands (Tihama) in the west and the Eastern Midlands and Highlands in the east. The boundary in the West is clear on the satellite images: the light coloured sand of the Lowlands and the dark coloured mountains of the Western Midlands; that in the east is the watershed. The rivers of the Western Midlands and Highlands flow westwards to the Red Sea; the rivers of the Eastern Midlands and Highlands flow east towards the great inland desert of the southern part of the Arabian peninsula (Rub al Khali Basin). The selection of the watershed as boundary had a purpose: water resources play an important role in the NORADEP project. The watershed was located on the topographic maps and transferred to the land use map.

The Western Midlands have elevations ranging from about 200 m to 1000 m and are situated between the Lowlands (Tihama) and the Highlands. The Midlands can be subdivided into three physiographic units: piedmont, upland and plateau. The plateau is rugged with steep slopes, and wadis cut deep into it. The geology determines the steepness of the terrain: shales and limestone produce steep slopes, volcanic material gentle slopes and granite and gneiss are responsible for a rugged landscape.

The Highlands are above 1000 m and the topography is very rough. Here also the geology has an important bearing on the topography: limestones and shales result in an undulating topography; volcanic materials have steep slopes and granite and gneiss have generally moderate slopes.

Besides slope and elevation rainfall and man-induced processes also influence the land use. The Western Midlands have a mean temperature of 26 degrees. The annual rainfall increases towards the east: 300 mm in the foothills to a maximum of 600 mm at the higher elevations; then it decreases to the northeast. The climate of the Highlands is about the same as that of the Midlands except that higher altitude causes a lowering of temperature and an increase in rainfall. The man-induced processes such as terracing and irrigation are pronounced in the Western Midlands and Highlands.

The major part of the Western Midlands and Highlands has **natural vegetation** with dwarf grasses, grasses and open shrubs on rocky slopes, mostly used as rangeland. The rainfed and hill slope runoff agriculture is mainly concentrated in the western part of the Western Midlands and Highlands, because of the higher rainfall. The crop land is mainly bunded or lightly terraced, the fields receiving water direct from the rain but also indirectly from either the nearby mountain slope or the fields above. Cereals (sorghum and millet) and tropical fruits are found at low elevations. High-value cash crops such as qat, coffee and deciduous fruits (grapes) are also grown in the higher, low temperature areas. On lands above 1000 m qat is the main crop.

The irrigated land (spate and groundwater) is mainly in narrow elongated strips in the wadibeds. These areas are scattered in the Western Midlands and Highlands; often their size is too small to map at a scale of 1:500 000. The main crops are cereals, qat, citrus fruits and vegetables - tomatoes, onions and potatoes.

Terraced agriculture is found on the mountain slopes. The terraced mountain slope is a very distinct and fascinating feature, man made and started at least 2000 years ago. Man has transformed the stony soils on slopes to fertile cultivable land by removing the stones, moving the soil, adding manure and ploughing. Terraced agriculture is mainly found on slopes exposed to the rain. Terraces intercept the rain and the runoff very well; another advantage of terraces is the collection of eroded soil material. On the terraces mainly high value cash crops are grown: tropical fruits, cereals and beans are found on the larger terraces at low elevations; qat, vegetables, coffee and deciduous fruits (grapes) are grown in the higher, low temperature areas. On lands above 1000 m, qat is the main crop.

3.3 HIGHLAND PLAINS AND SURROUNDING CATCHMENTS

The Highland Plains and Surrounding Catchments have an altitude of about 1800 m to 2600 m, and are situated in the Eastern Midlands and Highlands, where depressions have been filled with a thick layer of alluvial, pyroclastic and aeolian material forming the Highland Plains. The total area occupied by the Highland Plains and Surrounding Catchments is only 2.1% of the NORADEP project area. The most important areas are those around Amran and Sa'dah. The mean annual rainfall ranges from 125 mm to about 250 mm.

Land use accords with the geomorphological characteristics and the availability of water. The wadis originate in the surrounding midlands and highlands. The Plains are flat and gently sloping and once the wadi debouches onto the plains the velocity of the water drops and it percolates into the soil. Here the irrigated land (spate, and ground water, mainly wadi beds) is found; water for this land use classification unit is obtained by spate or pump (groundwater). The irrigated land (groundwater, mainly plains) is found on the plains around the wadibeds. The farmers, living in this land use classification unit pump groundwater to supplement rainfall.

The high altitude of the plains results in a temperate climate. Besides sorghum high-value cash crops such as qat, vegetables and fruits-apples, citrus and grape - are also grown. Some plots have sorghum intercropped with sesame and beans. The higher and the rocky areas have natural vegetation cover and are used for rangelands (natural vegetation/ rangeland).

3.4 EASTERN MIDLANDS AND HIGHLANDS

The watershed is the natural western boundary of the Eastern Midlands and Highlands; the eastern boundary is the Saudi Arabian border.

