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Remote Sensing Applications
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# Water Resources Management

## 6.1. Introduction

Water is a key driver of economic and social development and one of the fundamental elements in sustaining the integrity of the natural environment. It is the major renewable resource amongst the various natural resources. Water being an indispensable constituent for all life supporting processes, its assessment, conservation, development and management is of great concern for all those who manage, facilitate and utilize.

Issues related to water resources development and management are not in isolation but are inter-related with other human activities. The issues involved range from those of basic human well-being (food, security and health), economic development (industry and energy) and preservation of natural ecosystems on which ultimately we all exist and sustain. The combination of lower precipitation and higher evaporation in many regions is diminishing water quantities in rivers, lakes and groundwater storage, while increased pollution is damaging ecosystems and the health, lives and livelihoods of those without access to adequate, safe drinking water and basic sanitation. The increase in frequency of occurrences of extreme events is probably firm illustration of fundamental changes that are altering water resources worldwide, including India. Therefore the conservation and optimal utilization of this scarce resource is extremely important for sustainable development. In order to meet present/ future demands for food, the world food production is to have an annual growth rate of about 3%. Present total harvested area is about 1600 million ha and FAO assessments put the world's area of potentially suitable cropland at some 3200 million ha. The water management in the coming years is likely to have profound impact on human society with regard to its quality of life and its very existence.

### 6.1.1. Water Resources of India

Water resources of India are quantitatively large but significantly divergent in their occurrence, distribution and utilization. The annual precipitation aggregated as 4000 km$^3$ with utilizable resource of 1122 km$^3$ (28%). Out of which utilizable surface water resources are 690 km$^3$ and ground water resources are 432 km$^3$. According to National Commission for Integrated Water Resources Development, basins-wise average annual flow in Indian river systems is 1953 km$^3$. India is endorsed with a large network of 12 major river basins covering 256 M ha, 46 medium river basins covering about 25 M ha besides other water bodies like tanks and ponds covering 7 M ha, with the ultimate irrigation potential of 140 M ha. In India, since its independence, sizeable financial resources (approx. Rs. 2400 billion) were invested to harness water resources for irrigation, domestic, industrial, and other sectors. This constituted about 15% of total public sector outlay till 2001.

### 6.1.2. Water Requirements of India

Indian water resources utilization mostly dominated by agricultural sector nearly accounting to 428 km$^3$ (around 69% of total water use) with 300 km$^3$ from surface resources and 128 km$^3$ from ground water resources. To meet the increased food production requirements and to achieve food security, the agriculture sector would command a quantum jump in water utilization and is expected to be in the order of 708 km$^3$ by the year 2050. Domestic water requirements are around 25 km$^3$ at 5% of total usage, out of which surface water contributes 7 km$^3$ and ground water contributes 18 km$^3$. With the significant urbanization of population, it is expected that around 54% of population would be living in urban areas by 2050, which increases the domestic demand to 90 km$^3$. Industrial usage is in the order of 15 km$^3$ which is likely to grow up to 103 km$^3$ by 2050.

The total water requirements of the country are expected to be around 1450 km$^3$ by the year 2050, which is significantly higher than the present estimate of utilizable water resources potential of 1122 km$^3$. It is estimated that Indian ground water overdraft is of the order of 66% which places food and livelihood security at great risk and could lead to 25% reduction in India's harvest. The per capita availability of 1820 m$^3$ (2001) is fast endangered with teeming population and likely fall to 1191 m$^3$ by 2050 getting precariously closer to water scarce condition (FAO).

### 6.1.3. Gaps and Issues related to Indian water resources

The above statistics indicate the impending crisis, which Indian Nation is likely to encounter. The surface water potential developed only to an extent of 37% and that of groundwater to 38%. Significant gap exists in the ultimate irrigation potential, creation and the utilization. In addition, the water-use efficiency in the country is reported to be only 25-30 percent. While India has about 16% of the global population, it only has 4% of total water resources, and many parts of India already face water scarcity. The problems associated with the water resources development are varied and complex. Some of them are:

- Spatial and temporal variations in availability
- Falling per capita availability of the country
- Expanding multi-sectoral demand
- Under and inefficient utilization of irrigation potential
- Loss of surface storage due to reservoir sedimentation
- Frequent floods severely affecting the flood prone area development
- Recurring drought
- Over-exploitation and depletion of the ground water resources
- Deteriorating water quality and environment
- Climate change impact on water resources

Coping and managing the above problems largely depends upon our preparedness through a well structured system. It calls for great challenges in the best use of available water resources through surface water capture and storage, long distance conveyance and inter-basin transfer, ground water exploitation, watershed management, conjunctive use of surface and ground water and de-salinization. This necessitates having relevant information at appropriate time for arriving at rational decisions which would support sustainable water utilization. New tools have to be developed to facilitate integrated water resources management. Managers have to be able to access to quality data through a well-structured data acquisition, flow and access system. Conventional data collection is a well established practice, although the convertibility between available data and readily usable information is little. They are oriented more towards archival than operational usage and in-situ observations are generally characterized by inadequacy and non-reliability. To achieve maximum water use efficiency and to cope up with varying water resources availability conditions, real time information on various aspects, which control and influence the supply & utilization regimes are to be obtained. The satellite remote sensing geo-spatial techniques promise to be potential tools to aid water management decisions. Systematic approaches and studies involving satellite remote sensing techniques have supported scientific efforts of water management.

## 6.2. Role of Satellite Remote Sensing For Water Resources Management

Measurements from satellite remote sensing provide a means of observing and quantifying land and hydrological variables over geographic space and support their temporal description. Remote sensing instruments capture upwelling electromagnetic radiation from earth surface features which is either reflected or emitted. The former is reflected solar radiation and the latter is in thermal infrared and microwave portions of electro-magnetic spectrum. Active microwave radars obtain reflected/returned microwave signals. The reflected solar energy is used for mapping land & water resources like land use, land cover, forests, snow & glaciers, surface water features, geologic & geomorphologic features, water quality, etc. The thermal emission in the infrared is used for surface temperature, energy fluxes and microwave for soil moisture, snow & glacier, flood, etc.

Remote sensing has several advantages over field measurements. First, measurements derived from remote sensing are objective; they are not based on opinions. Second, the information is collected in a systematic way which allows time series and comparison between schemes. Third, remote sensing covers a wide area such as entire river basin. Ground studies are often confined to a small pilot area because of the expense and logistical constraints. Fourth, information can be aggregated to give a bulk representation, or disaggregated to very fine scales to provide more detailed and explanatory information related to spatial uniformity. Fifth, information can be spatially represented through geographic information systems, revealing information that is often not apparent when information is provided in tabular form.

Towards evolving and supporting comprehensive water management strategies space technology plays a crucial role. Systematic approaches involving judicious combination of conventional ground measurements and remote sensing techniques pave way for achieving optimum planning and operations of water resources projects. Remote sensing has shown enormous promise for providing wealth of data and information that were deficient with the in-situ observations. It has also been a valuable tool in many hydrologic modeling applications due to its capability of providing unrestricted collection of information with wide spatial coverage and temporal revisit.

Earth Observation Satellite (EOS) data has been extensively used to map surface water bodies, monitor their spread and estimate the volume of water. The SWIR band of AWIFS sensor in IRS-P6 was found to be useful in better discrimination of snow and cloud, besides delineating the transition and patch in snow covered areas. Snow-melt runoff forecasts are being made using IRS-WiFS/AWiFS and NOAA/AVHRR data. These forecasts enable better planning of water resources by the respective water management boards. Monitoring reservoir spread through seasons has helped to assess the storage loss due to sedimentation, updating of rating curves. Satellite data derived spatial and temporal information on cropping pattern, crop intensity and condition forms basic inputs for developing indicators for agricultural performance of the irrigation systems and bench marking of systems. Satellite data derived geological and hydro-geomorphologic features assist in prospecting the ground water resources to plan aquifer recharging, water harvesting and drinking water sources. High resolution satellite data remarkably augmented the remote sensing services extending it to infrastructure planning & management.

The overall applications of RS & GIS in water resources sector can be broadly categorized into the following:

- Water Resources Assessment
- Water Resources Management
- Water Resources Development
- Watershed Management
- Flood Disaster Support
- Environmental Impact Assessment & Management
- Water Resources Information & Decision Support Systems

Table 6.1 provides the details of Sensors / satellites data suitable for Water Resources Management.

**Table 6.1: Sensors / Satellites data suitable for Water Resources Management**

| **Application** | **Satellite and sensor** |
|---|---|
| • Field/Plot boundaries<br>• Irrigation network/infrastructure<br>• Cartographic information<br>• Micro-scale features | Cartosat -1 & 2(PAN),<br>Ikonos, QuickBird,<br>SPOT (PAN) |
| • Land use<br>• Land cover<br>• Surface water resources<br>• Crop identification<br>• Crop yield / condition<br>• Soil salinity<br>• Water logging | IRS, Landsat, SPOT, ASTER, CBERS |
| • Evapotranspiration<br>• Soil moisture | NOAA, Aqua, Terra, Landsat, ASTER, CBERS |
| • Surface roughness<br>• Soil moisture | ERS, Radarsat, RISAT |
| • Flood inundation<br>• River bank erosion<br>• River control works | IRS, Landsat, SPOT, ERS, Radarsat, JERS, RISAT<br>IRS, Landsat, SPOT, Cartosat-1 & 2<br>Cartosat-1 & 2, Ikonos, Quickbird |
| • Surface Water<br>• Snow cover<br>• Glaciers | IRS, Landsat, SPOT, ASTER, NOAA, Aqua, Terra |
| • Snow depth<br>• Snow water equivalent | ERS, Radarsat, JERS, RISAT |
| • Water quality | IRS, Landsat, SPOT |
| • Precipitation | TRMM, METEOSAT |

Various applications have been developed, since last 3 decades, wherein SRS data is being put into use to provide quantitative and reliable information, there by facilitating improved water resources management.

- Snow & Glacier
  - Snow cover mapping & monitoring
  - Snowmelt runoff forecasting
  - Glacier mapping & monitoring
  - Glacier Lake monitoring
  - Glacier mass balance (R&D level)
- Surface water resources
  - Water bodies
  - Wetlands
- Irrigation water management
  - Inventory of Irrigated Agriculture
  - Performance Evaluation & Bench Marking
  - Monitoring Intervention Schemes
  - Near Real-Time Monitoring
  - Surface Water Logging
  - Soil Salinity/Alkalinity
  - Irrigation Infrastructure Mapping
  - Assessment of Irrigation potential creation
  - Pre-feasibility studies
  - Actual Evapotranspiration estimation (R&D level)
  - Irrigation Information System (R&D level)
- Reservoir Sedimentation
  - Assessment of Sedimentation
  - Updation of Elevation-Area-Capacity Curve
  - Estimation of Reservoir Capacity
  - Assessment of Rate of Siltation
  - Estimation of Life of Reservoir
  - Reservoir Catchment Analysis
  - Impact of Foreshore Cultivation
- Hydro-Power generation
  - Submergence area analysis
  - Inputs for pre-feasibility assessment
  - Inputs for ranking studies
  - EIA studies
- Interlinking of rivers
  - Pre-feasibility studies
  - Canal alignment studies
  - Submergence area analysis
  - Land irrigability
  - Inputs for Detailed Project Reports
- Flood disaster monitoring and management
  - Flood inundation mapping & monitoring
  - Flood hazard zonation
  - Flood forecasting (R&D level)
  - Flood inundation simulation
  - Disaster management & support

- Watershed Management
  - Water harvesting
  - Sustainable Action plans
  - Soil erosion & Catchment's area treatment
- River engineering
  - River migration
  - River control works mapping & monitoring
- Ground Water Prospecting
- Environmental Impact Assessment and Management

### 6.2.1. Major Application Projects

Satellite RS applications in India evolved during mid to late 70's during which Landsat-1 & 2 data provided first insights of remote sensing capability for natural resources applications. Recognizing the potential of RS data for water resources management (WRM) a joint Indo-US workshop was organized during April, 1978 and broad strategies for extended and sustained use of satellite data for water resources management were formulated. During the period 1980-1990, the remote sensing data applications were focused on image interpretation, 3D aerial photographs, and methods of classifying and transforming digital satellite data into images or sorts of maps. The initial phase – Landsat data utilization – provided the required understanding and experience for generating geo-spatial information and water related events mapping. The advent of Indian Remote Sensing (IRS 1A/1B) series satellite data provided the much needed fillip to RS applications for water resources sector through availability of multi-spectral information at various resolutions and at affordable prices. The subsequent IRS satellites (IRS 1C/1D/P2) expanded the applications going far beyond visual interpretation/mapping to monitoring, digital data base, quantitative analysis, modeling, etc. The more recent constellation of IRS satellites, namely, Resourcesat-1, Cartosat-1 & Cartosat-2, extended the remote sensing applications to near real time monitoring, hydrological modeling, infrastructure planning, mapping & monitoring, information systems, and decision support systems and so on. The following sections provide brief account of some of the satellite remote sensing based applications in water resources sector.

## 6.3. Water Resources Assessment

(Snow cover, Glacier, Surface Water, Rain/Runoff, Water balance)

The rapid growth of population and urbanization resulting in steady increase in water demands for agriculture, domestic and industrial requirements. Accurate information on surface water, its existence, spatial extent, temporal changes is essential to manage this resource judiciously.

Surface water occurs in the form of liquid water in lakes, reservoirs, rivers, oceans and in its solid form as snow, glacier and lake ice. Remote sensing platforms are amenable to detect and map the spatial extent of both forms of water.

### 6.3.1. Snow & Glacier Studies

Snow cover and the equivalent amount of volume stored supplies at least one-third of the water that is used for irrigation and for the growth of crops world wide. Northern rivers of India receive significant inflows due to snowmelt during summer months. Snowmelt runoff feeds many multi-purpose storage reservoirs that provide irrigation, hydropower, urban/industrial water supply and recreation.

