Module
6

MANAGEMENT OF WATER RESOURCES

LESSON 3

REMOTE SENSING AND GIS FOR WATER RESOURCE MANAGEMENT

Instructional objectives:

On completion of this lesson, the student shall learn about:

1. The techniques of Remote Sensing and Geographic Information System (GIS)
2. Different types of remotely sensed images
3. Application of Remote Sensing in water resources engineering
4. Application of GIS in water resources engineering

6.3.0 Introduction

The term Remote Sensing is applied to the study of earth's features from images taken from space using satellites, or from nearer the earth using aircrafts. The technique of remote sensing has picked up in the past half a decade, largely due to the availability of digital computers, improved communication systems, digital imaging techniques and space technology. Remotely sensed data can be said to have its origin in photography, where the information about a target area is interpreted from photographs. Later this technique was extended to aeroplane - borne cameras giving rise to the science of aerial photography. This technique is still used, but largely the signal cameras have been replaced by Laser operated ones where the reflectance of a Laser beam projected from the bottom of the aircraft is sensed by electronic sensors.

In this chapter we shall discuss remote sensing using satellite as India has strived ahead in this field and made good use of satellite images. The satellite launching program of our country is one of the most ambitious in the world, and is still continuing to be so in the future as well. Amongst other fields, the Water Resources Engineers have benefited greatly by using satellite imaging techniques, some applications of which have been highlighted in this chapter.

The other topic that is discussed in this lesson is the Geographic Information System (GIS) that has wide applications in planning any spatially distributed projects. Fundamentally, a GIS is a map in an electronic form, representing any type of spatial features. Additionally, properties or attributes may be attached to the spatial features. Apart from its spatial data analysis capabilities, it provides an interface to remotely sensed images and field surveyed data. This technique has specifically benefited the Water Resources Engineers, which has been discussed in some detail.

6.3.1 Remote sensing through satellites

Remote sensing means assessing the characteristics of a place (usually meant as the surface of the earth) from a distance. Though this term was coined during the 1960's, similar technology had been practiced earlier like fitting a camera to a balloon and allowing it to float over the earth's surface taking pictures, which may then be developed and interpreted for specific purpose like geology, agriculture, forestry etc. Photogrammetry, that is, taking pictures of the land surface from a low flying aircraft and comparing subsequent pictures to obtain the terrain relief has been extensively used in the last century and many books have been written on the subject.

In satellite remote sensing, too, cameras are fitted to the orbiting satellite and are focussed towards the earth. However, the cameras are special in the sense that they are sensitive to other wavelengths of the electromagnetic spectrum as well. As may be observed from Figure1, the electromagnetic spectrum identifies the wavelength of the electromagnetic energy, of which the visible portion (or light) occupies only a small portion. Actually, electromagnetic energy refers to light, heat and radio waves. Ordinary camera or the human eye are sensitive only to the visible light. But the satellites are equipped with Electromagnetic Sensors that can sense other forms of electromagnetic radiations as well. This includes not only the Blue (0.4-0.5μm), Green (0.5-0.6μm) and Red (0.6-0.7μm) of the spectrum but also longer wavelength regions termed as the Infrared (IR) spectrum (0.7-1000μm), which can again be further subdivided into the following:

a) Photographic IR : 0.7-0.9μm
b) Very near IR : 0.7-1.0μm
c) Reflected/Near IR : 0.7-3.0μm
d) Thermal IR : 3.0-1000μm

Still longer wavelength is the microwave portion of the spectrum, which extends from 3000μm to 3m. The common remote sensing systems operate in one or more of the visible, reflected-infrared, thermal-infrared and microwave portions of the spectrum.

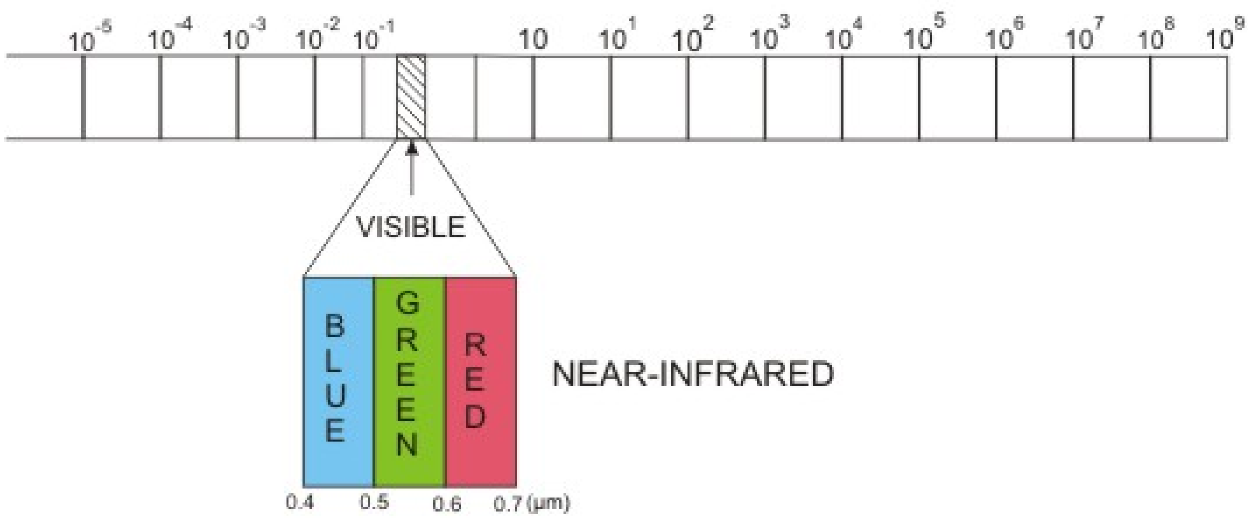


FIGURE 1. The energy spectrum

6.3.2 Interaction of electromagnetic radiation and earth

Electromagnetic energy of the sun incident on the earth's surface reaches fully upto the top of the atmosphere. However, as illustrated in Figure 2, not all of this energy reaches the surface of the earth, since part of the energy gets either scattered, absorbed or reflected by the atmosphere or cloud cover, if any. Only a part is transmitted upto the earth's surface. Specifically, it may be said that although the electromagnetic radiation reaching the top of the atmosphere contains all wavelengths emitted by the sun, only specific wave bands of energy can pass through the atmosphere. This is because the gaseous components of the atmosphere act as selective absorbers. Molecules of different gases present in the atmosphere absorb different wavelengths due to the specific arrangement of atoms within the molecule and their energy levels. The main gaseous component of the atmosphere is nitrogen, but it has no prominent absorption features. Oxygen, Ozone, Carbon Dioxide and Water Vapour, the other major components absorb electromagnetic wavelengths at certain specific wavelengths. The wavelengths at which electromagnetic radiation are partially or wholly transmitted through the atmosphere to reach the surface of the earth are known as atmospheric windows, as shown in Figure 3. Since these radiations reach the surface of the earth, they are useful for remote sensing as they would be reflected or absorbed by the features of the earth giving the typical signatures for the sensors in the satellite (or any other space borne device) to record. This is shown graphically in Figure 4.