Land use is very much determined by the available moisture and geology. The mean annual rainfall in the Western part is about 125 mm and decreases to the east. This rainfall pattern can also be observed clearly in the vegetation; in the dry eastern part bare rocks with isolated shrubs are found. These extensive areas have very little agricultural development and are hardly inhabited. The climate is hot and dry. Two different lifestyles can be found: the Bedouin nomadic herding, and agriculture along the wadis, which occupies small areas. The shrubs in the wadis are situated at the beginning of the wadis, and on the land use map only the large units are indicated; the unit is used as rangeland.

As rainfall increases towards the west, the number of shrubs gradually increases and grasses appear, changing the bare rocks with isolated shrubs to natural vegetation/rangeland. The rainfed agriculture is mainly found in the western part of the area. Rainfall is slightly higher but the main water source for the rainfed agriculture here is hill slope-runoff here.

In the western part of the mapping unit geology is also an important factor in the land use. The gently sloping limestones with steep volcanic outcrops are very pronounced. These geological formations are sometimes covered with aeolian and alluvial deposits. The limestone has cracks into which the water disappears but the volcanic material is much less permeable. The difference in waterholding capacity of the parent material and the thickness of the aeolian and alluvial deposits are also factors in the location of rainfed agriculture.

The irrigated land (spate and ground water) is dominantly found in the wadibeds. Ground water is very important for agriculture in the Eastern Midlands and Highlands. The main crop is sorghum.

The existing information and the collected data from other studies allow the establishment of a monitoring system, an advanced use of data manipulation. Based on the generated information decisions can be taken to allocate, use and manage natural resources. Decisions and actions often have strong interactions and side effects and can result in a degradation of the environment. A monitoring system with a continuous update of resource and ecology information in an overlay system will allow careful evaluation of the impact of decisions. Using this information, "what if" situations can be studied, and all actions leading to the realization of goals attuned to one another, resulting in a minimum of environmental damage long-term strategies and action programs for sustained development of the project area can be generated.

ANNEX 1

REFERENCES

ANNEX 1 REFERENCES

- Technical Paper No.: HWC 1, Monographs on Water Resources in the Yemen Arab Republic. March 1990 (UNDP/UNDTCD).
- A Summary of Available Information, Report WRAY-1. August 1984 (YOMINCO Department of Hydrology & TNO-DGV Institute of applied Geoscience).
- World Benchmark Soils Report No. 1. October 1985 (Cornell University & SMSS & Ministry of Agriculture)
- The Vegetation of the Republic of Yemen (Western Part). 1991 (DHV)
- NORADEP YEM/87/015; Inception Report, Draft, Volume 2-Annexes. October 1990 (DHV).
- Environmental Profile Tihama. January 1990 (DHV)
- Environmental Profile Dhamar Governorate. May 1990 (DHV)
- Land Use Summary & Arabic Translation, Final Report (Contract No. AID/NE-C-1665). May 1983 (Resource Information Laboratory Cornell University).
- Report on Master Plan Study for Hajjah Province Integrated Rural Development in the Yemen Arab Republic, Volume 2, Study Report (Draft) (Japan International Cooperation Agency).

ANNEX 2

PRINCIPLES OF REMOTE SENSING

BASIC PRINCIPLES OF REMOTE SENSING

Albert van Dijk

DHV CONSULTANTS
P.O.Box 421
Jakarta 10001
Indonesia
Phone : 021-711795
712431
718011
771131
Telex : 47355 dserco ia
Telefax: 021-710551

1. Introduction

To start with, it is important to recognize that man's relationships to his natural resources are extremely complex. He has to take decisions to allocate, use and manage the natural resources for his continued existence. Decision and action in any use of resources often have strong interactions and side effects on others. Therefore it is very important to monitor the impacts of the decisions very carefully, so that all actions leading to achievement of the goal are attuned to one another.

The role of remote sensing in the decision and monitoring process is fundamentally simple. It is merely to provide reliable information, at an acceptable level of accuracy, in a timely, cost-effective manner.

2. What is Remote Sensing?

The original meaning of remote sensing is to identify and observe an object at a distance without direct touching. This is a very broad definition: our senses, except taste and tactile sense, can be regarded as remote sensors.
Since the USA launched the world's first Earth Observation Satellite (LANDSAT-1) in 1972, we have been able to observe the earth from space and, at a jump, remote sensing technology has become regarded as an important technology; therefore, a sharper definition was necessary. A complete remote sensing system must be capable of performing the full sequence of operations that begins with data collection and ends with the presentation of thematic results.

The general flow of remote sensing data from airborne or satellite sensor to the data/imagery user is as follows:

1. data collection
2. pre-processing
3. processing
4. interpretation

3. Data Collection

The remote sensing imagery collection is considered to have four basic parts:
1. the radiation source
2. the atmospheric path
3. the target and
4. the sensor

A radiation source is the sun, whose energy is spectrally distributed throughout the electromagnetic spectrum. The energy propagates through the atmosphere and its intensity and spectral distribution are modified by the atmosphere. The energy then interacts with the target and is reflected, transmitted and/or absorbed by it. The reflected/emitted energy then passes back through the atmosphere and again is subjected to spectral and intensity modifications. Finally, the energy reaches the sensor where it is recorded.