The vast difference in spectral properties of snow and other natural land cover supports its identification on satellite data. The relatively high albedo of snow reflects much higher percentage of incoming solar shortwave radiation than snow free surfaces (80% for relatively new snow whereas roughly 15% for snow-free vegetation). The snow cover can be detected and monitored from a variety of remote sensing platforms. Both reflective and thermal remote sensing is being extensively used for mapping snow cover area, its build up during winter and depletion during summer seasons. Microwave instruments are providing parameterization of snow cover physical properties such as snow water equivalent, density, grain size, depth, state (wet/dry) and age. Remote sensing images provide accurate information on the glaciers and their spatial extent. The glacier lakes are easily identifiable on multi-spectral satellite data of medium resolution (24-30 m) to fine resolution (6 m).

**Snow Cover Mapping**

Snow cover mapping is done using both reflective and microwave remote sensing data. Snow cover, with relatively high albedo, appears very bright on standard false colour composite (FCC) images and is easily differentiated with other land cover features. However, cloud and snow bound areas appear similar in standard FCC images, which is resolved through SWIR band response in which snow covered areas have low reflectance. Remote sensing platforms with SWIR band have been extensively used for snow cover mapping and monitoring.

Space Application Centre (SAC), Ahmedabad is involved in snowcover mapping of entire Himalayas at the request of Ministry of Environment using IRS AWiFS data. Generation of ten daily snow cover products and area-altitude distribution products to observe the snow cover variability for 28 basins of the Western Himalayan region is being executed. Using Normalised Difference Snow Index (NDSI) and IRS-P6 AWiFS data for 8 sub basins in Himalayan region snowcover maps were prepared. Snow cover Atlas of the Ganga basin for the year 2006-07 was prepared. Some of the sensors operationally used for snow cover mapping are shown in table 6.2.

**Table 6.2: Some of the sensors operationally used for snow cover mapping are:**

| **Satellite - Sensor** | **Snow cover mapping status** |
|---|---|
| NOAA – AVHRR<br>MODIS – Aqua/Terra | Region level snow cover area mapping on daily basis |
| Resourcesat 1 - AWiFS | Regional to basin level snow cover area mapping and monitoring on five daily basis |
| Resourcesat 1 – LISS III;<br>Landsat – ETM;<br>ASTER;<br>SPOT | Basin to sub-basin level snow cover area mapping and monitoring |

**Snowmelt Runoff Forecasting**

Accurate estimates of the volume of water stored in the basin in the form of snow in winter and its rate of release due to melting in summer are needed for many purposes. These include stream flow and flood forecasting, reservoir operation, watershed management, water supply, and the design of hydrologic and hydraulic structures. The planning of new multi-purpose projects in the Himalayan region further emphasizes the need for reliable estimates from rain, snow and glacier runoff. The variation of runoff depth can vary greatly from year to year for mountain basins because of differences in seasonal snow cover. Melting of snow cover in summer is an important source of water for many Himalayan rivers, and an increase in atmospheric temperature accentuates the melting of snow cover.

In general, snowmelt models can be divided into two types of models, namely energy balance models and index models. Broadly, energy balance models require the information on radiant energy, sensible and latent heat, energy transferred through the rainfall over the snow and heat conduction from ground to the snow pack. Several meteorological parameters are to be monitored to obtain this information over the snow pack. A thorough understanding of the basic energy transfer processes and their role in melting of snow pack helps in improving the performance of the operational snow melt models. Index models use one or more variables in an empirical expression to estimate snow cover energy exchange. Air temperature is the most commonly used index, but other variables such as net radiation, wind speed, vapour pressure and solar radiation are also used. The degree-day method is more popular because temperature represents reasonably the energy flux and at the same time, it is relatively an easy parameter to measure, extrapolate and probably to forecast. However, snowmelt prediction can be significantly improved by using vapour pressure, net radiation and wind rather than the temperature variable alone. The accumulation and recession of snow cover in a basin is found useful to quantify snowmelt runoff.

NRSC, for the last 20 years, provides advance forecast of snowmelt runoff into Bhakra reservoir to Bhakra Beas Management Board (BBMB). The forecast provided by NRSC assists BBMB to allocate water for different sectors and sharing among five northern States. Snow cover in Sutlej basin is monitored from October to June to understand the accumulation and depletion pattern of the snow pack in the season using NOAA/AVHRR satellite data. The relative comparison of the current year recession pattern with that of previous years helps in characterizing the nature of snow pack present in the basin, rate of depletion and onset of depletion. The comparative analysis is done to identify the interval in which current year inflows are expected to be and accordingly forecast is made. The forecast of snowmelt runoff inflows into Bhakra reservoir during the period Apr-May-Jun months is provided to Bhakra Beas Management Board in 1st week of April. A revised forecast is made in last week of May. The snow accumulation and depletion in Sutlej basin during 2006-2007 season is shown in figure 6.1.

National Institute of Hydrology (NIH) used water balance approach to estimate the average contribution of snow- and glacier-melt runoff in the annual flow of the Beas River at Pandoh Dam. About 45% of the basin area is covered by snow during winter and about 15% remains covered by permanent snow and glaciers. Snow and glacier-melt contribution was estimated by computing the other components, i.e., rainfall, runoff and losses through evaporation, of the water balance equation. The results of the analysis show that the snow- and glacier-melt runoff contributes about 35% to the annual flow of the Beas River at Pandoh Dam. NIH also carried out a study on estimation of snow and glacier melt runoff in Ganga and Chenab basins using satellite data. Snow and Avalanche Study Establishment (SASE), Chandigarh carried out snow melt run-off prediction based on point energy balance method for sub-catchments of Beas Basin.

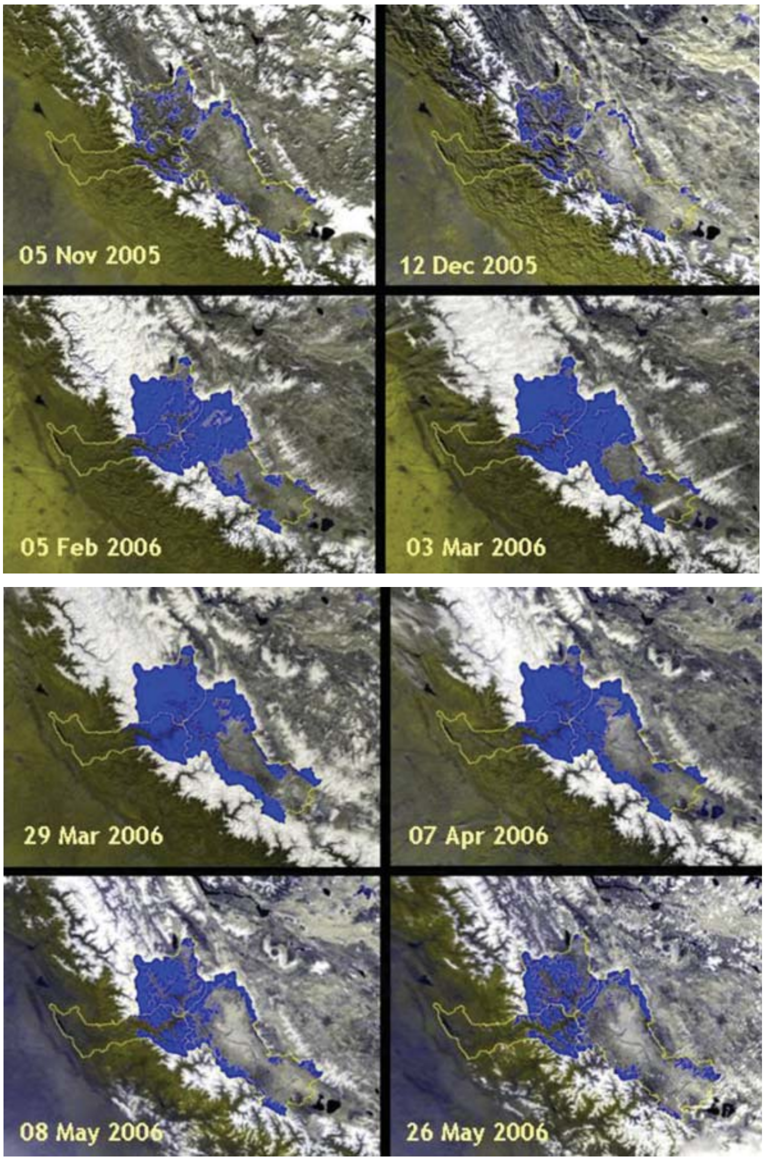

*Figure 6.1: Snow cover accumulation and depletion in Sutlej basin*

**Inventory of glaciers, Glacial Mass Balance, and Glacial retreat**

Retreat of glaciers is the cause of great concern for the perennially fed Himalayan river system. The Ganges, the Brahmaputra and the Indus rivers rely on the glacier resources like snow and ice from the Himalayas. The long-term database on glaciers and melting patterns of snow in the above river basins is expected to provide evidence of climate change impacts and consequent effect on river discharges. Glacier lakes can also result into outburst leading flooding which may cause disaster in the down stream. Therefore, monitoring their formation, status and changes is of utmost importance to safeguard down stream utilities. Satellite data forms the only source to map and inventory these natural entities as they lie in most inaccessible regions. Remote sensing images provide ample information on the status of the glaciers and dynamic changes over time. The glacier lakes are easily identifiable on multi-spectral satellite data and their spatial extent can also be measured with reasonable accuracy. Satellite data of medium resolution (24-30 m) and fine resolution (6 m) is found suitable to map these frozen entities.

Many studies have demonstrated the capabilities of satellite data for identification, mapping of glacial lakes. Inventory of glacial lakes was carried out in Dhauliganga basin, Sutluj basin up to Nathpa dam using LISS-III data shown in figure 6.2. Glacial Lakes/ water bodies greater than 2 hectares in area were identified and monitoring was done in the case of glacial lakes/water bodies which are greater than 10 hectares in area during the monsoon

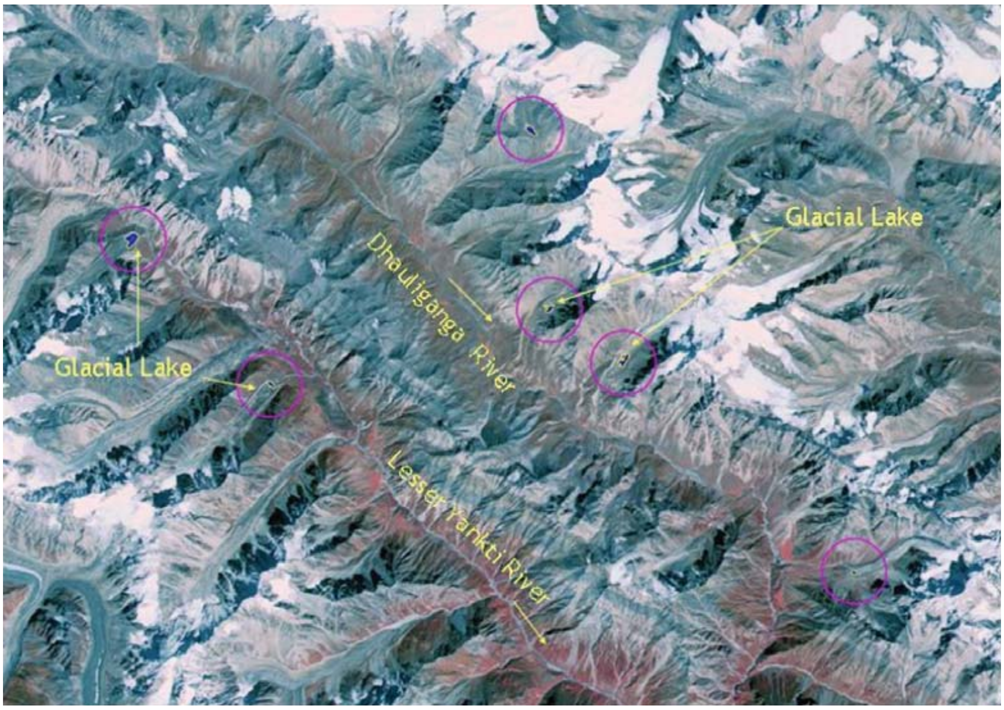


*Figure 6.2: Glacial lake identification on satellite data*

period. Similar effort was also done in Mangadechu basin. A major project has been launched by MOEF and DOS to study the Snow and Glaciers in the country. Glacial inventory of entire Himalayas was carried out on 1:50,000 scale and snow cover monitoring on 1:250,000 scale for every 10 days. Efforts are on to use these databases for glacier retreat & mass balance studies and for development of Himalayan Snow and Glacial information System in the country. Survey of India taken up inventory of major Glaciers in Indian Himalayas supported by the Department of Science and Technology (DST) on 1:1 Million scale.

A collaborative project between SAC, Ahmedabad and SASE, Chandigarh was executed for snow and glacier investigations and snow-pack characterization. A technique was developed to monitor seasonal snow cover using WiFS data, Weekly on-going charts were supplied to commanding officers in near real time.

Space Application Centre, Ahmedabad and Himachal Pradesh Remote Sensing Cell and Government college, Dharamsala carried out studies on change in glacier area and glacial retreat of 466 glaciers in the Chenab, the Parbati and the Baspa basins of Himalayas using data from the Indian Remote Sensing satellite and field expeditions and comparing them with the 1962 topographic surveys by the Survey of India. The study has shown an overall 21 per cent reduction in the glacier surface area. The process of deglaciation also led to the fragmentation of the larger glaciers. The mean area of glacial extent also declined from 1 sq km to 0.32 sq. km. during 1962-2004. In addition number of glaciers has increased between 1962 and 2001 due to fragmentation due to the detachment of tributary glaciers from main glaciers as a result of glacier retreat. Dokriani glacier in Garhwal Himalayan was studied in detail over the last ten years as part of Himalayan Glaciology Programme of the Department of Science and Technology (DST). Remote-sensing, radar technology and other geophysical methods are being used in the studies.

**Snow Avalanches**

Snow and Avalanche Study Establishment used satellite data for avalanche hazard zonation in parts of J&K, Uttaranchal and HP. Under avalanche mapping, a number of highways and lateral road axes in J&K, HP and Uttaranchal have been studied for identification and registration of snow avalanche paths, snow drift deposition and ice formation sites; frequency and severity of avalanche activity; and the extent of highway affected. Avalanche atlas was published comprising terrain data, frequency of occurrence of avalanches, magnitude of damage, proposed control measures etc.