The remote sensing system sensors are designed in such a way that can capture information for those wavelengths of electromagnetic radiation that occur within the atmospheric windows.

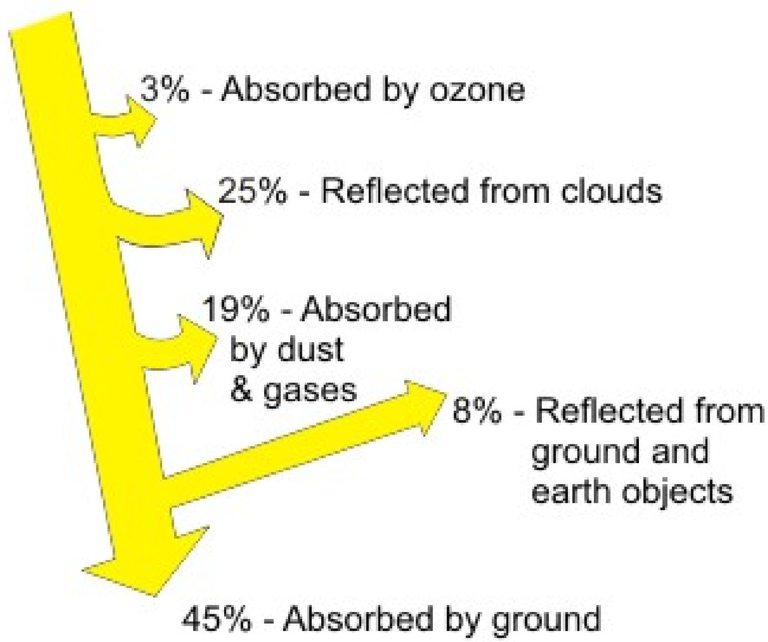


FIGURE 2. Fate of incoming solar radiation to earth

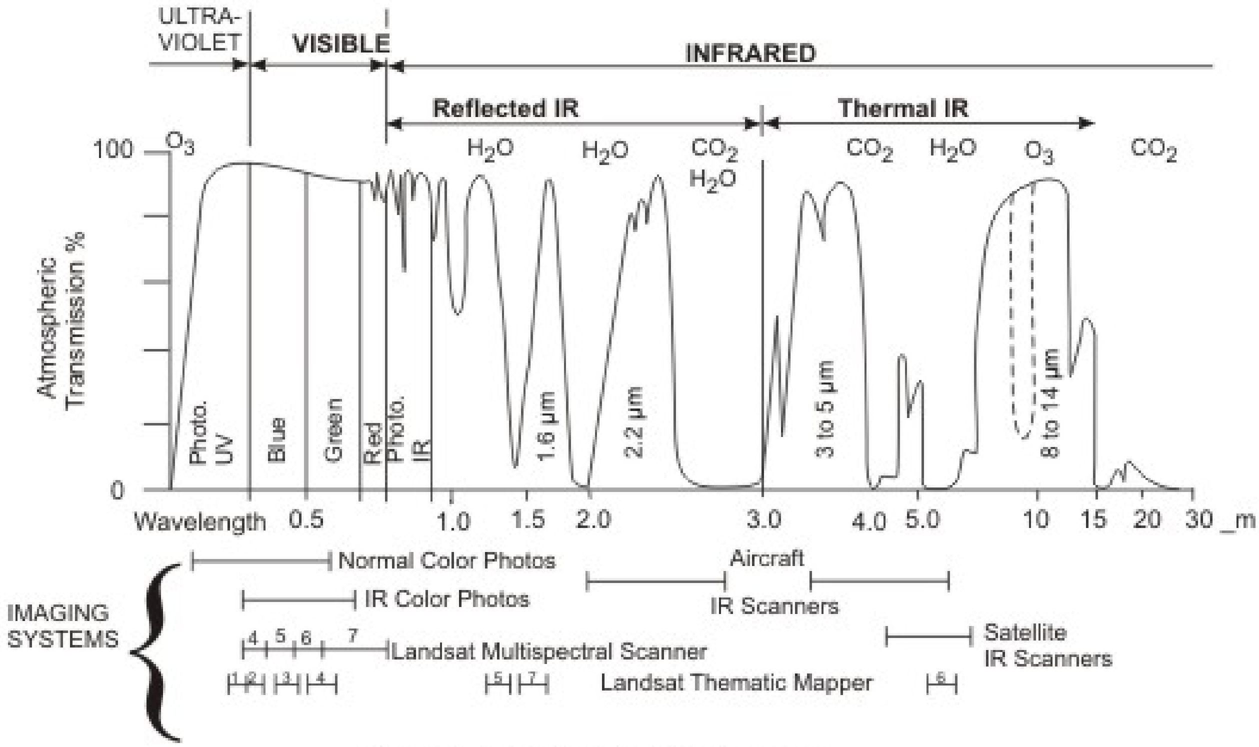


FIGURE 3. Atmospheric windows

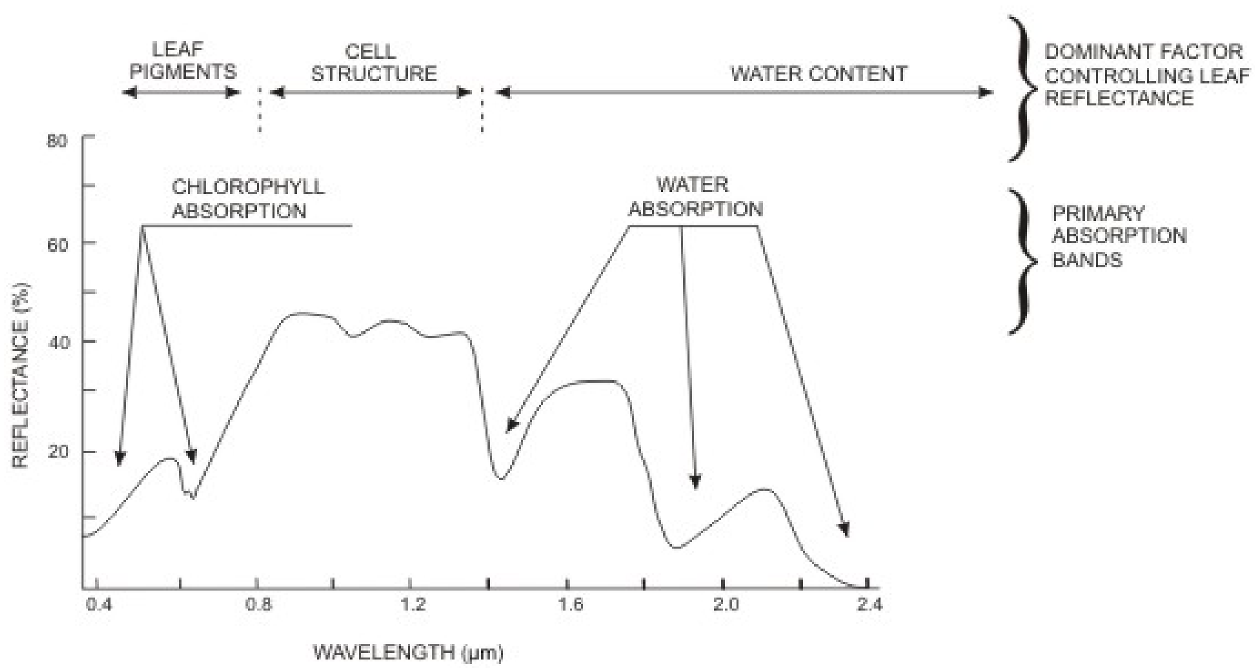


FIGURE 4. Spectral signature of vegetation

6.3.3 Interaction of electromagnetic radiation with a surface

When electromagnetic radiation strikes a surface, it may be reflected, scattered, absorbed or transmitted. These processes as not mutually exclusive: a beam of light may be partially reflected and partially absorbed. Which processes actually occur depends on the wavelength of the radiation, the angle at which the radiation intersects the surface and the roughness of the surface. Reflected radiation is returned from a surface at the same angle as it approached, the angle of incidence thus equals the angle of reflectance. Scattered radiation, however, leaves the surface in all directions. Whether or not incident energy's reflected or scattered is partly a function of the roughness variations of the surface compared to the wavelength of the incident radiation. If the ratio of roughness to wavelength is low (less than one), the radiation is reflected whereas, if the ratio is greater than one, the radiation is scattered. A surface which reflects all the incident energy is known as a Specular reflector whereas one which scatters all the energy equally is a Lambertian reflector. Real surfaces are neither fully specular nor fully lambertian. However, for remote sensing purposes, a Lambertian nature is better. A remotely sensed image of a fully specular surface gives a bright reflectance (or signature) for one position of the camera and dark image at other positions. If the surface is uniform lambertian, then the reflectance obtained for the surface will be same irrespective of the location of the camera because the radiation from the surface would be scattered equally in all directions. Most natural surfaces that are observed using remote sensing systems are approximately lambertian at visible and infrared wavelengths.

6.3.4 Interaction of electromagnetic radiation with earth surface features

From the general discussion on the nature of interaction of electromagnetic energy with any surface, we turn on to the earth features as these would be useful in Water Resources Engineering.