Photography, a well known technique, is a way to collect information on an object from a distance, being thereby a form of remote sensing - the camera is the sensor and the film the recorder. In most cases data recorded are electromagnetic radiation in the wavelengths between 0.40 and about 0.75 um, the part of the electromagnetic spectrum called visible light. The result is a familiar image directly recognized through another remote sensor, the human eye. The term image covers data storage media such as photographs and magnetic tapes.

However, the electromagnetic spectrum encompasses more than visible light alone. The wavelengths are expressed in units, ranging from Angstroms to kilometers covering from short to long: Gamma Rays, X-rays, Ultraviolet, Visible, Infrared, Microwave and Radiowaves. Also, other parts of the electromagnetic spectrum can be used for data collection.

3.1 Radiation Source

First, with reference to the radiation source, there are two types of remote sensing systems. An active remote sensing system supplies its own source of radiation which is directed at the object in order to measure the returned energy (radar, flash photography). In a passive remote sensing system the primary radiation source is the sun.
All matter at temperatures above absolute zero (-273 C or 0 K) radiates electromagnetic waves. The hotter the object, the more radiation it emits. The peak radiation lies at a certain wavelength depending on the absolute temperature of the object. For our Sun, the power peak of its radiation lies at 0.47 um (blue light). This position, and also the distribution curve of radiation is closely related to the blackbody radiation curve at 5900 K, suggesting a similar surface temperature of the Sun.

3.2. The Atmospheric Path

The atmosphere between the radiation source and the target and between the target and sensors has a significant effect on the data. The atmosphere is a variable absorber, emitter, reflector and scattering medium at different wavelengths. About 18% of the Sun's energy is absorbed and scattered by particles in the atmosphere. Absorption mainly is caused by H2O, CO2 and in the UV part, by 03. Thirty-five percent of the Sun's energy is reflected by the Earth and atmosphere including clouds. Forty-seven percent of the sunlight is absorbed by the Earth's surface.

The fact a cloudless sky is blue is an example of selective scattering.
Blue light has a wavelength comparable to the size of the particles in the atmosphere. The result is that blue light is scattered. Light with longer wavelengths (like red light) passes unhampered. The result is that the sky appears blue and the Sun yellow. When the particles are big, say like the tiny droplets in a cloud, then scattering is total and the cloud looks white.

The Earth's atmosphere has a disturbing influence on the propagation of radiation so that only a limited number of "windows", which are relatively unaffected by atmospheric absorption of water vapor, carbon dioxide, carbon monooxide, nitrous oxide and ozone, are usable. (see Figure 1).

The most important windows are:
- visible 0.4-0.75 um and near infrared 0.75-1.1 um
- two spectral bands in medium (thermal) IR 3 5 and 6 - 14 um
- microwave region (1 mm to several meters).

For monitoring the earth's surface, the most important window by far is the 0.4 - 1.1 um, the visible and near infrared.

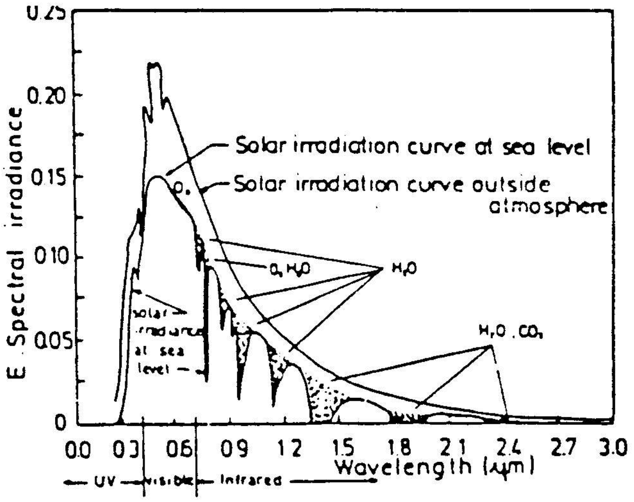

Figure 1: Energy curves of electro-magnetic radiation of the Sun before and after passing through the atmosphere.

3.3 The Target

The energy that hits the earth's surface, direct or indirect, is absorbed or reflected. The absorbed energy keeps the earth's surface at an average temperature of about 300 K. Just like the Sun, the Earth itself now becomes an emitter of EMR, but with a much lower energy output and a distribution curve of radiation with a peak near 10 um.
It stretches from 3.5 um into the microwave region. The reflected and emitted energy can be collected by a sensor.

There is hardly any spectral gap between the region of emitted and reflected energy and, in theory, it should be possible to use a large slice of the electromagnetic spectrum for remote sensing between the ultraviolet and very low frequency (VLF) radio waves. However, the present state of the art and the windows only permit the use of a few narrow bands.