### 6.3.2. Surface Water Mapping & Monitoring

Temporal fluctuations in water resources occur in different seasons of the year, with great variations in water spread area of water bodies during monsoon to summer. Capturing these variations and systematic inventorying on regular basis is operationally difficult task through conventional techniques. However, with the availability of satellite data at multiple spatial resolutions and at regular time intervals, surface water bodies can be mapped and monitored in terms of their occurrence and spatial extent. Generation of such information has many field level applications and provides continuous audit of surface water resources over space and time.

**Surface Water Bodies Mapping**

The typical spectral response of water facilitates its accurate identification and delineation on remotely sensed images. The time series data provides a record of changes in these storages.

The use of multi-spectral images in mapping and inventorying surface water bodies was demonstrated through many early RS studies (Thiruvengadachari, 1978; Sharma *et al.,* 1989). Water bodies were mapped up to 0.9 ha surface area in Jodhpur district, Rajasthan state using Landsat TM images which were other wise indistinguishable by Landsat Multispectral Scanner (MSS) due to the latter's poor spatial resolution. The Landsat TM data facilitated reliable and reasonable accuracy of ±10%. The comparison with Survey of India topographical maps of the year 1958 revealed reductions in the water surface and drainage basin areas up to 1.8 to 2.4 and 6.0 to 8.0 times, respectively, over a period of 28 years (1958-1986) due to the biotic interference like cultivation and urbanization resulting in desertification in the large adjoining areas.

NRSC initiated a major effort in mapping surface water bodies at national level through development of automatic feature extraction techniques using multi-spectral data from multi-date IRS LISS III/AWiFS data sets.

**Wetlands Mapping**

Vegetation laden swamps and wet lands form important constituents' of natural ecosystems. Both reflective and thermal infrared images are extensively used to map and monitor these water bodies. As part of inland wetland mapping by ISRO-RRSC's, integrated land use, turbidity and aquatic vegetation maps were generated using multi-season IRS LISS III data. Wetland statistics were generated for all the 65 districts in Gujarat, Bihar, J&K, MP, Rajasthan, UP, Karnataka, Tamil Nadu and AP. Field data was integrated for prioritization of wetlands towards conservation planning as part of MoEF/UNDP sponsored project.

### 6.3.3. Runoff and Hydrologic Modeling

The status of water availability, particularly spatial and temporal pattern at the basin level is essential for regional planning and decision making on water management. Runoff is an indication of availability of water. Thus in situ measurement of runoff is useful, however in most cases such measurements are not possible at the desired time and location as conventional techniques of runoff measurement are expensive, time-consuming and difficult. Therefore, rainfall–runoff models are commonly used for computing runoff.

Rainfall-runoff modeling has many applications:

- Basin level water resources assessment
- Flood wave run simulation
- Flood protection design to support down stream rescue and management
- Reservoir storage management
- Hydrologic balance computation
- Climate change modelling

Basic components of rainfall-runoff modeling are:

- Precipitation – (point, spatial extension)
- Runoff components – (Interception, evapotranspiration, accumulation in depressions, infiltration, percolation)
- Runoff concentration
- Channel flow

Runoff, the quantity of water volume flowing through a hydrological basin/river cross section cannot be directly measured by remote sensing techniques. However, there are two general areas where remote sensing can be used in hydrologic and runoff modeling:

- Determine watershed geometry, drainage network, and other map-type information for distributed hydrologic models and for empirical flood peak, annual runoff or low flow equations; and
- Provide input data such as soil moisture, delineated land use classes that are used to define runoff coefficients.

Topography is also basic need for any hydrologic analysis and modeling. Remote sensing can provide quantitative topographic information of suitable spatial resolution to be extremely valuable for model inputs. For example, stereo Cartosat-1 imagery can be used to develop a Digital Elevation Model (DEM) with 30 m horizontal resolution and vertical resolution of 10 m. Interferometric SAR is also capable of providing digital elevations and terrain models.

Another major input for rainfall–runoff modelling is land-cover. Satellite remote sensing is the best source of mapping this information. Using multi-date remote sensing data, both spatial and temporal patterns of the land-cover can be derived, which can be used to generate the spatio-temporal pattern of derived parameters.

Many applications of remote sensing data in hydrologic models were developed to quantify surface runoff. Most of the work on adapting remote sensing to hydrologic modeling has involved the Soil Conservation Service (SCS) runoff curve number model (US Department of Agriculture, 1972) for which remote sensing data are used as a substitute for land cover maps obtained by conventional means. Other types of runoff models that are not based only on land use are also developed (Papadaakis *et al.*, 1993).

Satellite remote sensing data can be incorporated into the system in a variety of ways: as a measure of land use and impervious surfaces, for providing initial conditions for flood forecasting, and for monitoring flooded areas (Neumann *et al.*, 1990). The GIS allows for the combining of other spatial data forms such as topography, soils maps as hydrologic variables such as rainfall distributions or soil moisture (Kouwen *et al.*, 1993). The Soil and Water Assessment Tool (SWAT) model (Arnold and Fohrer, 2005) has proven to be an effective tool for assessing water resource and non-point source pollution problems for a wide range of scales and environmental conditions across the globe.

Zade *et al.*, (2005) estimated runoff for all major basins of India using satellite data using SCS approach. The study provided analysis of intra and inter-basin runoff potential for major basins of India. The runoff in the Brahmaputra, Narmada and Mahanadi basins responded well to rainfall, i.e., high runoff coefficient, whereas low runoff coefficient was found in the Cauvery basin.

The amount and intensity of runoff on catchment scale are strongly determined by the presence of impervious land-cover types, which are the predominant cover types in urbanized areas. Chormanski *et al.*, (2008) examined the impact of different methods for estimating impervious surface cover on the prediction of peak discharges, as determined by a fully distributed rainfall-runoff model (WetSpa). The study showed that detailed information on the spatial distribution of impervious surfaces, as obtained from remotely sensed data, produces substantially different estimates of peak discharges than traditional approaches based on expert judgment of average imperviousness for different types of urban land use.

**SCS Method**

The model developed by the United States Department of Agriculture (USDA) Soil Conservation Society (SCS) known as curve number (CN) is popular among all rainfall–runoff models because of its simple mathematical relationships and low data requirement. The CN represents the watershed coefficient, which is the combined hydrological effect of soil, land use, agricultural land treatment class, hydrological condition and antecedent soil moisture condition (AMC). Generally, the model is well suited for small watersheds of less than 4000 ha, as it requires details of soil physical properties, land use, conservation treatment and vegetation condition. The CN method is based on the assumption of proportionality between retention and runoff. The mathematical relation for runoff is given by:

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)} \qquad (1)$$

where Q is the actual runoff, P the precipitation, $I_a$ the initial abstraction which includes interception, surface storage and infiltration into soil and S the potential retention. Since $I_a$ = 0.2, S (based on the analysis performed by SCS for the development of the rainfall–runoff relation for average condition, i.e. AMC II), AMC is determined by the sum of the last five consecutive days' rainfall. In addition, the, following relationships between initial abstraction and potential maximum retention have been developed for Indian condition.

Equation (1) can be written as:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \text{ for black soil} \qquad (2)$$

$$Q = \frac{(P - 0.3S)^2}{(P + 0.7S)} \text{ for other soil groups} \qquad (3)$$

where, S is determined by CN, through the following relation:

$$S = \frac{25400}{CN} - 254$$

The first step in the model was to derive a hydrological soil grouping (HSG), which is a qualitative term given by the SCS. It is categorized into A (lowest runoff potential), B (moderately low runoff), C (moderately high runoff), and D (highest runoff) using in- formation on soil texture. Ideally, a hydrological soil grouping was to be derived on the basis soil type, infiltration, soil depth and permeability. Since most of these parameters are soil texture-dependent, HSG was done on the basis of soil textural map and tentative map of hydrological soil groups. The raster theme of HSG was integrated with the land-cover theme to generate the hydrological soil cover complex (HSCC). This HSCC map was used for assigning the CN (CN ranges from 0 to 100, i.e., no runoff to runoff equating rainfall).

### 6.3.4. Water Balance Studies

The water balance is useful for predicting some of human impacts on the hydrologic cycle. Many models are available for computing runoff or water balance in a watershed. SCS curve number method, Soil Moisture Accounting Model, Green Ampt Model, Thornthwaite and Mather model, etc., are very popular models used for computing runoff. All these models take the information derived from the remote sensing data. Thornthwaite and Mather model is widely used for computing water balance. It is a book-keeping method, very useful for computing runoff at preliminary stage of planning of any water resources project. It can be applied for big size watersheds also. It follows the concept of energy budget.

The water balance of a small drainage basin underlain by impervious rock at depth can be represented by the equation:

P = I+AET+OF+DSM+DGWS+GWR

Where, P is precipitation, I- Interception, AET- Actual evapotranspiration, OF- Overland flow, DSM- Change in soil moisture, DGWS – Change in ground water storage, GWD- Ground water runoff.

Here, the symbols, expressed as equivalent depth of water for specified time interval, precipitation, interception, evopotranspiration, overland flow, change of soil moisture storage, change of ground water storage, and ground water runoff (figure 6.3).

To compute the climatic water balance, it is necessary to obtain data of water supply (precipitation) and climatic water need potential evapotranspiration (PET). For the computation of water balance, potential evaporation data can be calculated by using either evaporation data or empirical equation or by analytical methods.

PET is a primarily function of climatic conditions (energy from the sun) and is not a function of type of vegetation, type of soil, soil moisture content, or land management practices (Mather, 1978). PET can be calculated using different methods like Penman-Monteith method, Thornthwaite method etc.

The water storage capacity (SM), which depends upon the soil texture type, rooting depth of vegetation and land use, in the root zone of the soil must be determined. Then, from the readily available tables or graphs or by using the empirical formula for dry season months we can find how much water will be retained in the soil after various amounts of accumulated potential water loss. For the case of wet seasons soil moisture values can be determined by adding the excess precipitation to the soil moisture value of the previous month until the total storage again reaches the water-holding capacity of the soil.

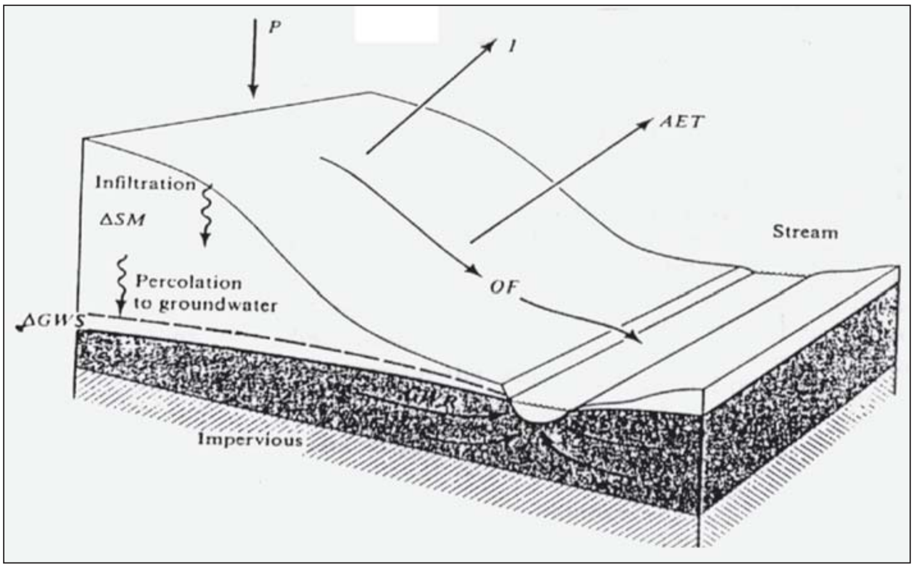


*Figure 6.3: Componants of water balance on a hill or a small cachment*

The ability of soil to retain water depends upon the amount of silt and clay present; higher the amount, the greater is the soil moisture content. The change in moisture content ($\Delta$SM) that is equal to the difference of soil moisture in a month and its proceeding month should be calculated. Actual evapotranspiration (AET) represents the actual transfer of moisture from the soil and vegetation to the atmosphere.

Ottle *et al.*, [1989] have shown how satellite derived surface temperatures can be used to estimate ET and soil moisture in a model that has been modified to use these data. Duchon *et al.*, [1992] have used Landsat TM satellite data to identify uniform land cover areas and GOES data for input insolation for a monthly water balance model.

## 6.4. Water Resources Management

(Irrigated Agriculture, Reservoir Management, Urban Water Supply)

### 6.4.1. Irrigation Water Management

Investment and development of irrigation infrastructure has been long and continued priority in India. In 1950-1951 the net irrigated area in India was 21 million ha and as a result of sustained efforts, fuelled by Nehru's call to make irrigation works the 'temples of modern India', this expanded to close to 100 million ha by 2006. The role of irrigation in India in expanding crop production, reducing output instability and providing protection against periodic drought has been a major factor in the substantial achievement of Indian agriculture over the past four decades. Programs such as Bharat Nirman/AIBP accelerate the irrigation potential creation and efforts are on for improving the performance of existing irrigation systems to bridge the gap between potential created and utilized and to improve overall water use efficiency/productivity.

With the growing competition for fresh water resources from other sectors and increasing uncertainty of water quantities due to impending climate change, irrigation water management is faced with increasing needs for more reliable, consistent and timely water resources related data flow. Data collection in irrigation systems is a well established practice, although the convertibility between available data and readily usable information is little. The conventional data acquisition is oriented more towards archival than operational usage and in-situ observations are generally characterized by inadequacy and non-reliability. To achieve maximum water use efficiency, real time information on various aspects, which control and influence the supply & utilization regimes are to be obtained.