As observed from Figure 5, it is seen that a part of the electromagnetic energy reaches the earth's surface, a part of it gets absorbed by the body, a part gets transmitted within the body, and a part gets reflected from the surface of the body. The proportion of energy that is reflected, absorbed and transmitted varies with the particular earth feature, like whether it is vegetation, water, urban landscape, etc. Besides, the proportion of energy is also dependent on the wavelength of the electromagnetic spectrum that is interacting with the surface. Thus, for a particular feature, the proportion of energy that is reflected, absorbed or transmitted varies with the wavelength that is interacting.

This means that two different features may reflect equal proportion of energy in one wavelength range and may not be separately identified but for another wavelength range their difference reflectance may allow a sensor to distinguish between the two features. This variation in interaction of electromagnetic energy with any surface can be explained in the way we distinguish objects by separate colours. As we know, the wavelengths in the visible range of the spectrum strike all surfaces, but we observe different colours because each surface reflect only a particular wavelength and absorb the rest.

Most of the sensors in remote sensing systems also operate in the wavelength regions in which the reflected energy predominates and thus the reflectance property of surfaces is very important. Of course, the sensors do not capture only the reflected energy in the visible range of wavelength but different sensors are designed to capture the reflected energy in other ranges of wavelengths as well.

The reflectance characteristics of the different features of the earth surface may be quantified by measuring the portion of incident energy that is reflected by a surface. This reflected energy is measured as a function of the wavelength and is called Spectral Reflectance. Quantitatively this is defined as the ratio of the energy of the wavelength reflected from an object and the energy that is incident upon it.

Spectral reflectance of any object usually varies according to the wavelength of the electromagnetic radiation that it is reflecting. A graph showing the spectral reflectance of an object for various wavelength is known as a Spectral Reflectance Curve (Figure 6). The pattern of a Spectral Reflectance Curve gives an insight into the spectral characteristics of the object. It also helps in selecting the wavelength bands which may be suitable for identifying the object.