Objects at the Earth's surface have their particular reflection curves, showing the percent of reflectance at different wavelengths. In Figure 2, the reflection curve for a healthy green leaf is given. Over the whole visible spectrum absorption is high, often 80 - 90%. Absorption of blue (0.40 - 0.47 um) and red (0.60 - 0.70 um) light is higher than of green light (0.50 - 0.54 um). Reflected or transmitted light of leaves is, therefore, green, taking into consideration the sensitivity of the human eye. Little radiation is absorbed between 0.7 and 1.0 um.

In Figures 3 and 4, the reflection curves (spectral signature) as recorded for various types of foliage and soils are shown.

3.4 Sensors

Measurement on the reflection curves from the target is performed by sensors. The general term covers a wide range of devices used to collect and record data concerning terrestrial objects, e.g. cameras, scanners, radars, etc. Sensors are carried by platforms which may be aircraft, balloons, or satellite.

Different sensors are used for the different windows:

- the visible (0.4 - 0.75 um) and near infrared (0.75 - 1.1 um).
  The data in these windows is solar energy reflected by objects and can be collected by sensors. Sensor sensitive in this part of the spectrum are conventional aerial photography cameras and more recently, multispectral scanners
- two spectral bands in medium (thermal) IR (3.5 and 6.14 um). The data collected in this window are energy radiated by terrestrial objects. Photo emulsion cannot be used at these wavelengths.
  The sensors are scanning devices equipped with detecting cells sensitive to thermal IR radiations
- the microwave region (1 mm to several meters). The sensors used are two types - active and passive.

3.5 Characteristics of the Sensors

The sensors can be divided into three broad classes:

a. cameras
b. scanners
c. radar

The first sensors to be used for satellite remote sensing were metric cameras. Metric cameras are characterized primarily by their high-precison metric qualities: very low distortion, provision of reference marks at the rear of the camera, recourse to stereoscopic observation and to measurements and processes permitting the high-accuracy location of objects on the ground in terms of their x, y and z coordinates.

By combining different focal lengths and different altitudes, a large range of scales can be achieved (1 : 1,500 to 1 : 100,000). For the recording film, Black and White, IR Black and White, UV, Color IR, Color can be used, but also a photo sensitive camera tube (Return Beam Vidicon Camera).

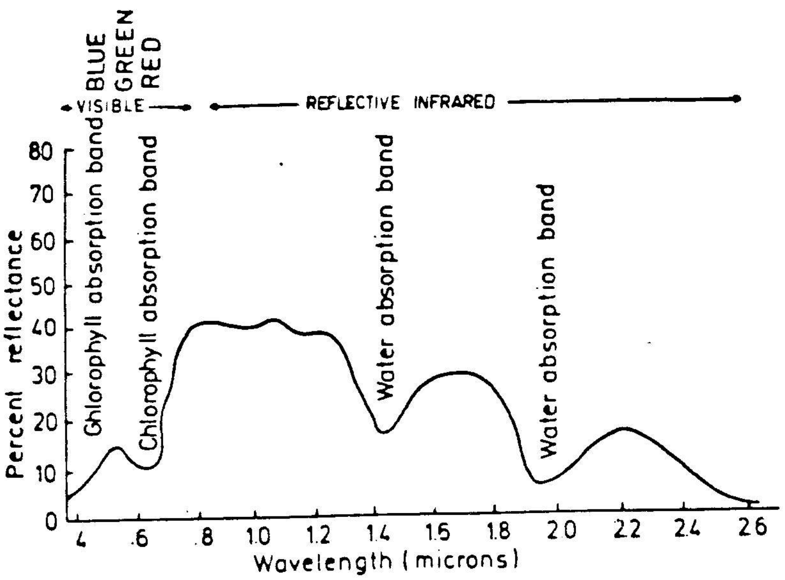

Fig. 2
Reflection curve for a healthy green leaf.

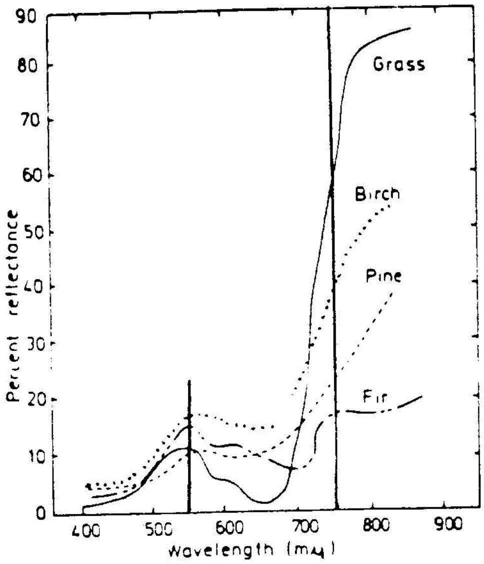

Fig. 3
Reflection curves for various types of foliages.