Advances in communications and remote sensing satellites provided many new opportunities to generate and transmit information on weather, water and agriculture. Use of satellite remote sensing data for IWM has been demonstrated through many studies addressing: base line inventory, performance assessment & monitoring, providing in-season inputs, monitoring physical progress of potential creation, generating inputs for feasibility assessment of new projects, environmental impacts such as water logging & soil salinity, reservoir management, etc. This would support the field departments to cope up with water scarcity and augmenting the water use efficiency through integration of geo-spatial information with their conventional practices.

#### 6.4.1.1. Inventory of Irrigated Agriculture

Mapping of cropping pattern and crop condition assessment using remote sensing data was carried out as early as during early 1990s after successful launch of first Indian Remote Sensing (IRS) satellite IRS-1A in 1988. Mapping of crops in irrigation command area was carried out through visual interpretation (Rao and Mohankumar, 1994) of image prints to analysis of multi-spectral optical remote sensing data using various image processing algorithms and also using microwave radar data (Saindranath *et al.*, 2000, Chakraborty *et al.*, 1997). Baseline information on cropping pattern was generated using remote sensing from basin level (Biggs *et al.*, 2006) to water course level. Multi-temporal optical (Sesha Sai and Rao, 2008) and microwave data was used to identify multiple crops in irrigated agricultural system. Murthy *et al.*, (2003) used advanced classifiers like ANN back-propagation technique for classification of irrigated crops.

Various satellite derived indices have been used to evaluate crop condition. Some of the indices like NDVI were found to be directly related to crop yield and thus were used for estimation of crop yield. Crop yield has been estimated for cereal crops like paddy (Murthy *et al.*, 1996) and wheat (Patel *et al.*, 2006). NDVI was also used for ground sampling of crop cutting experiment in irrigation system (Murthy *et al.*,1996).

NRSC has also executed various command area projects under National Water Management Project (NWMP) and Water Resources Consolidation Project (WRCP). In addition to the above, NRSC has also executed several projects (28) for various State Irrigation and Command Area Departments. Inventory and monitoring of irrigated agriculture in Nagarjuna Sagar Project & Krishna Delta is shown in figure 6.4.

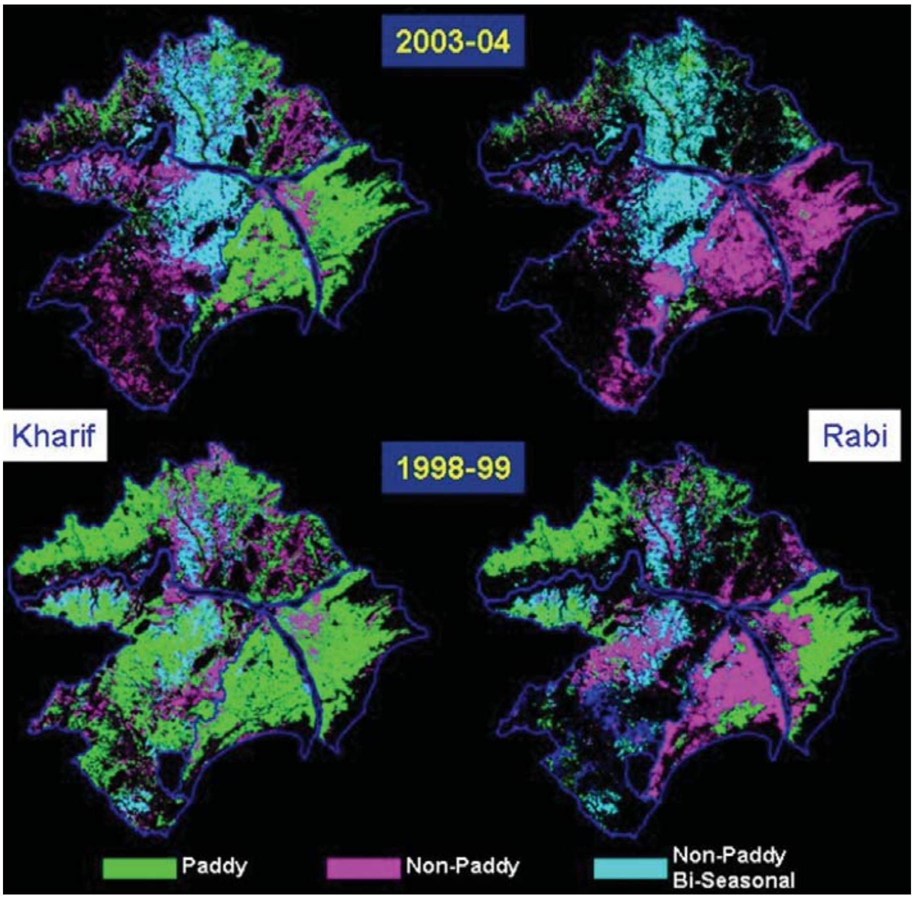


*Figure 6.4: Inventory and monitoring of irrigated agriculture in Nagarjuna Sagar Project & Krishna Delta*

#### 6.4.1.2. Performance Assessment

Many Indian irrigation systems perform at a very low level and number of National efforts has been initiated to improve the performance of existing irrigation schemes. In most of the existing irrigation schemes there is a serious lack of reliable and adequate information on system performance and one of the extraordinary characteristics of irrigation projects is that a large number of projects generated revenue in far excess of the largest business corporate, there is virtually no information on the extent of which these projects are achieving the designed per-formance objectives. Before taking up any improvement measures, it is essential to evaluate the present per-formance and identify the areas/pockets whose performance is below par. Such exercise would help the irrigation man-agers to prioritize the improvement measures. Although, information of irrigation system performance can be obtained by conventional techniques, they are often subjective, inconsistent and are mostly point based measurements and extended spatially. While conventional procedures are capable of providing system performance at a gross command area level, they are in general time consuming and cost-intensive. Satellite Remote Sensing (SRS) has

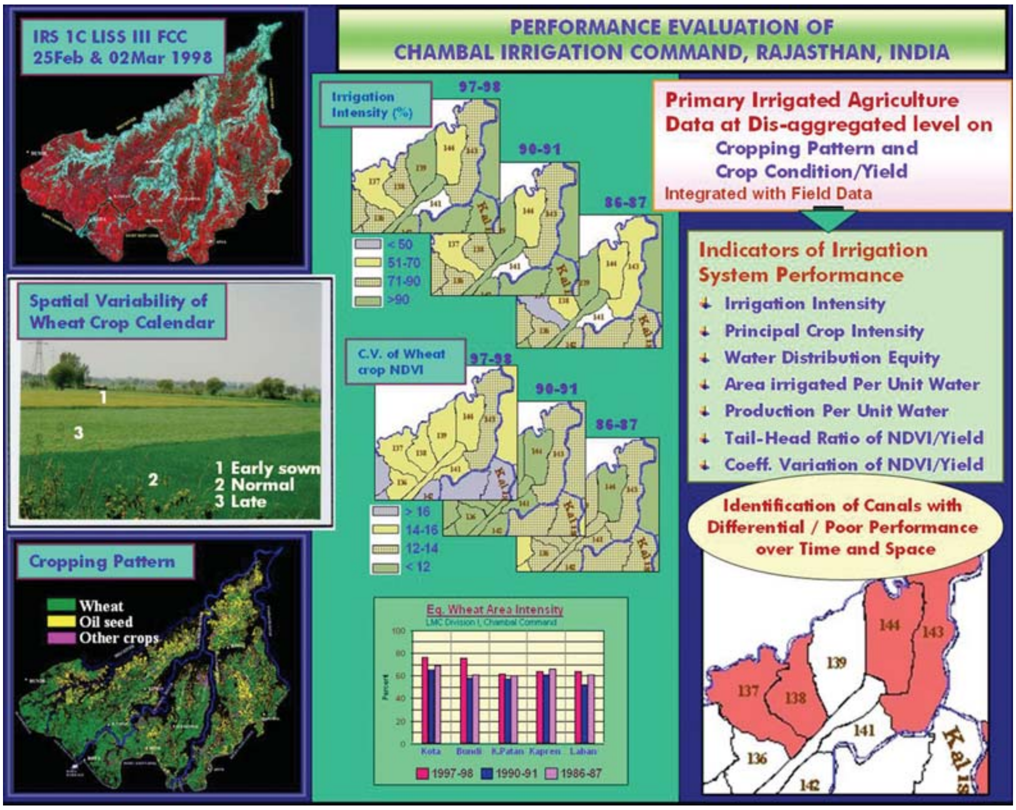


*Figure 6.5: Performance evaluation and problem pockets identification*

established itself as an effective and accurate tool for providing essential elements for characterizing the irrigation system performance. The accuracy of SRS derived information is significantly higher than the conventional methods. Another advantage of SRS data is to create time series- as much as 15-20 years- for monitoring the changes in time. It is being operationally used to assess the performance of irrigation systems, bench marking, identifying low performing pockets, effectiveness and sustainability of improvement schemes, etc.

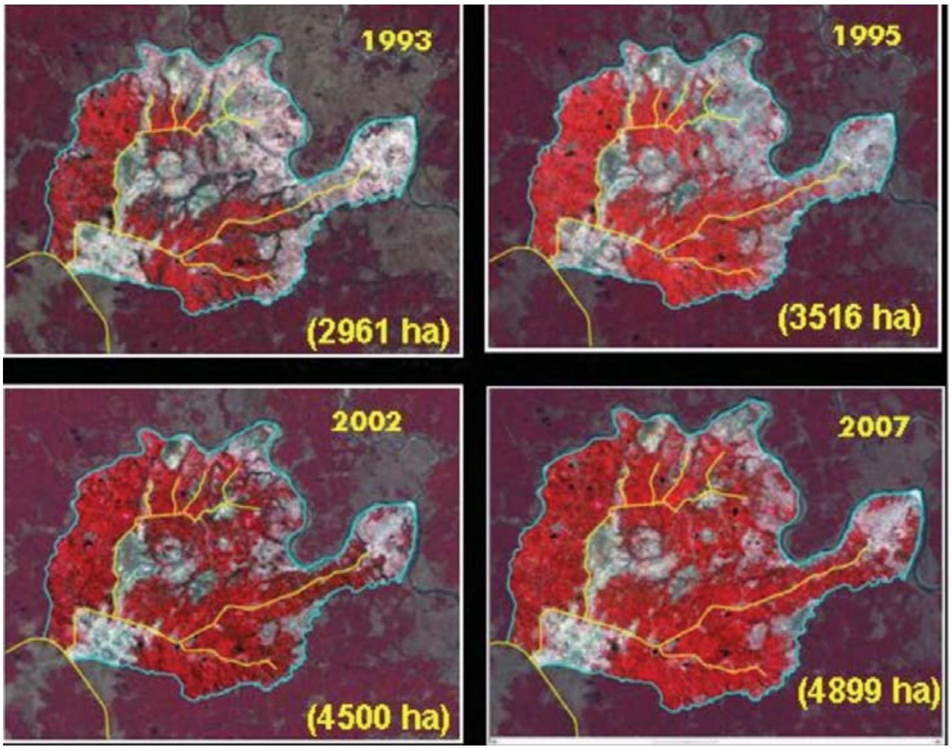


*Figure 6.6: Impact and sustenance monitoring of intervention schemes*

Performance evaluation of an irrigation system requires the spatial information on crop intensity, crop type, crop calendar and crop condition/productivity etc. Multi-spectral satellite data is found useful to derive primary information on cropping pattern and crop condition, which can be used to quantify the agricultural performance of the system. This spatial information can be integrated with relevant field data to generate various performance indicators to gauge the performance and compare with targeted, in order to identify and rank the pockets of poor performance. Some of the performance indicators generated from satellite data are:

- Crop Intensity
- Equivalent crop area intensity
- Principal crop intensity
- Proportionate Crop Intensity
- Crop Condition
- Coefficient of variation in crop condition
- Tail-Head ratio of cropping intensity
- Tail-Head ratio of crop condition
- Sustainability in crop intensity

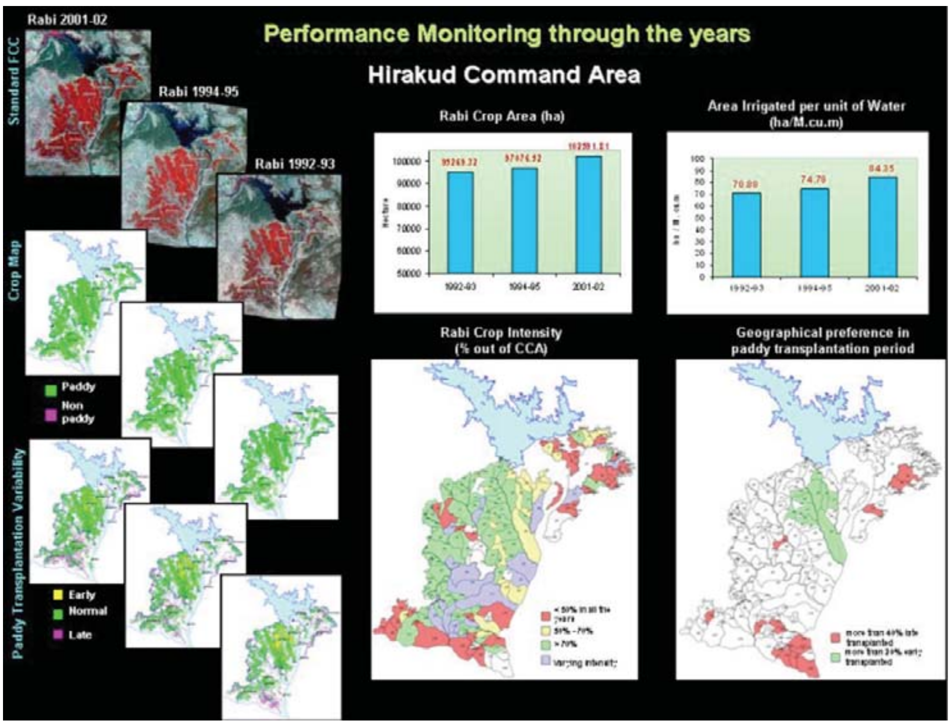


*Figure 6.7: Performance monitoring through the years*

Satellite data based monitoring and evaluation of irrigation command areas was initiated by NRSC in 1991-92. Initially base line inventory of irrigated crop areas and their extent was carried out at distributary group in Bhadra project command area in Karnataka state. Remote sensing based performance indicators were used for performance assessment of various irrigation systems in the country. Performance evaluation and problem pockets identification is shown in Figure 6.5. Bastiaanssen (1998) has listed the performance indicators derived from RS algorithms supplemented by ground data. Ray et al (2002) used RS data has to compute three indices namely, adequacy (AI), equity (EI) and water use efficiency (WUE) for the evaluation of performance of distributaries in an irrigation system. Panigrahy et al (2005) attempted to derive crop indices like Multiple Cropping Index (MCI), Area Diversity Index (ADI) and Cultivated Land Utilization Index (CLUI) using satellite derived parameters such as cropping pattern, crop rotation, and crop calendar, crop type, acreage, rotation and crop duration. NRSC executed, CAD, MOWR selected 13 irrigation commands on a pilot basis to evaluate the performance of these irrigation schemes using satellite remote sensing techniques (1997-98 to 1998-99). NRSC (March, 2005) successfully organized 5 regional workshops as a part of this study. In figure 6.6, impact and sustenance monitoring of intervention schemes is shown. Per-formance monitoring of irrigation command area all through the years is shown in figure 6.7.