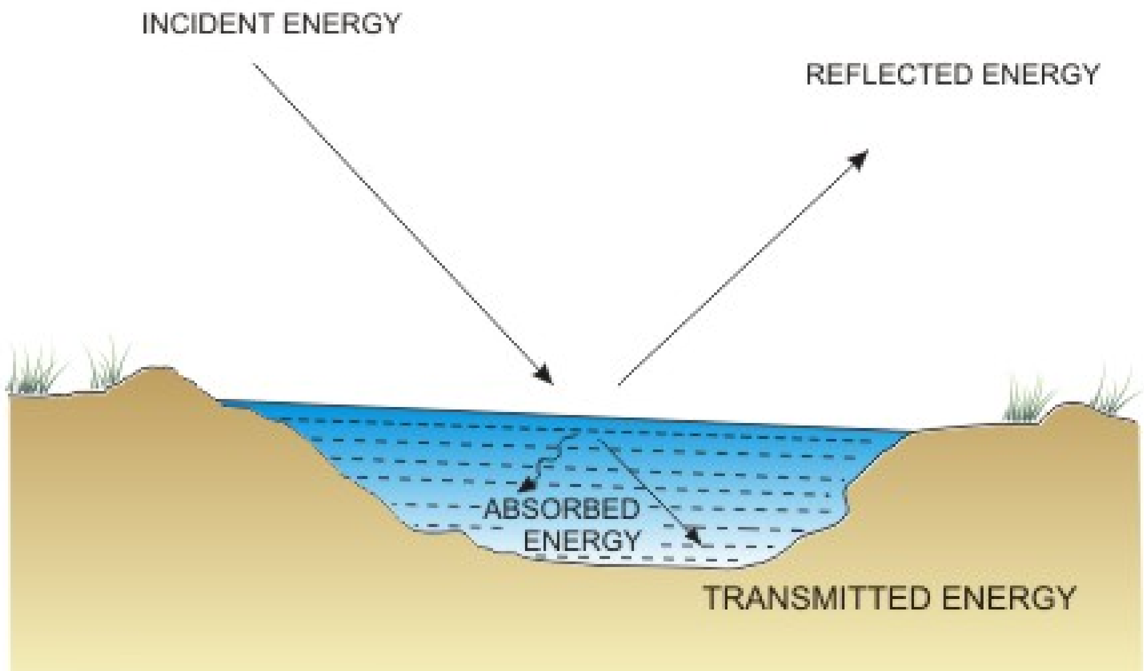


FIGURE 5. Fate of energy reaching an object

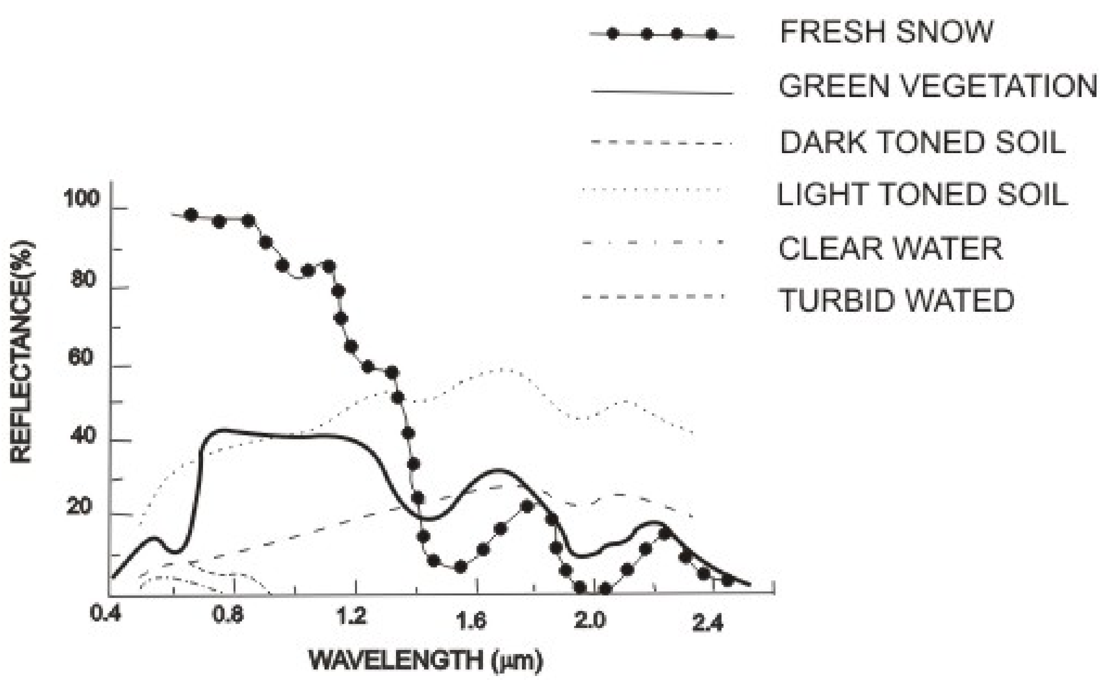


FIGURE 6. Spectral reflectance curves of vegetation, soil, water and snow

6.3.5 Spectral signature of earth features

For optimum use of remotely sensed data in various wavebands in identification and differentiation of different objects or features on earth, it is important to have a thorough knowledge and understanding of their spectral reflectance characteristics. Usually, the features that are classified through satellite remote sensing may be grouped into inanimate objects like soil, minerals, rock, water, etc. or animate object which is usually vegetation. Soil is a heterogeneous mixture of minerals, containing considerable amount of organic matter and often moisture. The proportion of these determine the spectral characteristics of the particular soil type. Rocks are assemblages of minerals and hence the reflectance spectrum of rocks is a composite of individual spectra of its constituent minerals. As for vegetation, the reflectance spectra vary according to the freshness of the leaves. Thus the characteristics of the reflectance of various earth features for different electromagnetic wavelength bands is used to identify different earth objects and are hence also known as Spectral Signatures. A study of the spectral reflectance characteristics of natural earth surface features shows that the broad features are normally separable. In the following paragraphs, we discuss the spectral signatures of certain typical earth features, natural and artificial.

Vegetation

The spectral signature or reflectance of healthy green vegetation is as given in Figure 6. In the visible range of electromagnetic wavelength spectrum, it has an absorption band in the blue and red parts because of the presence of chlorophyll. One may notice these at

0.45μm and 0.65μm. Even within the green part of the spectrum, only 10 to 15 percent of the incident light is reflected. The reflectance peak is seen to be at 0.54μm, which is in the green wavelength region.

The reflectance property of healthy vegetation is seen to be much larger (40 percent or more) in the infrared portion of the spectrum and is nearly constant from 0.7μm to about 1.3μm. In this range of electromagnetic spectrum, the reflectance variation is different for different plants and also between healthy vegetation and stressed vegetation. Hence, a reflectance measurement in this range permits one to discriminate between different species of vegetation, though this differentiation is not very apparent in the visible range of the spectrum.

Beyond 1.3μm, low spectral reflectance for vegetation is noticed at 1.4μm, 1.9μm and 2.7μm with intermediate peaks at about 1.7μm and 2.2μm.

Soil

The spectral signature of soil is simpler in soils compared to that by vegetation since all the incoming radiation is either reflected or absorbed due to very little transmittance. A typical reflectance curve for soil shows increase in wavelength in the visible and near-infrared regions (Figure 6).