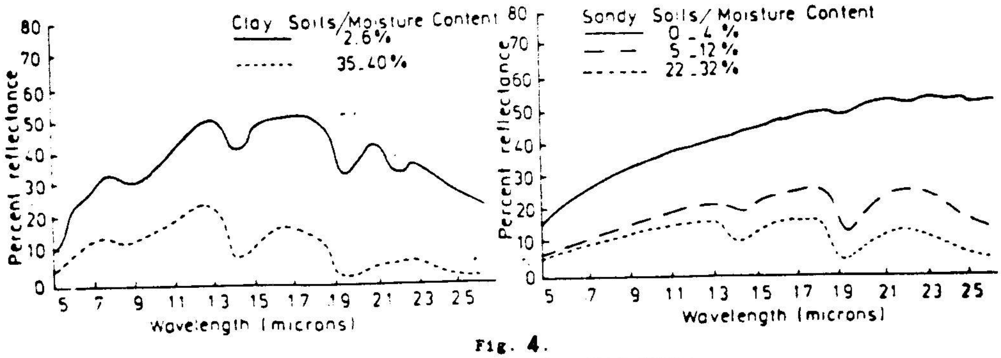

Fig. 4.
Reflection curves for two soil types under different moisture contents.

A) Multicameras

The idea of multispectral reconnaissance is that by comparing two or more pictures of the same object made in different regions of the EM spectrum we may learn something about the object that we could not learn by studying the total values of just one picture.
Taking Figure 3 as an example, we see that by using two cameras with a variety of emulsions or optical filters, it is possible to produce two photographs which represent, respectively, the reflectance of 0.5 - 0.6 um and of 0.7 - 0.8 um. In the 0.5 - 0.6 um image there is not much contrast between the various types of foliage but the contrast in the 0.7 - 0.8 um image makes a distinction between the types of foliage possible (see Figure 5). A multispectral camera can be seen as a battery of cameras with a variety of emulsions or optical filters which offers a means of obtaining the required information.

Cameras used in satellite remote sensing:

- the Gemini two man mission	(1965, 1966)
- the Apollo program	(1969)
- Skylab	(173, 1974)
- Soyuz/Salyut	

B) Scanners

A scanning system works briefly as follows: A rotating or oscillating mirror gathers the energy emitted or reflected by a narrow strip of terrain, perpendicular to the platform's ground tract. The extremities of this strip are determined by the device's maximum scanning angle.
The image of the terrain is then produced by the forward movement of the platform.

The radiation reflected from the ground is separated into several distinct wavelength bands by filters (prism or dichroic mirrors). The energy sensed by the detectors is converted into an electric signal for recording on tape or transmission to an earth receiving station. See Figure 6.

Another mode of scanning is obtained by using a linear array of detectors instead of a mirror. Multi spectral scanners are on board Landsat and SPOT. The reflected light is separated into spectral components by optical systems and is sensed by detectors in respective wavelengths:

satellite		electromagnetic spectrum
Landsat	SPOT	
band 4	band 1	0.5- 0.6 um (green colour light)
band 5	band 2	0.6- 0.7 um (red colour light)
band 6	band 3	0.7- 0.8 um (near infrared)
band 7		0.8- 1.1 um (near infrared)

C) Radar

Radar imaging systems provide a source of electromagnetic energy (microwave) to illuminate the terrain. This energy is transmitted by an antenna as a series of pulses. Upon reaching the ground part of this radiation is scattered. The energy returned from the ground is detected by the system and recorded.

4. Preprocessing

The term preprocessing covers all those operations intended to correct known faults in the image and to yield a document suitable for preliminary direct analysis. For example, the quality of imagery can be improved by enhancing details and augmenting contrast and by correction of geometrical deformations in the image which are the result of an oscillation of the platform.