#### 6.4.1.3. In-Season Inputs for Irrigation Water Distribution

To maintain control over the process of delivering water, real time information is to be obtained on various aspects, which control and influence the supply & utilization regimes. Intentional water requirements does not always meet the actual use due to changes in the field environment such as weather conditions, farm management practices, water distribution mechanism, etc. In the event of mismatch between planned and actual water requirements, distribution needs changes considering the actual demand. Irrigation managers are constrained by the lack of real time information on - to what extent irrigated agriculture is confirming with their plans and the extent of deviations, if any.

Multiple satellite observations, at high time frequency, during the irrigation season can capture the temporal changes that are taking place in an irrigated command area. AWiFS on board IRS-P6 (Resourcesat-1), can acquire images at 5-day interval and its ~56 m resolution coupled with multi-spectral information were found very useful to capture and monitor the periodical changes right up to tertiary canal level. These data sets are capable of providing near-real-time information on:

- Extent of crop area
- Progression of crop acreage
- Cropping pattern
- Variations in crop calendar
- Crop condition variations across time and space

Such information, when derived and provided during supply time, would equip the managers to make real-time decisions and to sensitize the water release pattern in accordance with demand variability and its sensitivity. Spatial and temporal variations in progression of irrigated agriculture is shown in figure 6.8.

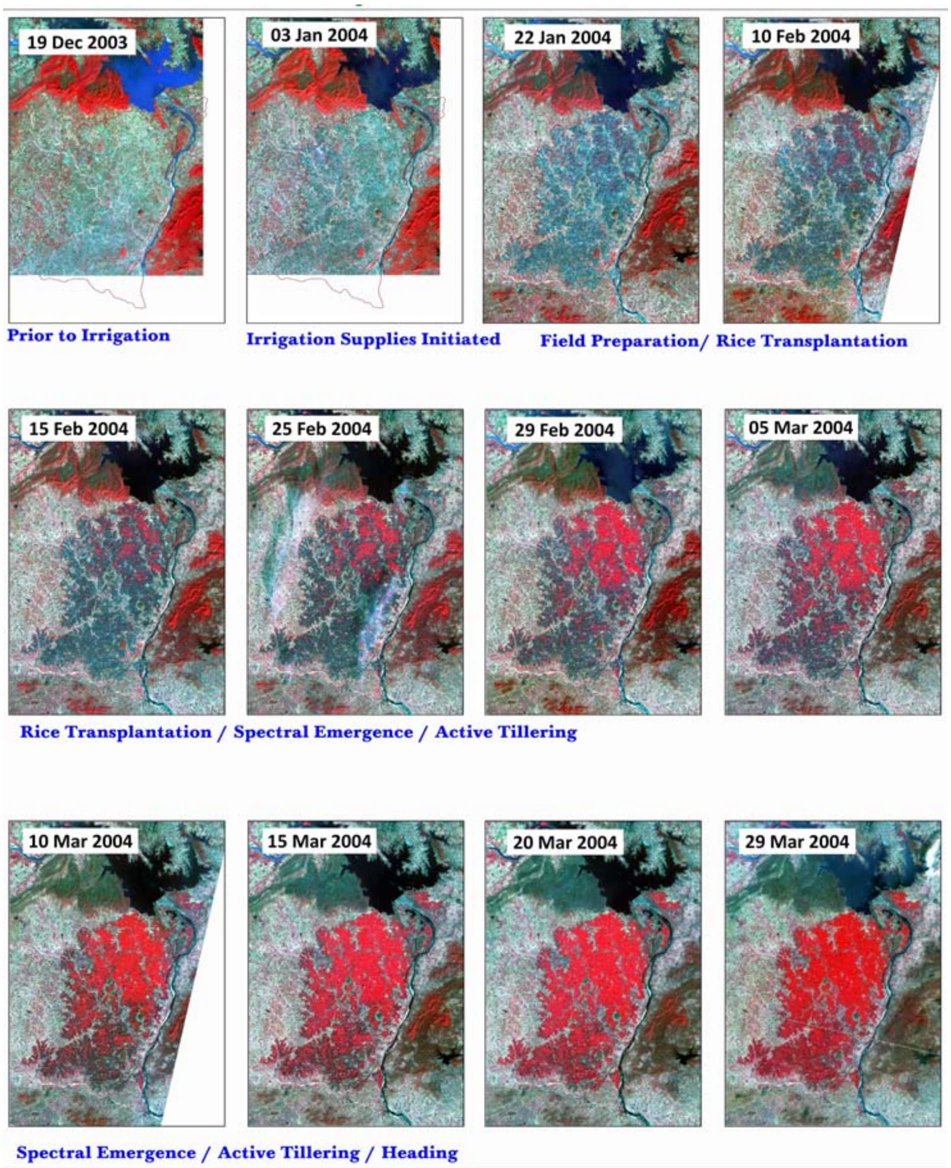


*Figure 6.8: Spatial and temporal variations in progression of irrigated agriculture*

#### 6.4.1.4. Salinity and Waterlogged Area Mapping & Monitoring

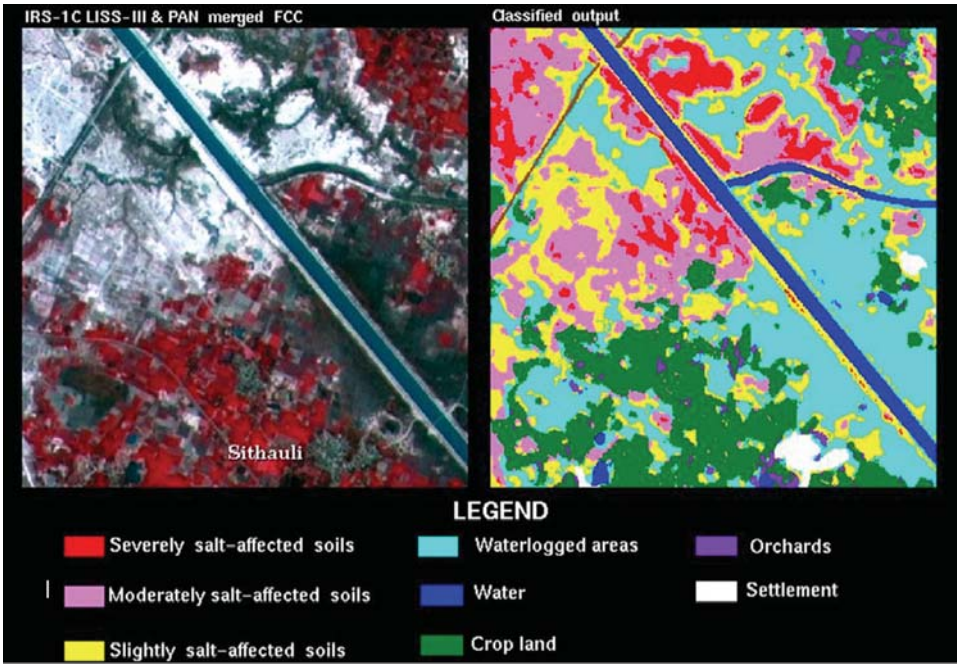


*Figure 6.9: Mapping of salt affected soils and water logged areas*

Waterlogging and subsequent salinization and/alkalization are the major land degradation processes operating upon in the irrigation commands of the semiarid regions. The significant occurrence of salt affected soils lies in the arid and semiarid regions reducing considerably (7–8%) the productive capacity of the land surface in the world. Due to improper management of soil and water resources in the command areas, the problems of salinity/alkalinity and water logging are reported to be on the increase. Information on the nature, extent, spatial distribution and temporal behaviour of areas under water logging and salinity/alkalinity is essential for proper management of irrigated lands.

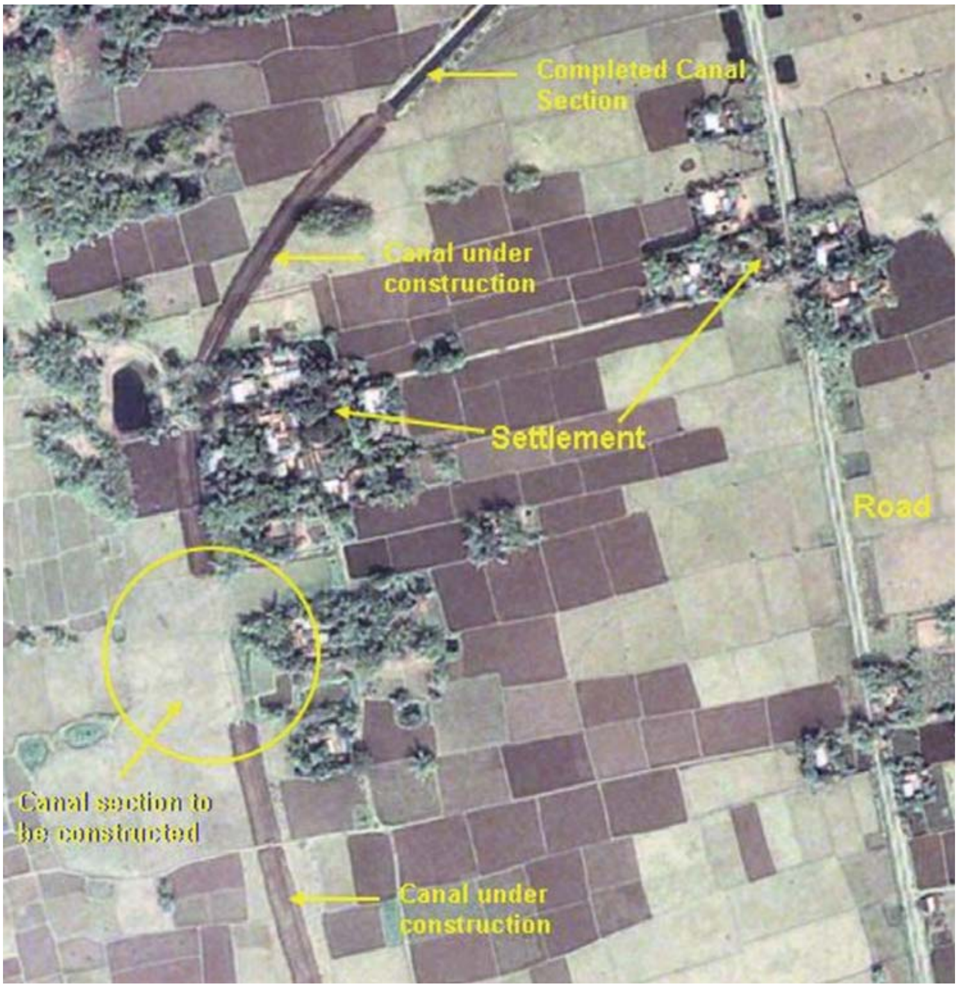


*Figure 6.10: Monitoring progress and status of Irrigation network creation*

Until recently, information on the nature, extent, magnitude and spatial distribution which is a pre-requisite for amelioration and management of salt affected soils, has been generated through traditional soil surveys which are tedious and time-consuming apart from being cost-prohibitive. Among the new technologies developed for soil survey, remotely sensed data from space borne sensors like Landsat-MSS, TM, IRS-LISS-I/II/III, Resourcesat-1, SPOT MLA/PLA etc., proved to be valuable to map and monitor salt affected soils and water logged areas. Satellite data are being used regularly for mapping of salt affected soils (Singh & Dwivedi, 1989; NRSA, 1995; 1996) and waterlogged areas (Sharma & Bhargava, 1987; Dwivedi & Deka, 1990). Command Area Development (CAD) programme, the Ministry of Water Resources, Government of India, supported a programme to apply satellite remote sensing techniques to generate distributary-wise information on the status of water logging and salinity/ alkalinity periodically during selected years of operation in selected command areas. The information on nature, extent, and spatial distribution of waterlogged area and salt-affected soils was derived through systematic visual interpretation of standard false colour composite (FCC) prints on 1:50,000 scale.

The National Remote Sensing Centre (Department of Space) Hyderabad, prepared state-wise the salt affected soils map of India on 1:250,000 scale using remote sensing data and ground truth jointly with the Central Soil Salinity Research Institute (ICAR), Karnal , National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), Nagpur. The database contains maps showing physiographic features, distribution and extent of salt affected soils supported by a basemap and a descriptive dataset showing nature and degree of salinity/sodicity. Mandal and Sharma (2006) used GIS to integrate salt affected soil maps for a composite database of the Indo-Gangetic Plain in India and derived information on the extent and distribution of salt affected soils for agro-climatic regional and zonal planning.  Satellite derived salt affected and soil and water logged areas is shown in figure 6.9.

#### 6.4.1.5. Monitoring New Irrigation Potential Creation

Ultimate irrigation potential of India is 139.89 M ha and at present only 99.76 M ha is under place. Major National programs such as AIBP are expediting the new irrigation infrastructure creation. High resolution satellite data is assisting the sponsoring institutions to monitor the physical progress and status of the new potential creation. (Figure 6.10).