The reflectance property of soil varies with soil moisture content, texture (that is, the relative content of sand silt and clay that makes up the soil), surface roughness, colour, content of organic matter, presence of sesquioxides, etc. In the visible portion of the spectrum, there is a distinct decrease in reflectance as moisture content increases, since more moisture in soil makes a soil appear darker causing less reflectance. Soil texture influences the spectral reflectance by the way of difference in moisture holding capacity and due to difference in the size of the particles. Soils with higher organic matter appears as light brown to grayish in colour. The reflectance characteristics in the visible region of the electromagnetic spectrum has been observed to be inversely proportional to the organic matter content. The presence of iron oxide in soil also significantly reduces the reflectance, at least in the visible wavelength.

Water

For water resources engineer, locating areal extent of water bodies like lakes, rivers, ponds, etc. from remotely sensed data is an important task. The spectral response from a water body is complex, as water in any quantity is a medium that is semi-transparent to electromagnetic radiation. Electromagnetic radiation incident on water may be absorbed, scattered and transmitted. The spectral response also varies according to the wavelength, the nature of the water surface (calm or wavy), the angle of illumination and observation of reflected radiation from the surface and bottom of shallow water bodies. Pure clear water has a relatively high reflectance in the visible wavelength bands between 0.4 and 0.6μm with virtually no reflectance in the near-infrared (0.7μm) and higher wavelengths (Figure 6). Thus clear water appears dark on an infrared image. Therefore, location and delineation of water bodies from remotely sensed data in the higher wave bands can be done very accurately.

Water containing heavy sediment load, as in the water in the estuary, has a turbid composition. The sediment suspended within the body of water tends to increase the reflectivity at longer wavelengths of the visible part of the spectrum, that is, in the yellow/red range.

Man-made structures

Sometimes it is required to identify artificial structures that is useful to an engineer. For example roads, paved surfaces, canals, and even dams and barrages can be identified from remotely sensed images by their reflectance characteristics. Many of these, especially linear features, are clearly discernible in the visible waveband of electromagnetic spectrum.

6.3.6 Remote sensing and imaging systems

The remotely sensed images are captured by sensors fitted to satellites (and at times below aircrafts) that work on two basic technologies (Figure 7). One of these, the Passive System, records the reflected electromagnetic energy of the earth, the source of the energy being the radiation of the Sun. The other, called the Active System, employs its self-generated pulses and records the reflected pulse. These two systems may be compared to taking photographs in sunlight and with flashlight respectively. The active remote sensing systems mostly use radars that emit radiation in the microwave band of the electromagnetic spectrum. This system is useful in cases where passive systems do not give sufficient information. For example, images of flood inundated areas are important to a Water Resources Engineer. However, most of these images taken by the passive systems are blocked by cloud cover since incidents of floods are most common during the monsoons and are almost coincident with heavy cloudy days. Radar based systems, on the other hand, are able to penetrate the cloud cover and give a clear picture of the flood inundation extent.

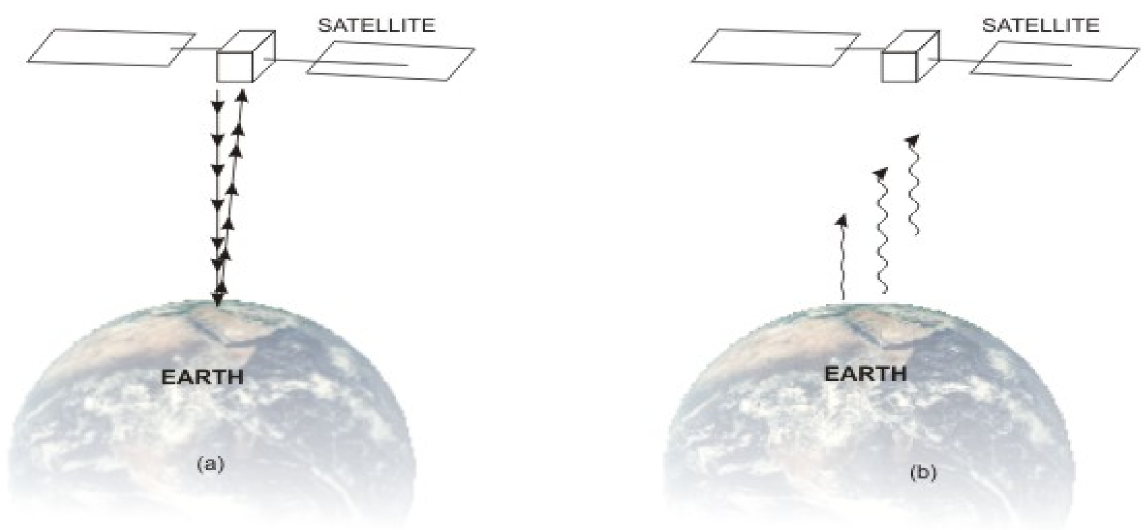
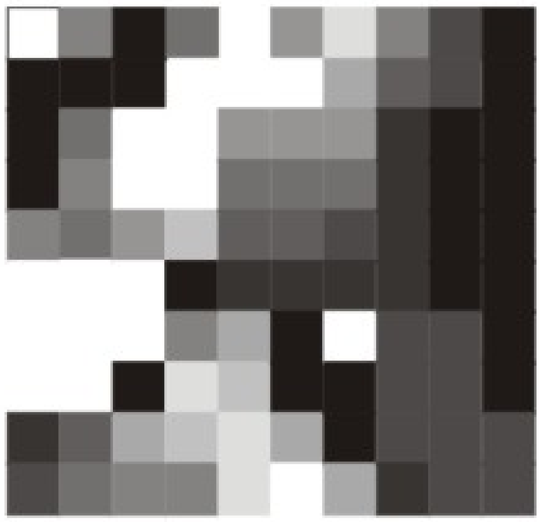


Figure 7.a Active remote sensing , using energy generated by a source.
b Passive remote sensing , which detects energy

The images recorded by a remote sensing sensor is a digital map of the scene that comprises of a regular grid array of squares, called pixels, with an unique value attached to each (Figure 8). The value of each pixel is proportional to some property, like average reflectance, recorded by the sensor for the equivalent area on the ground. The pixel values normally range from 0 to 255. For example, images recorded in the visible spectrum are usually a combination of three values for each pixel, one each for blue, green and red colours. For each colour, the pixel has a value ranging from 0 to 255. A pixel that records the image of a pure white area, will have the pixel values of all the three bands as 255. For a pure black region, the three individual bands would have values of 0. A blue looking area shall have the value 255 for the image that records the blue colour, and 0 for green and red.