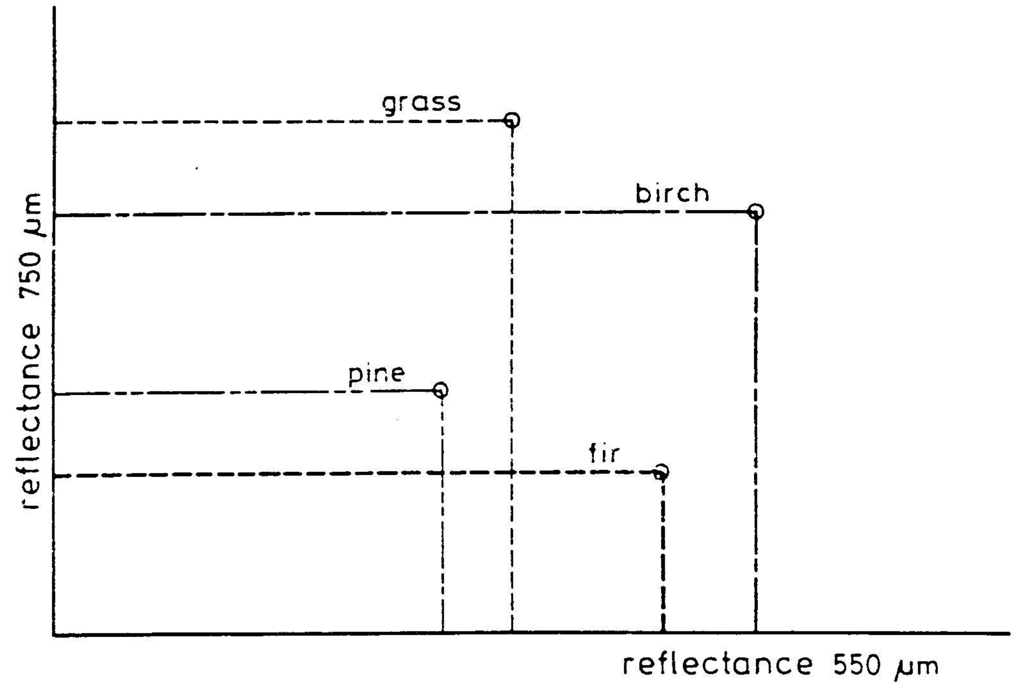

Figure 5
Relative reflected light of Pine, Fir, Birch and Grass across 1 and 3 SPOT band (wavelength 550 um green and 750 um near infrared)

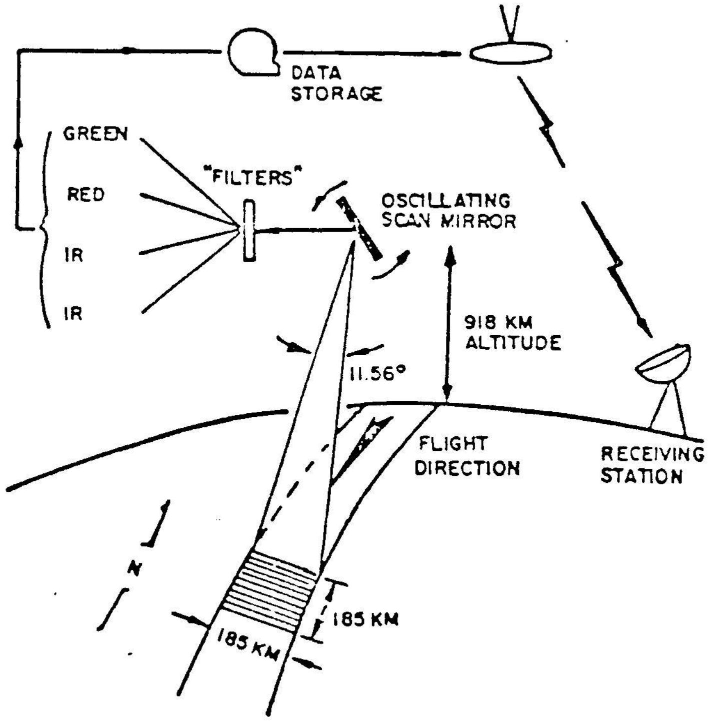

Figure 6

Landsat multispectral scanner. For each terrain scene four images are transmitted to a receiving station. From NASA (1976 figure 2-4)