NRSC at the request of Ministry of water Resources, GOI, monitors the progress of irrigation infrastructure creation and potential creation in AIBP funded projects using high resolution satellite data. The pilot project in Teesta command area, West Bengal state and Upper Krishna project, Karnataka state led to National level activity for 53 projects spread over 18 states. The high resolution satellite data from the Indian satellite sensors (Cartosat-1& Cartosat-2) are extensively used for this activity. The next phase is expected to cover all the remaining projects under AIBP.

#### 6.4.1.6. Satellite data for Evapotranspiration studies

An important step forward in hydrology for water management is the work on the evapotranspiration flux using satellite data. The available amount of water on land (Q) is determined by the amount of rainfall (P) minus the evapotranspiration (ET)  (i.e. the water that returns from the land surface to the atmosphere). Thus, in its simplest form, the water balance is $P – ET = Q$.

Quantifying evapotranspiration in time and space facilitates determination of the amount of water resource in catchments, support characterization of irrigation scheme in terms of actual water usage, water productivity, water distribution efficiency and ground water usage. It is also one of the critical elements for carrying out both long term and short term water balance studies. At present, evapotranspiration from satellite data is confined to regional level assessment, providing basin level water balance appraisal.

Satellite data was used to derive crop-wise monthly crop coefficient data for estimation of crop evapotranspiration. Jonna et al (2007) studied spatial variation in crop surface properties like emissivity and canopy surface temperature (CST) using moderate-resolution imaging spectrometer (MODIS) satellite data and diurnal ground measurements.

### 6.4.2. Reservoir Management

#### 6.4.2.1. Reservoir Sedimentation

Reservoirs lose their storage capacity due to sedimentation. The analysis of sedimentation data of Indian reservoirs show that the annual siltation rate has been generally 1.5 to 3 times more than the designed rate and the reservoirs are generally losing capacity at the rate of 0.30 to 0.92 per cent annually. The consequence of loss in storage due to sedimentation is precluding the intended usages such as flood protection/moderation, irrigation, hydro-power generation, etc. Sedimentation in reservoirs occurs not only in dead storage but also in live storage region simultaneously, which reduces the useful storage and affects the water utilization pattern of the project. Periodic assessment of sedimentation rates is essential to ascertain the current reservoir live storage capacity for efficient and productive management of water resources. This information is also necessary to plan for the upstream catchment treatment in order to control the rate of sedimentation. Such assessment would also facilitate characterization of basins/catchments in terms of their siltation rate potential and provide realistic basis for planning new reservoir schemes. Conventionally, assessment of sediment deposition in the reservoir is carried out either by inflow-outflow measurement method or by hydrographic survey. Hydrographic survey method is in practice for quite long time in India and elsewhere.

The reduction in storage volume results from the decrease in water spread area due to sedimentation at different elevations. Therefore, capturing the water spread at various reservoir operating levels would help in estimating the current reservoir storage and a comparison with previous or original storages would provide the loss in storage due to sedimentation. In this context, satellite remote sensing plays a very useful role due to its synoptic and repetitive coverage. Water, by virtue of its typical spectral response characteristics is noticeably manifested on satellite data. Multi-spectral satellite data facilitates distinct separation between water bodies and the surrounding land-use/landcover. The water spread boundary captured by the satellite data provides water spread contour at that particular reservoir water level. By taking a series of satellite data covering various reservoir operating levels, the water spread contours can be derived for the corresponding elevations. Using mathematical formulae, the actual reservoir storage between the observed water levels can be computed. This helps in generating present area-capacity curves and a comparison with previous curves provide the changes in reservoir storage.

Multi-temporal satellite data have been used as an aid to capacity survey of many reservoirs in a cost and time effective manner in India. While this technique helps in revising capacity table between minimum and maximum draw down level observed in satellite data, loss of dead storage capacity can be obtained only through conventional hydrographic surveys. A National action plan of sedimentation survey of 124 reservoirs using remote sensing technology has been taken up in India during the 10th Five Year plan by Ministry of Water Resources.

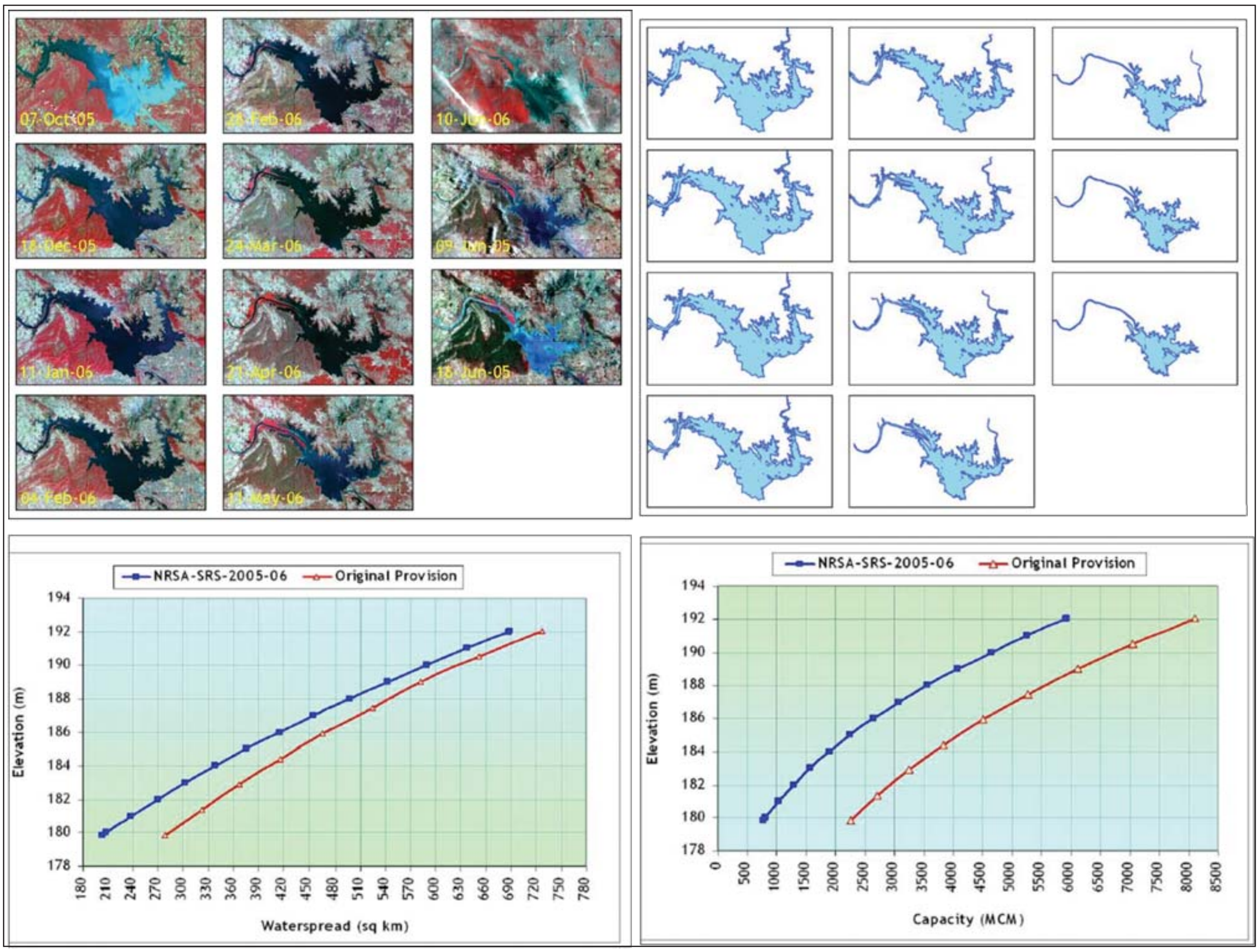


*Figure 6.11: Reservoir capacity loss and sedimentation assessment*

Reservoir sedimentation surveys of the balance 54 reservoirs of National Action Plan were executed by NRSC/DOS/Others. CWPRS and NRSC have jointly executed two reservoir sedimentation projects viz. Sri Ram Sagar Project reservoir in Andhra Pradesh State (2003-2004) and Ujjani reservoir sedimentation survey project in Maharashtra. NRSC recently carried out satellite data based updation of elevation-area capacity curves and sedimentation assessment of Hirakud reservoir, Orissa state for the year 2005-06, as shown in figure 6.11.

#### 6.4.2.2. Catchment Area Treatment

Storage reservoirs structures are one of the most important infrastructure investments offer essential services: drinking water, irrigation water, flood and torrent control, hydroelectric power, fisheries, wildlife, recreation, and other environmental benefits. The catchment's behaviour and its resource capability especially in regions of soil erosion is one of the major threats to water resources storage and management. Soil erosion and sedimentation reduce the economic life of storage structures through the inflow and deposition of soil particles. In addition, sedimentation results in dramatic environmental impacts on water quality and aquatic habitat. Sustainable management and conservation of such expensive investments and their catchment is crucial for the long-term quality of resource and its utilization. The catchment behaviour is mainly affected by vegetation cover, topographic features, climatic variables, and soil characteristics. The human activities and large-scale developments alter the vegetation cover, impacting upon the behaviour. Topographic features such as ground slope, slope length, and shape affect rill and inter-rill erosion. The climatic variables such as rainfall amount and precipitation intensity, temperature are also important.

Assessing the soil erosion rate is essential for the development of adequate erosion prevention measures for sustainable management of land and water resources. Remote Sensing & Geographic Information System (RS & GIS) technologies are valuable tools in developing models through their advance features of data storage, management, analysis, display and retrieval. While soil erosion models only calculate the amount of soil erosion based on the relationships between various erosion factors, RS and GIS integrated erosion prediction models do not only estimate soil loss but also provide the spatial distributions of the erosion. Especially, generating accurate erosion risk maps in GIS environment is very important to locate the areas with high erosion risks and to develop adequate catchment area treatment plans and strategies. The most common empirical erosion prediction models, integrating with RS and GIS, are Revised Universal Soil Loss Equation (RUSLE). The RUSLE was developed to estimate the annual soil loss per unit area based on erosion factors including soil erodibility, topography, rainfall and vegetation cover. The potential soil erosion risk is calculated as a function of soil erodibility, erosivity, and topography. The vegetation cover data is very important parameter in erosion models since intensity of vegetation cover significantly affects erosion rates. Using medium to high resolution satellite imagery, image classification techniques have been used to generate accurate and reliable land use/cover data and spatial inputs for erosion modelling.

## 6.5. Watershed Management

(Water harvesting, Sustainable Action plans, Soil erosion)

Watershed is a natural hydrologic unit, considered as the most appropriate basis for sustainable integrated management of the land and water resources. Judicious management and conservation of soil and water resources on watershed basis is perquisite for sustaining the productivity. Characterization and prioritization of watersheds are essential steps in the integrated management of land resources. Watershed characterization involves measurement of related parameters, such as geological, hydrogeological, geomorphological, and hydrological, soil, land cover/land use etc. Remote sensing using aerial and space borne sensors can be effectively used for watershed characterization and assessing watershed priority, evaluating problems, potentials, management requirements and periodic monitoring. Remote sensing data greatly facilitates mapping of forest, vegetation cover, geology and soils over watershed, which would assist in the study of land use, watershed potential, degradation etc. This, along with ground based information, can be used for broad and reconnaissance level interpretations for land capability classes, irrigation suitability classes, potential land uses, responsive water harvesting areas, monitoring the effects of watershed conservation measures, correlation for runoff and sediment yields from different watersheds and monitoring land use changes and land degradation.

Watershed development requires delineation, characterization, prioritization, generation of development plans, monitoring their implementation and impact assessment. An essential component for preparation of watershed development plans is the database of the natural resources.  Generation of such a database by conventional means is tedious, expensive and time consuming.  Information on all the natural resources of the watershed namely soils, geology, geomorphology, ground water, land use/ land cover, slope, generated from satellite data are highly efficient. Thus, space borne remote sensing data is playing a crucial role in this effort.  Availability of stereo data helps in delineation of a micro-watershed and higher spatial resolution data facilities better characterization of micro-watershed in terms of its resource potential.

### 6.5.1. Water Harvesting

The problem of water shortage in arid and semi-arid regions is low rainfall and uneven distribution through out the season, which makes rainfed agriculture a risky enterprise. Water harvesting for dry-land agriculture is a traditional water management technology to ease future water scarcity in many arid and semi-arid regions of world. As the appropriate choice of technique depends on the amount of rainfall and its distribution, land topography, soil type and soil depth and local socio-economic factors, these systems tend to be very site specific. The water harvesting methods applied strongly depend on local conditions and include such widely differing practices as bunding, pitting, micro-catchments water harvesting, flood water and ground water harvesting.