10	9	20	25	26	34	35	11	20	25
76	34	11	15	41	42	77	14	30	24
47	25	13	11	10	55	41	39	42	65
42	19	15	19	22	52	71	56	34	35
34	20	16	60	27	85	35	17	25	16
25	30	29	23	18	49	38	78	19	29
30	42	20	13	57	23	73	74	60	20
19	60	45	28	40	11	79	32	48	45
64	36	55	58	38	13	80	28	64	55
36	70	31	62	15	15	70	58	76	66

FIGURE 8.a A digital image represented by pixels with different colours.
b Corresponding digital number for each pixel.

Similarly, sensors record pixel values in the infrared areas of the electromagnetic spectrum in passive systems and in the microwave areas in the active systems. The Indian Remote Sensing (IRS) satellites are, till now, equipped with active sensors that record images in four wave bands and others that record in a single wave band. The latest group of satellites available for earth imaging are the IRS-IC/ID. There are three sensors in these satellites, and each has its own characteristics, as given below.

- **LISS (Linear Imaging Self-Scanning Sensor)-III.** This medium resolution sensor that records data in four spectral bands: Two in visible range (0.52-0.59μm and 0.62-0.68μm), one in near infrared range (0.77-0.86μm), and one in short wave infrared (1.55-1.70μm) region. The spatial resolution, that is, the pixel size of the images are 23m for the first three bands and 69m in the last band.

- **PAN (Panchromatic, or single wave band).** This is a high resolution (5.8m pixel size) sensor operating in the 0.50-0.75μm range.

- **WFS (Wide Field Sensor).** This is a coarse resolution (188m) sensor operating in two bands: visible (0.62-0.68μm) and near infrared (0.77-0.86μm).

6.3.7 Spectral signatures

By deducing earth features from Multi Spectral Scanned (MSS) images the Water Resources Engineer may derive various important information of a wide region of the earth that may be useful for analysis. Hence, primarily, the earth features have to be identified from MSS images based on the Spectral Reflectance characteristics or signatures of various objects as discussed in Section 6.3.5.

An MSS data of a region comprises of two or more images of the same area that has been scanned by the remote sensing sensor. For example, the LISS-III sensor shall give four images of the area corresponding to the four spectral bands in which the data is collected. Each of these images comprise of data stored for each pixel, which is in the form of a Digital Number (DN) corresponding to the pixel's average reflectance property in the particular waveband. The DN varies from 0 to 255, and hence, each image may be printed or discussed in a gray-scale. However, all the four images for a region printed or displayed in gray-tone may not be useful individually. Hence, a combined image is produced, called the False Colour Composite (FCC) image, which combines the characteristics of the images of all the four bands.

An FCC image which simulates a colour infrared image, the visual interpretability of features is better than that from image of each band taken separately. The typical colour signatures of some of the features on the surface of the earth in standard FCC is given in the following table:

Features on the earth surface	Colour signature
Healthy reflection	

Broad leaf type Needle leaf type	Red to magenta Reddish brown to purple
Stressed vegetation Pre-visual stage Visual stage	 Pink to blue Cyan
Water Clear Turbid due to sediments	 Dark blue/black Light blue
Soil Red soil/red bed outcrop Moist soil Sand-dunes	 Yellow Distinct dark tong Yellow/white
Land-use Uncultivated land City/town	 Blue/white Blue
Others Cloud/snow Shadow*	 White Black with a few visible details

∗Shadow is not very significant in MSS satellite images with the present day spatial resolution as the scales of features are too small to aid in recognition.

Digital interpretation

Visual image interpretation requires the person to have thorough knowledge of the features being identified and their spectral reflectance characteristics. The technique is subject to human limitation. Hence, another technique – the Digital method of image interpretation – is often used in identifying earth surface features from remotely sensed images. Infact, this comprises of a very important area, the details of which may be obtained in standard textbooks on Remote Sensing and Image Processing. Here only a brief account of the process is given below.

Primarily, this is possible due to the fact that an image actually comprises of a number of pixels, each being assigned a Digital Number (DN) according to the average reflectance of the corresponding ground area in the particular spectral band. Thus, an image is nothing but a matrix of DNs. Computer algorithms are available in Image Processing Software Packages that make use of these numbers to identify the feature of land corresponding to each pixel. The numerical operations carried out on these digital images are grouped as follows:

1. Pre-processing: Removal of flawed data, correction of image.
2. Image registration: Translation, solution or stretching of the image to match earth's true geometry.
3. Image enhancement: Improving images or image patches that suffer from low contrast between pixel DN values.
4. Image filtering: Methods to identify clearly the boundary between two district regions of separate reflectance characteristics.
5. Image transforms: Combination of one or more images of different spectral bands of the same area.

6. Image classification: Automatic categorization of pixels into various land-cover classes.

Though digital image interpretation has the capability to classify earth surface features with the help of a computer, it must be supplemented with ground truthing, that is, verification of the interpreted regions with actual information gathered from the ground by field survey.

6.3.8 Application areas of Remote Sensing in Water Resources Engineering

The interpretation of remotely sensed images may provide valuable information to the Water Resources Engineer, some of which are discussed below for various fields of applications

Sl. No.	Field of application	Useful interpreted information	Helpful in
1.	Irrigation Engineering	Crop area, Crop yield, Crop growth condition, Crop areas that are water stressed and are in need of water	Estimating the amount of irrigation water that is to be supplied to an irrigated area over different seasons
2.	Hydrology	Different types of soils, rocks, forest and vegetation of a water shed, soil moisture	Estimating runoff from a watershed, where the land-cover type and soil moisture would decide the amount that would infiltrate
3.	Reservoir sedimentation	Plan views of reservoir extent at different times of the year and over several years	Estimating the extent of sedimentation of a reservoir by comparing the extent of reservoir surface areas for different storage heights
4.	Flood monitoring	Flood inundated areas	Flood plain mapping and zoning
5.	Water Resources Project Planning	Identification of wasteland (from MSS images), mapping of infrastructure features (from PAN images) like existing roads, embankments, canals, etc. apart from plan view of a river	Recent information helpful in planning and designing of a water resources project based on the present conditions of the project area

6.3.9 Geographic Information System (GIS)

A GIS is a computer application program that stores Spatial and Non-Spatial information in a digital form. Spatial information for an area is what is traditionally represented in maps which for a region, may broadly be classified as given in the following table. The corresponding source of such data for our country is also indicated.