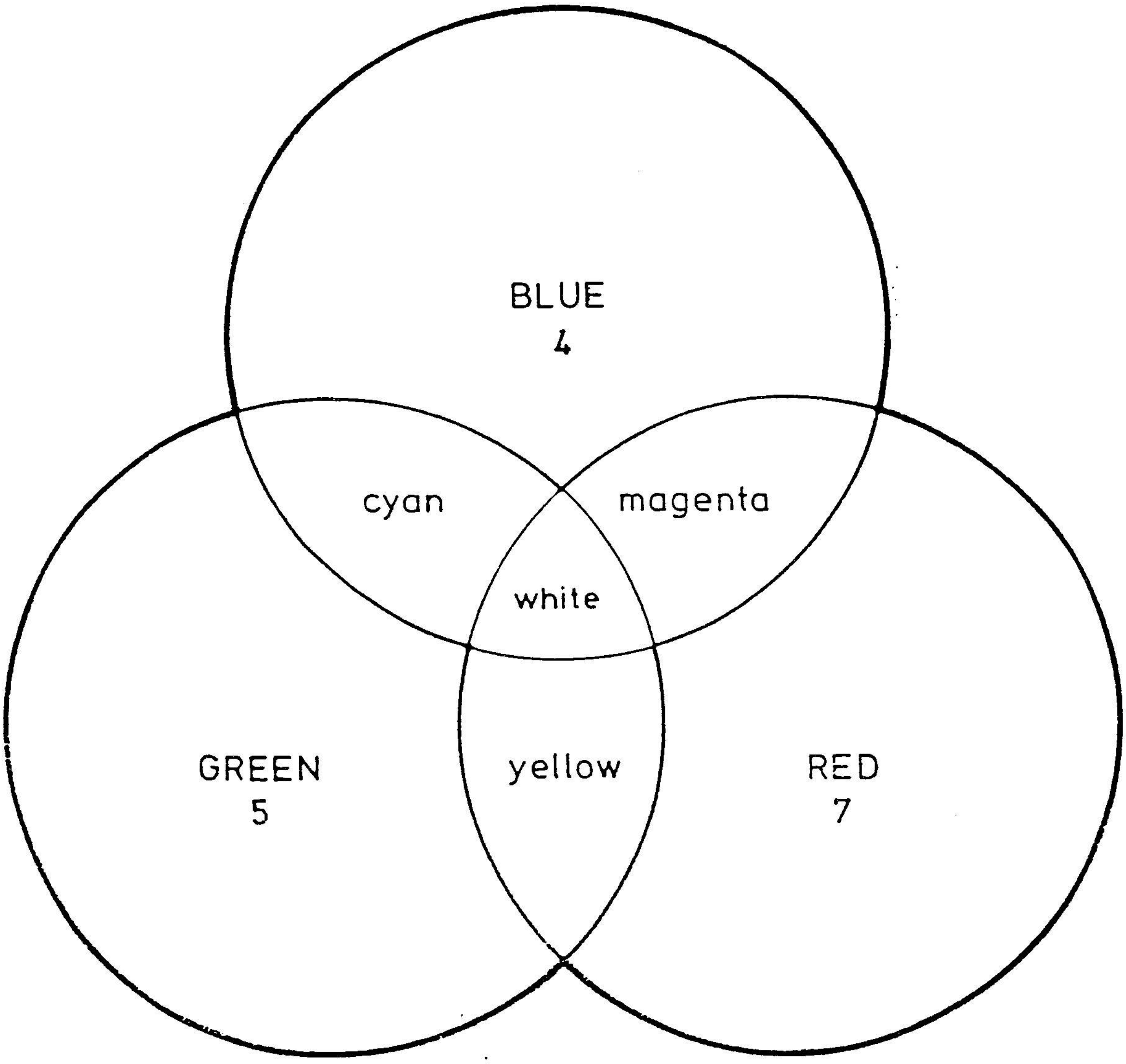

Figure 7

Color Additive Viewing - Diagram for determining the result of adding of the primary colors.

5. Processing

The term processing covers all the activities to extract all the available information in an image that is helpful for interpretation. Take Landsat as an example. The multispectral reconnaissance is in 4 bands. To distinguish different aspects, one has to consult images of the other bands. The intercomparison of two or more black and white images is inconvenient and tiresome, and the more subtle differences between features are particularly difficult to detect.

By allocating colours to the different images and by combining them, it is possible to put all the spatial and spectral information into one image. The three primary colours are: blue, green and red. This means that only three bands can be merged into one colour image. It is possible to allocate any colour to any band, for instance: band 4 - blue; band 5 - red; and band 7 - green. This combination image is called natural colour image because its colour contrast is nearly natural colour.

The most commonly used combination is:

- band 4 - blue
- band 5 - green
- band 7 - red.

This combination is, in fact, a shift of one colour interval into a shorter wavelength. It is called a false colour image because its colour contrast is different to the colour contrast of the human eye.

Other processing activities than combination of images corresponding to several spectral bands are:

- combination of images of different periods
- optical and electronical analogue processes (such as density slicing)
- multi-spectral digital processing.

6. Interpretation

Interpretation is the fourth phase of a remote sensing operation; it is thus the phase leading directly to usable results. Throughout the phases preceding interpretation, i.e. during data collection, preprocessing and processing, the aims and requirements of the final phase must be constantly borne in mind.
Coming back to the Landsat example, Figure 7 is a diagram for determining the result of adding of the primary colours (colour additive viewing). It is possible to determine the colour of grass on a Landsat colour composite with the usual colour allocation to the bands. Going back to the spectral signatures of vegetation (Figure 3), there is some reflection in band 4. A minor amount of blue is added to the colour composite. There is almost total absorption in band 5 (due to photosynthesis in chlorophyll). No green is added. There is a very high reflection in band 7; much red is added.

The colour composite consequently shows mainly red, at times a bit purplish varying with the amount of reflection in band 4. It is important to bear in mind that only vegetation shows this absorption in band 5 combined with the very high reflection in the nearinfrared. The resulting colour red is without exception indicative for vegetation.

Depending on the natural resources being investigated, a certain number of field measurements must always be carried out at the time of data collection. Field measurement data are called ground truth and may cover temperature, humidity and spectrometry measurements, land-use information, data on the phenological state of plant life or the nature of the terrain, etc. Although the number of field measurements is expected to decrease as remote sensing techniques progress, such measurements will undoubtedly remain indispensable for some time yet.

References

1.American Society of Photogrammetry, 1983. Manual of Remote Sensing. Falls Church, Virginia, USA, 22046.

2. DHV 1987. Interfacing the Image Processing Systems for the MARS Project. DHV Consulting Engineers, Amersfoort, The Netherlands

3. ERDAS 1986. ERDAS PC and PC_KIT Image Processing System User's guide. ERDAS, 430 Tenth Street, N.W. Suite N206. Atlanta USA 30318.

4. A. van Dijk. Consultancy Report Training Course in Remote Sensing Applied to Agriculture, Soils and Geomorphology (Hanoi, 18 October-19 November 1982). Food and Agriculture Organization of the United Nations Rome, 1982.