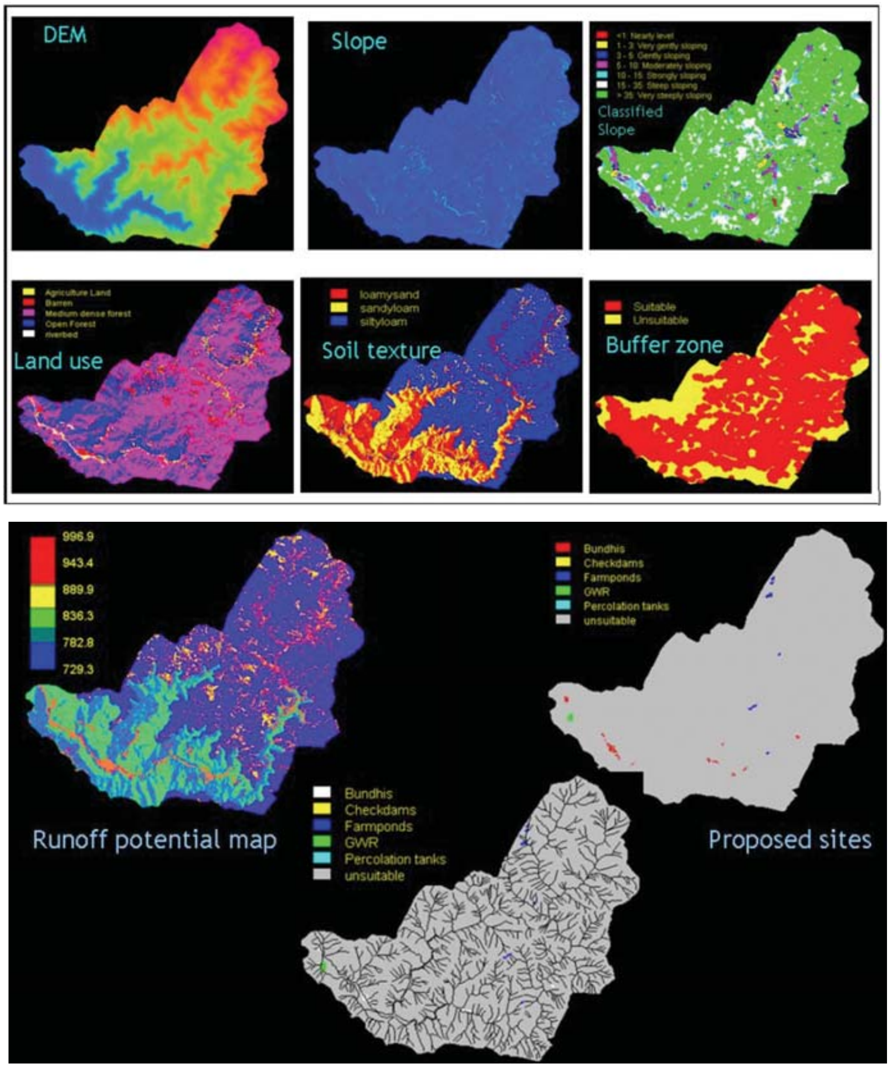


*Figure 6.12: Water harvesting structures planning using geo-spatial data*

Parameters for identification of suitable rain water harvesting areas are:

- Rainfall
- Land use or vegetation cover
- Topography and terrain profile
- Soil type & soil depth
- Hydrology and water resources
- Socio-economic and infrastructure conditions
- Environmental and ecological impacts

Using the above parameters in a watershed, various water harvesting structures can be identified as shown in figure 6.12.

### 6.5.2. Sustainable Action Plans

#### 6.5.2.1. Integrated Mission for Sustainable Development (IMSD)

The Department of Space, Govt. of India launched project called ‘Integrated Mission for Sustainable Development’, for watersheds spread across the country by integrating the information on various natural resources such as land cover, soils, hydro-geo-morphology along with the slope information and provided recommendations for construction of soil and water conservation structures and in situ action plans for selection of appropriate farming systems. This project covered 174 districts covering 84 M ha was carried out in India. In many of the watersheds, plans are being implemented by the government as well as by the voluntary agencies. Besides evolving locale-specific prescriptions for development, this project succeeded in harmonizing the local wisdom of small and marginal farmers with scientific knowledge and administrative acumen.

#### 6.5.2.2. National Agricultural Technology Project (NATP)

Development of regional scale watershed plans and methodologies for identification of critical areas for prioritized land treatment in the watersheds of rainfed rice, oilseeds, pulses, cotton and nutritious cereals production systems was taken up under NATP.

All the natural resources were mapped in the selected watersheds at 1: 50000 scale using satellite data. A methodology was developed for identification of critical areas. A representative micro watershed of an area of 500 – 1000 ha was selected from the critical areas for preparing natural resource inventory at 1:12,500 scale using high resolution satellite data. Detailed thematic maps of soils, land use / land cover, hydro-geomorphology were prepared using satellite data. The methodology developed was applied to identify critical areas for land treatment in the selected micro watersheds. The critical areas were addressed through specific action plans for development of land and water resource in consultation with local farmers & cooperating centers. All the cooperating centers implemented action items such as construction of water harvesting structures, soil conservation measures, crop improvement techniques, etc., were identified in their respective micro watersheds. The positive impact of the implementation work was also studied using satellite data. This study revealed that by using the advanced technologies like remote sensing and GIS, critical areas could be located in the watersheds in a short time and cost effective manner, thus helping the researcher / planner to focus more on these areas while planning for watershed development following the production system approach.

#### 6.5.2.3. Other Efforts

Monitoring and evaluation of 77 sub-watersheds (854 micro-watersheds) in 5 districts (in 3 Phases) in Karnataka State. With the establishment of monitoring and evaluation (M & E) units in all the 5 study districts, baseline survey was completed in Phase 1 & 2 watersheds and initiated in Phase 3 watersheds; Mid term evaluation for Phase 1 watershed completed; Concurrent monitoring is on in all the watersheds; Various software packages (Sujala-Mahiti, Sukria_Naksha & Sukria_Vivera) have been developed, installed and operationally being used for effective monitoring and evaluation process. The entire M&E approach evolved by ISRO has been acknowledged by World Bank review team as “a model of excellence and should be promoted widely for other projects to follow”. Monitoring and evaluation of Watersheds treated under NWDPRA, a nation wide project has been completed for all the 122 watersheds in 12 States treated under 8$^{th}$ & 9$^{th}$ Five Year Plan. This involved multi-season satellite data analysis for pre and post monitoring towards preparation of land use/ land cover and vegetation dynamics change detection to quantify the impact of watershed development programme.

Following the devastating Earthquake in Kachchh on January 26, 2001, at the initiative of the Prime Minister’s Office (PMO) and at the request from the Government of Gujarat, Indian Space Research Organisation (ISRO) with SAC, Ahmedabad as nodal agency took a project for generation of water and land resources developmental plans for Kachchh district on 1:25,000 scale using IRS IC/ID merged data. The main objective of the study was to prepare land and water resources plans for the district at 1:25,000 scale. The study led to mark the following:

- Demarcation of micro-watersheds
- Prospective sites/zones for ground water exploration, various rain water harvesting structures and artificial recharge
- Suggestion for change in land Use for agriculture resources development, grassland and wasteland development
- Suitable soil and moisture conservation measures

### 6.5.3. Soil Erosion

Out of 328 million ha of land area, India’s approximately 175 million ha are suffering from intense soil erosion. Soil erosion is a natural process caused by water, wind and ice. In situ soil erosion and its off-site down stream damages cause soil productivity, degradation of landscape, sedimentation of storage schemes, water quality deterioration, etc. Assessing the soil erosion rate is essential for the development of adequate erosion prevention measures for sustainable management of land and water resources. Quantifying and characterizing spatial distribution of soil erosion using conventional measurements is difficult, time consuming and expensive. The sediment load measurements at outlet of catchments do not provide the spatial distribution. In addition to field measurements, empirical and process based models have been developed to estimate soil erosion.

Soil erosion causes both physical (gullies and rills) and visible (exposure of different soil layers) changes in the surface properties of soils on the landscape. These changes are amenable for measurement through remote sensing sensors. There have been many studies on modeling soil erosion by utilizing RS and GIS technologies. The capabilities of these technologies increase when they are integrated with empirical erosion prediction models. The relationships between various erosion factors, RS and GIS integrated erosion prediction models do not only estimate soil loss but also provide the spatial distributions of the erosion. Especially, generating accurate erosion risk maps in GIS environment is very important to locate the areas with high erosion risks and to develop adequate erosion prevention techniques (Sazbo *et al.*, 1998, Bojie *et al.*, 1995). GIS analysis provides satisfactory results in developing erosion surveys and risk maps by using GIS data layers such as DEM, slope, aspect, and land use. The most common empirical erosion prediction models, integrating with RS and GIS, are Revised Universal Soil Loss Equation (RUSLE), The Water Erosion Prediction Project (WEPP), and COoRdination of INformation on the Environment (CORINE), which can be used for soil erosion risk assessment (Yuksel *et al.*, 2008). The most widely used model is USLE (Universal Soil Loss Equation) and RUSLE (Revised) for estimating sheet and rill erosion, in spite of its limitations. The RUSLE was developed to estimate the annual soil loss per unit area based on erosion factors including soil erodibility, topography, rainfall, and vegetation cover. In the WEPP model, sediment yield and erosion rates were estimated for multiple time periods based on specific erosion factors.

**Universal Soil Loss Equation**

The Universal Soil Loss Equation (USLE) presented by Wischmeier (1959) in the USA. The USLE can be presented as:

$$A = R * K * L * S * C * P \qquad (3)$$

Where,

A = Average annual soil loss,
R = Rainfall erosivity index,
K = Soil erodibility factor,
L = Slope length factor,
S = Slope steepness factor,
C = Cropping management factor, and
P = Conservation practice factor

This equation can be modeled in GIS environment and factors can be determined by using remote sensing and GIS.

## 6.6. Water Resources Development

(Inter linking of rivers, Land irrigability, Ground water prospecting)

### 6.6.1. Interlinking of Rivers

River basins vary with their water resource availability, utilization, adequacy and surplus-ness. Interlinking of rivers was considered to be the most effective way to resolve the regional water deficit, increase food grain production, and mitigate the drought and floods. The execution of Inter Linking of Rivers (ILR) requires a vast database on hydrology and a framework that can use the data to carry out the water budgeting for each river basin in terms of their topography, geology, hydrology and environment. Space based inputs to feasibility, detailed project, implementation strategy; monitoring and evaluation studies help in harmonizing them and lead to an optimal strategies.

Remote sensing inputs for preparation of pre-feasibility report (PFR), final report (FR) and detailed project report (DPR) in the context of Interlinking of Rivers are:

- River Surveys
- Reservoir Capacity Assessment
- Reservoir Sedimentation

- Submergence Area analysis
- Rehabilitation & Reconstruction
- Link Alignment
- Canal Network Planning
- Sites for Online New Storages
- Conveyance System
- Land irrigability assessment
- Ideal Site Selection of Dam
- Land Use/Land Cover analysis
- Cropping System Analysis
- Command Area Survey

For assessing the feasibility of proposed dam sites, maps of the terrain features, at appropriate scales are necessary. This encompasses the inventory/ assessment of land use/ land cover. Space technology plays a very important role in terrain mapping and scientific assessment of the ground conditions quickly. In case of construction of new dams, satellite data provide unique inputs on the terrain, soil characteristics, agricultural practices, natural ecosystem and habitats to determine the impact of new dams. Since the interlinking of rivers project envisages creation of new storage structures, satellite data of high spatial resolution of 2.5 m from Cartosat-1 and 5.8 m data from IRS LISS IV are very useful for assessing the feasibility of proposed sites. Several large dams built to provide the head and storage to feed the canals could submerge certain stretches of fertile lands, forests, villages and towns. Satellite data would provide wealth of information as valuable inputs for preparation of Feasibility Reports and the Detailed Project Reports (DPRs) of the proposed river links.

Studies were carried out for Krishna-Pennar link between Nagarjunasagar reservoir in Krishna basin and Somasila reservoir in Pennar basin, which is one of the components of peninsular, inter- basin water transfer. Recently, NRSC provided inputs from high resolution satellite data analysis for preparing feasibility assessment of proposed irrigation projects in Upper Betwa basin as a part of Ken-Betwa river link project. Close contour DEM generated from Cartosat-1 stereo-pair data and, land use / land cover information from LISS IV MX data provided the details of submergence and command for evaluating the proposed dam sites under the project (Figure 6.13 & 6.14).

Thematic mapping of the garland canal area and runoff computations on the given alignment was undertaken for planning diversion of west flowing Netravathi river water towards east by constructing 4900 km length of garland and service canals. The survey was carried out using total length covering 1 Km on either side of the proposed alignment. There are two reservoirs in first phase which were also surveyed. The mapping of the area is completed in 1:2500 scale.

ALTM-DC is being analyzed for generating large scale (1:2500) maps and DEM for Godavari-krishna link canal project. The generation of L-sections for entire length, cross section for every 400 m on the alignment was generated as part of planning inputs.

Based on operationally demonstrated applications of remote sensing, relevant to information needs of interlinking of Rivers, important aspects of aerospace technology based supports can be summarized as below:

- 3D Terrain modeling & finer level characterization from airborne digital photogrammetry and LASER Terrain Mapper (ALTM)
- Land and Water Resource Inventory
- Hydrological characterization
- Geomorphological characterization
- Ecological characterization
- Multi-criteria Decision Making and GIS Techniques
- Modelling Framework
- Planning of New Storage Reservoirs
- Stabilizing the existing Irrigation Systems
- Information on Command area Expansion
- Establishing Water Harvesting Structures
- Environmental Impact Assessment

- Enriches the scope and content of Pre-feasibility, Feasibility, and Detailed Project Reports, Project implementation strategy
- Facilitates monitoring during execution stage and impact assessment subsequent to implementation