Sl. No.	Spatial features of a region	May be obtained from
1.	• Elevation contours • Drainage • Location of roads, towns, villages	Survey of India, in the form of Topo-Sheets
2.	Soil map	National Burean of Soil Survey and Land Use Planning
3.	Geological map	Geological Survey of India
4.	Latest information on land-use and land-cover, like • Vegetation, forest, crops, etc. • Towns, villages and other human habitation • Roads, Embankments, Canals • Rivers	Satellite imageries
5.	Maps of District, Block, Thana, Mouza, Taluk, etc.	State Land Record office
6.	Location of ground water wells and corresponding water tables as observed over time	Central or State Ground Water Boards

Non-Spatial data, also called Attributes, refer to information like demographic distribution of a town or a village, width or identification tag of a road (like NH-6), daily discharge of a river at a particular place, etc.

Thus, a GIS conveniently manages all variety of data of a given region in a single electronic file in a computer. This is helpful to any regional planner, including that of a Water Resources Project since all information is conveniently stored and accessed with the computer. Further, though the scales of various printed maps may be different, a GIS stores all of them in the same scale. Normally, different spatial features are stored in sub-files, called layers. Hence, one may use the GIS to open all the layers showing all thematic features. Else, one may display one or a few themes at a time by activating the respective layers. For example, the land-use layer may be displayed along with elevation contours, the other layers being kept off.

Important features of GIS software includes handling of spatial and attribute data, data input and editing, data analysis and output of data, which are discussed briefly in the following sections.

A GIS may be considered to comprise of the following components:

• A software package, the components of which include various tools to enter, manipulate, analyse and output data
• A computer system, consisting of the hardware and operating systems.

6.3.10 Handling of spatial and attribute data in GIS

There are two types of data storage structures in a GIS-Raster and vector. According to the Raster system, the space is assumed to be divided into a grid of cells, with a certain value attached to each cell according to the data that is represented by a grid of cells, would be done by marking the corresponding cells black (and assigning a value 1), with all other cells remaining vacant (that is, assigning a value of 0). In the vector system of data storage, the particular point would be stored by the coordinates of the location. This was an example of a point feature. Other types of geographic features include line, area, network of lines and surface, which have been shown in Figure 9.

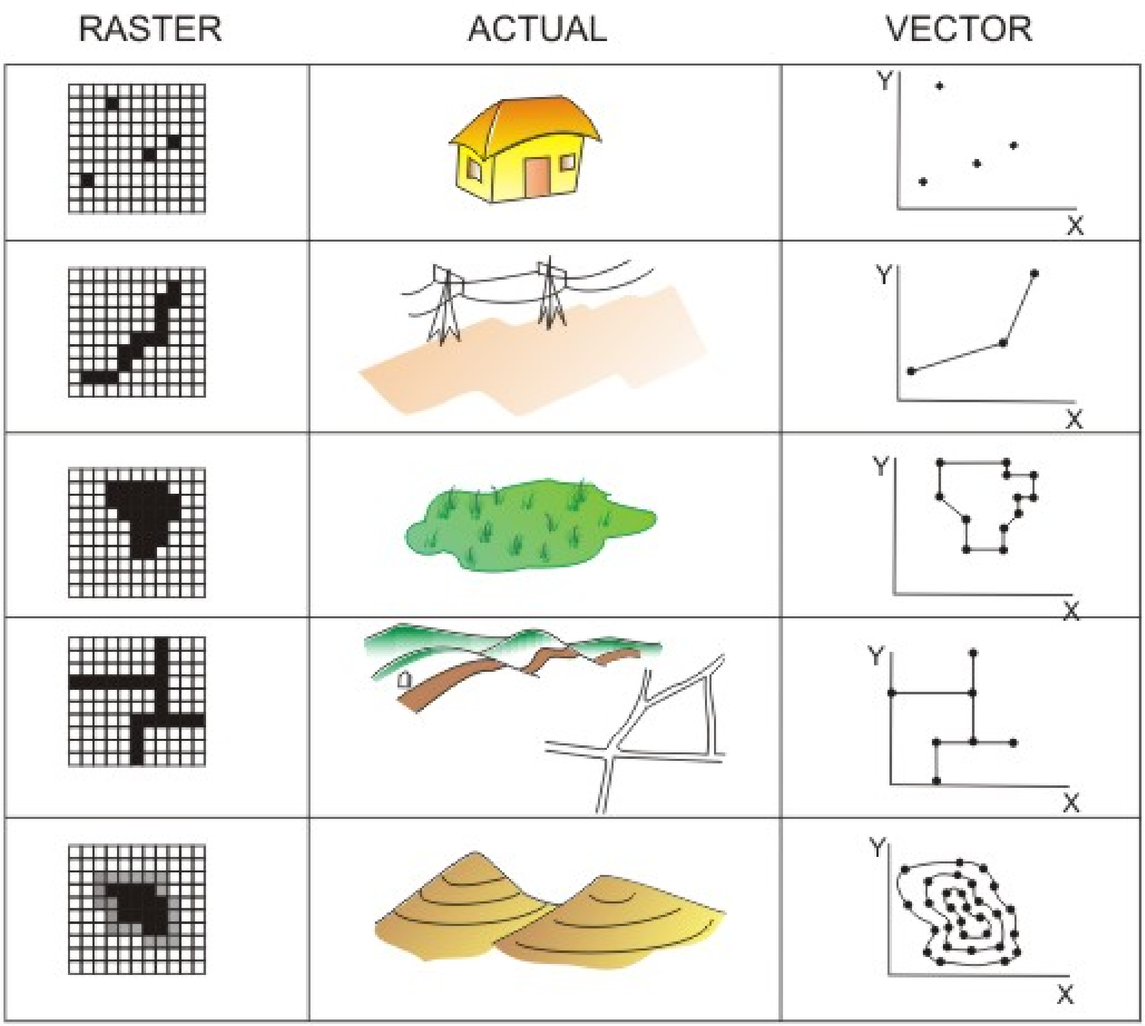


FIGURE 9. Raster and Vector representations of actual objects

It may be noticed that in the raster grid representation of an area, the size of the grids is a choice of the person using the GIS. For example, in representing the spatial information of a town, a grid size of 10 to 25 m may be sufficient but for a state, 100 to 250 m would be enough. Adopting a finer grid size would, naturally, provide a better representation of data. But that would require a higher computer storage space, which therefore has to be judged optimally.