5. Philip H. Swain/Shirley M. Davis. Remote Sensing the Quantitative Approach, McGraw Hill, 1978.

6. Sabins, Floyd F., Jr. Remote Sensing, Principles and Interpretation, Freeman and Co., 1978.

ANNEX 3

LANDUSE SURVEY PROGRAMME

ANNEX 3 LANDUSE SURVEY PROGRAMME

The aim of the landuse field survey was to:

- Investigate the land use at selected spots.
- Explore the farming systems in the different areas of the NORADEP Project. The farming systems are of interest, but also:
  - The crops grown.
  - The relationship between vegetation and altitude.
  - The relationship between vegetation and moisture.
  - The irrigation methods used.
- Check the preliminary land use map
- Relate the interpreted LANDSAT TM data to the actual situation found in the areas to be visited.

The field programme was as follows:

August 4 to August 6	Visit of the Wadi Mawr catchment, travelling from the lowland (Tihama) up to the (Midland) wadi and check spots relevant to interpretation of the satellite images. Stay overnight in Hajjah.
August 7	Sana'a: outline of different mapping units.
August 8	Visit the Al Madan area. Of special interest is the relationship between vegetation (crops or natural vegetation) and the environment.
August 10	Process findings field visits. Briefing of project staff of results of the mission sofar. Departure of A. van Dijk.
August 11&12	Make an west-east cross section of the Tihama near Wadi Al Qur to study the differentiation between agricultural and non-cultivable areas.
August 13&14	Survey of the plain and mountains near Al Mahabishah with field checks on the vegetation.
August 15	Study and summary of information obtained in Sana'a.
August 17	Survey of the Sana'a basin and Wadi as Sirr.
August 18 to 23	Land use interpretation and transfer of collected information on a transparent. Add updated topographic information to topographic base map. Prepare the map for digitizing.
August 24	Presentation of preliminary results to project staff in Amran.
August 25th	Departure of P. Getz for the Netherlands.

ANNEX 4

DIAGNOSTIC CHARACTERISTICS USED IN IMAGERY ANALYSIS

ANNEX 4 DIAGNOSTIC CHARACTERISTICS USED IN IMAGERY ANALYSIS

The following diagnostic characteristics were used in the imagery analysis:

Shape
Shape relates to the general form, configuration or outline of an individual object that is recorded as an image. For example, in identifying arable land in the wadis on the TM image, the narrow elongated red strips on imagery frequently infer the cultivation of arable crops in the wadi.

Size
Size relates to the surface dimensions of an object. Therefore, the interpreter must take the scale of the image into consideration. Roads that can be clearly defined on the TM image scale 1:250 000 are not visible on the TM image scale 1:1000 000.

Pattern
Pattern relates to the spatial arrangement of objects, but unfortunately crop patterns are not discernible on the TM imagery. The distinctive pattern provided by irrigated agriculture enables this land-use type to be identified on the TM images.

Tone
Tone relates to the brilliance with which light is reflected by an object. Without tonal differences between images, the images cannot be discerned. Tonal differences and colour contrast are inherent to the successful use of satellite imagery. Landsat, SPOT and TM images are digitally recorded over a 264 grey scale range, but for practical working purposes this is usually condensed to 64 grey levels or less. The human eye is even less discriminating, being able to discern 10-20 grey levels.

Colour Contrast
Using the Munsell theory of colour notation colours are represented in hues of blue, green and red and according to their chroma, brightness and greyness. Obviously colour notation provides a far greater range of image differences than the using of tone, so that, considering the very limited sensitivity of the human eye to tonal differences, colour contrast is often to be preferred when applying visual interpretation. Colour contrast is inherent to the successful interpretation of satellite imagery when studying the world's surface, including agricultural crops. For example, on the TM image, the agricultural crops, trees and natural vegetation appear in a range of "reds" and bare soil in a range of "blues", water surfaces are blackish and light blue, clouds whitish. The colours of soils are influenced by the spectral reflection differences caused by the following: moisture content, amount of organic matter, mineral characteristics, relative percentage of clay, silt, and sand, and soil surface roughness.

Texture
As applied to photographic imagery, texture may be defined as the frequency of tone change within the image. Texture is produced by an aggregate of unit features too small to be clearly discerned individually on imagery. It is a product of their individual

difference, size, shape and pattern. As the scale of the imagery progressively diminishes; the texture of the image of a given object becomes finer and will eventually disappear. Thus, on large scale aerial photographs, either black-and-white or in colour, texture is important for classifying rangelands, for identifying major groups of agricultural crops and tree plantations according to management and age classes; however it has very limited use in the interpretation of crops on satellite imagery.

Site

The location of an object in relation to other factors may be a very helpful clue to its identification, but this characteristic must be distinguished from "correlation" which is inferred and not observed. With regional knowledge and at a good resolution of the images, the site can be used in association with shape, size and tone/colour contrasts, to identify landforms.