For vector data representation, too, a better resolution of data may be achieved for line features by selecting more number of points closely. This applies also for representing the lines defining the boundary of an area. For surface representing more number of points defining the elevation contours would result in a more precise definition of the region.

Attribute data is non-spatial, that is, it is not something that varies continuously in space. This is actually the database that defines the spatial data. For example, the location of ground water wells is a spatial data, but the water level record or variation of water level with time is an attribute data of the particular well. Similarly, rivers may be represented as a network of lines, but the width and average depth at different points would be represented as attribute data.

6.3.11 Input and editing of data in GIS

The user of a GIS has to input data, whether Spatial (in Raster or Vector formats) or Non-Spatial (usually in the form of tables). Spatial data, as shown in section 6.3.9, may be obtained from different sources and in different formats. They may be input into a GIS in a variety of methods, depending on the format in which they are being supplied. For example, maps would usually be supplied in printed sheets but the satellite image of an area or the land-use map derived from it would be in electronic, that is digital, form. The latter may be directly transferred to a GIS but the former has to be Scanned and then Digitized. Scanning means producing an electronic file of the image, which would usually be a raster representation of the map. This may be done with the help of scanners that are available from sizes of A_4 (the smallest) to A_0 (the largest). The scanned images are not of much use to a GIS since it does not differentiate between the different objects indicated in the image. For this, manual help is required in the form of Digitization, where by a person uses a mouse over the scanned image to physically point to the various features and store them in GIS format. In order to do this, the vectorization tools of the GIS software would be used. Tabular attribute data may be directly transferred to a GIS and attached to the corresponding spatial data with certain tools provided by the GIS software. All the various data are stored in a GIS as layers, or themes.

After data input, the uses might have to edit some of the data to remove duplicacy, redundancy, etc. of some of the vector data or to remove specks or ‘noise’ in raster data. The errors in the vector data appear while undergoing the process of digitization and therefore, has to be corrected before an analysis with the data is made. For example, while digitizing the boundary of a reservoir from a map, the starting and ending points may not be located right over one another. The GIS would not recognize the outline as a closed boundary, and the reservoir plan cannot be defined as an area. Hence, an editing has to be done to correct this deficiency. Errors in raster data appear due to a variety of reasons, one being the presence of aberration during data capture. For example, LISS-III MSS imagery of an area used to classify land-use may be misrepresented by the presence over some places, unless these are removed, they may lead to false interpretation of land-use classification.

Once spatial and attribute data have been enclosed and edited, it may be necessary to process the different data obtained through various sources in such a way, that all are geometrically compatible.

Some of the mathematical transformations used in this process are:

1. Translation and scaling
2. Creation of a common origin
3. Rotation

6.3.12 Analysis of data in GIS

Once the derived data has been input in a GIS, they are analysed to derive meaningful information. Infact, analysis is essential for any decision-making strategy that may be derived from the stored GIS data. For example, imagine a GIS data that provides locations of ground water wells of a region and their corresponding water levels measured every month. This is overlain with the village boundary data of the region. By plotting the ground water table surface for every month, it may be seen which villages consume more water and when. In this simple example, the analysis is between two different data sets but overlain in the same GIS.

More complicated analysis may be done by interacting more themes or data layers. For example, if it is required to obtain the names of the villages that suffer from excess groundwater depletion in summer and also whose population is more than 10,000 then the population attribute data has to be considered in the query. Another example of using three layers for data analysis includes that of finding the names of the villages that are within 1 km distance from a river and also located at an elevation of 50 m or less. In this case, the river feature has to be 'buffered' with a 1 km zone on either bank and the surface area below 50 m elevation has to be plotted from the digitized contour map. On top of this, the layer representing digitized boundaries of villages has to be overlain to get the desired output.

Though the above examples are only limited to analysis of recorded data, considerable scope lies in the use of GIS data along with mathematical modeling tools that mimic physical processes. For example, watershed runoff model may be conveniently integrated with GIS to provide answers like:

- Which areas of a watershed produce more runoff if a rainfall of a particular intensity is given?
- If the land-use map of the area is overlain on the above is it possible to find out the areas that are prone to excessive soil erosion?

Hence, a GIS database may become extremely useful, if coupled with a modelling software. Much work on similar lines has been done by Prof. Maidment of University of

Texas by integrating GIS with hydrologic process models. Interested users may visit the following site for more information in the following web-site:

http://www.ce.utexas.edu/prof/maidment/GISHYDRO/home.html

6.3.13 Data output in a GIS

The most common form of output from a GIS is a map. In many cases, a thematic map would be that illustrate the spatial variation or pattern in a particular variable. Apart from maps, a GIS output may be in the form of table, like that that showing the names of villages whose groundwater drawdown is more understandable may be output for the decision-makers. For example, the ground water table contour may be output as a three dimensional surface, which may provide a visual guide to the trend of the water table's dip.

6.3.14 Application areas of GIS in Water Resources Engineering

There are many areas in Water Resources Engineering where GIS may be successfully applied. Some examples have been given in this lesson in the previous sections, and some more are illustrated below.

Project planning for a storage structure

In this example, a dam is proposed to be constructed across a river, for which the following information may be desired:

- Watershed area contributing to the project site
- Reservoir surface area and volume, given the height of the dam
- villages that may be inundated under reservoir

For the above, the following themes may be stored in a GIS:

- Elevation contours of the watershed area, including the project site
- Satellite image derived land-use map of the watershed
- Village boundary map, showing location of habitation clusters

Using the above data, one may obtain desired in information as follows:

- Watershed area may be found by using the elevation contour data, and using a suitable GIS software that has a tool to delineate the watershed boundary. Once the boundary is identified, the area calculation tool may be used in the GIS software to calculate the watershed area.

- Reservoir surface area can similarly found using the area calculation tool. Volume calculation tool of the GIS software may be used to find out the storage volume, which is the space between a plane at the reservoir surface and the reservoir bottom.

- By overlying the reservoir extent over the village boundary map and the locations of habitation clusters one may identify the villages that are likely to be inundated once the reservoir comes up. The area of the cultivable village farms that would be submerged may also be similarly identified, as it would be required to pay compensation for the loss to the villagers.

- The amount of forest land that is going to be submerged may be identified by overlaying the reservoir area map over the land use map, for which compensatory afforestation has to be adopted.

Project planning for a diversion structure

Here, a barrage is proposed across a river to divert some of its water through a canal, for which the following information may be desired:

- Location site of the barrage
- Location and alignment of the off taking canal
- Command area that may be irrigated by the canal