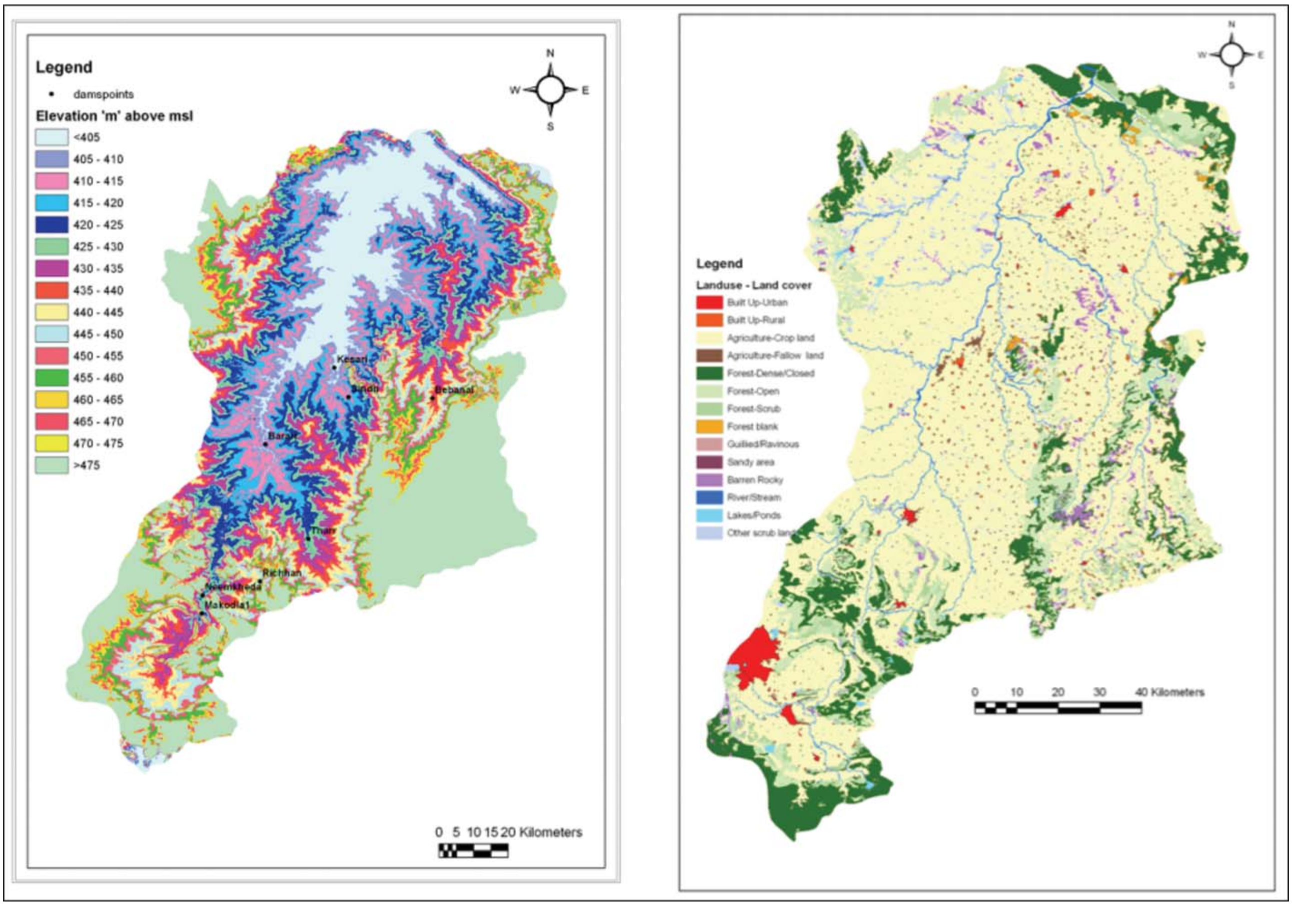


*Figure 6.13: Relief Variations and Land Use/Cover of newly proposed irrigation potential*

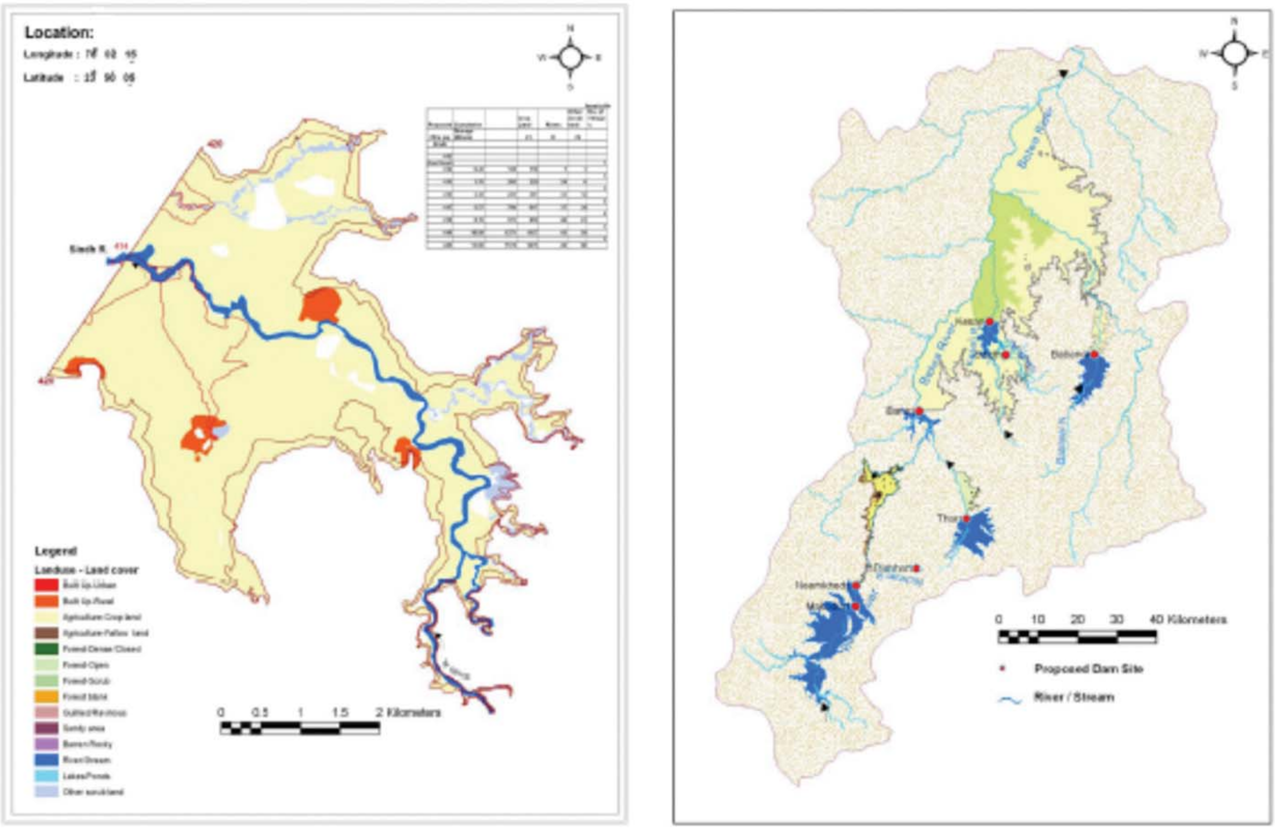


*Figure 6.14: Submergence and Command area analysis*

**Airborne Laser Terrain Mapping (ALTM)**

The 3-dimensional terrain modeling with the state-of art sensor data products from the Airborne Laser Terrain Mapper (ALTM)/ and high-resolution satellites (IKONOS/ Quick Bird/CARTOSAT-1)/ aerial photographs, is essential for precise identification of the alignment of canals and other structures. Digital elevation data derived from ALTM is effective for retrieving the close contour information towards precise canal network alignment. ALTM is a state-of-the-art tool for deriving the sub-metre level contour information of the terrain. ALTM provides accurate elevation data at cm level, and helps generating terrain maps with close (sub-metre) contours. These maps are useful in planning of the earthwork, alignment of distributaries in the commands, etc. With ALTM, digital elevation data sets can be collected at high resolution, meeting the requirements of different water resources engineering applications.

### 6.6.2. Ground Water Prospecting

Annually replenishable ground water in India is estimated to be 433 billion cubic metres (BCM) and Net Ground Water available for irrigation is 399 BCM and net draft for irrigation is 213 BCM. Ground Water constitutes 55% of irrigation water requirement and 50 % of water supplies of Urban and industrial areas and 85% of domestic use in rural areas. The above statistics reveal that the Ground water management is the key to combat the emerging problems of water scarcity in India. It being a hidden resource often developed without proper understanding. Therefore, there is a need for scientific planning of Ground water development in different hydrogeological set ups to evolve effective management practices.

Since ground water regime is dynamic system wherein, the framework in which the ground water occurs is as varied as that of rock types, as intricate as their structural deformation and geomorphic history, and as complex as that of the balance among the lithologic, structural, geomorphic and hydrologic parameters. The conventional hydrogeological maps are prepared mainly based on ground hydrogeological surveys provide geological unit-wise ground water prospects.

The Ground Water Prospects maps prepared under RGNDWM project contain information on 1:50000 scale on different rock types that occur in the area, various landforms that represents the terrain, dykes, linear ridges which form the barriers for ground water movement; weaker zones like fractures/lineaments which act as conduits for ground water movements etc. The maps also contain hydrological details like all stream courses, canals, water bodies (both seasonal & perennial), tank/canal irrigated areas and ground water irrigated areas etc. Each map contains information about nearly 80-100 wells collected during ground truth indicating type of the well, depth to water table, total depth of the well and its yield range with different symbols. By combining all the technical details referred above, the ground water prospects are evaluated for each hydrogeomorphic unit and the prospects are indicated on the map. In addition to the above, these maps show the locations of all the habitations indicating non-covered (NC) and partially-covered (PC) habitations in respect of sources of drinking water with different symbols. Tentative locations for planning different types of recharge structures are also shown nearer to NC/PC habitations to improve the sustainability of drinking water sources wherever required. These maps provide comprehensive information on ground water prospects indicating depth to water table, nature of aquifer, type of wells suitable, depth range of well suggested, expected yield range, success rate of wells, quality of water, type of recharge structures suitable and priority for recharge etc., with exhaustive legend. More than 2,00,000 wells have been drilled with a success rate ranging from 90-95 % and around 7500 recharge structures have been planned/ implemented by the line departments using Hydro-geomorphologic maps prepared using satellite data and collateral information under this Project. Till now 10 states, namely, Andhra Pradesh, Karnataka, Kerala, Madhya Pradesh, Chattishgarh, Rajasthan, Jharkhand, Himachal Pradesh, Orissa and Gujarat are covered under Phase-I & II. This project has successfully demonstrated the application of space technology for addressing the grass root level problem in the country and user departments are using these maps for last three years and achieved 90% success rate.

## 6.7. Flood/Cyclone Disaster Support

The increasing frequency of occurrence of extreme events of droughts and floods are posing great challenge to human society to absorb the consequent impacts and to get prepared to face such future events with reduced misery. Policies and practices adopted under extreme water conditions are influenced by the causes and characteristics of the extreme conditions. It is also important to consider the nature of activity affected, as the impact varies.

Remote sensing data, both historical and near-real time provide objective and authentic information both on the behavior and response of various activities to extreme water conditions. Such information is vital to create, understand and model the effects and formulate strategies to cope up with extreme water conditions. Over the last two decades it has been established as a reliable and cost-effective tool for managing extreme water conditions such as flood and drought. The timeliness of satellite data has proved to be very critical in flood management, rescue operations, damage assessment, planning the flood plains and to formulate long term strategies. In conditions of water scarcity, satellite data is useful for monitoring and assessing the drought severity and consequent impact on agricultural production. Integration of newer technologies such as Remote Sensing & GIS in conjunction with traditional knowledge would enhance the resilience of human society in coping up with extreme water availability conditions. However, building up the resilience would largely depend on the sound knowledge of the historical adaptive process that sustained overtime and remained functional.

### 6.7.1. Flood Disaster Monitoring and Management

Floods are the most common and widespread among all natural disasters in India. India is the worst flood-affected country in the world after Bangladesh and accounting one fifth of global death count due to floods. About 40 million hectares (mha) or nearly 1/8th of India's geographical area is flood-prone and the country's vast coastline of 5700 Kms is exposed to tropical cyclones originating in the Bay of Bengal and Arabian Sea. The annual average area affected by floods is about 7.57 Mha and the affected crop area is about 3.5 mha. The average loss in financial terms is about Rs13,000 millions.

One of the most important elements in Flood Management is the availability of timely information for taking decisions and actions. During floods, timely and detailed situation reports are required by the authorities to locate and identify the affected areas for organizing relief operations. To obtain the information by conventional means is virtually ruled as the areas may not be accessible. In this context, the Earth Observation satellites provide comprehensive, synoptic and multi temporal coverage of large areas in near real time and at frequent intervals which enables to compare the data before and after flood disaster. Remote sensing data coupled with Geographic Information System (GIS) tool proves to be capable of overcoming some of the critical limitations that are being faced using conventional techniques. The developments in space technology offer tremendous technological potential to address the critical information needs during all the phases of disaster management, which include mitigation and preparedness, response and recovery/relief.

During monsoon season, a constant watch is kept on the flood situation in the country and all possible satellite data will be procured over flood affected areas. The procured satellite data is analyzed for delineation of flood inundation layer. The flood inundation layer was integrated with district boundaries and district-wise flood inundation area statistics were generated. The flood inundation maps along with affected area statistics were furnished to - NDMA, Min of Home affairs, Govt. of India, New Delhi, Chairman, Central Water Commission, Govt. of India, New Delhi, Relief Commissioner of the concerned States and other Departments connected with flood management in the States & Central Government. Apart from providing flood inundation information, based on the historic flood inundation observed from the satellite data was used for generation of flood hazard zone maps for planning non-structural flood management measures. Using multi-date satellite data maps pertaining to river configuration, bank erosion and flood control works were prepared and furnished to user for planning structural flood control measures. NRSC is also contributing towards generation of National Database for Emergency Management which would help in planning suitable flood control measures, relief and rescue management and to formulate long term strategies.

The flood risk zone maps are updated with high spatial resolution data and digital elevation models based on close contour information. Flood damage vulnerability analysis requires integration of the information on satellite derive physical damage and socio-economic data. Since 1987, all major flood events of the country have been mapped in near real time and statistics on crop area affected and number of marooned villages generated. Near real time flood monitoring is being carried operationally in Brahmaputra (Assam), Kosi/Ganga (Bihar), Indus (J&K), Godavari (AP) and Mahanadi (Orissa) river basins using optical and microwave data. Studies have been carried out for delineation of flood risk zones in Bramhaputra and Kosi river basins.

### 6.7.2. Flood Forecasting

Flood forecasting and early warning to affected areas are among the most important and cost-effective measures for flood management. The Central Water Commission has set up a network of flood forecasting and warning stations on most of the inter-State rivers in the country. Currently, 157 flood forecasting stations are in operation and nearly 5500 flood forecasts are issued using gauge correlation techniques and using hydrological models in some basins every year. But many important flood prone rivers/tributaries are yet to be covered.

Traditionally, gathering and analyzing hydraulic and hydrologic data related to floodplains and river catchments has been a time-consuming effort requiring extensive field observations and calculations. With the development of remote sensing and computer analysis techniques, now traditional techniques can be supplemented with these new methods of acquiring quantitative and qualitative flood hazard information.

Since the 1930s, numerous rainfall-runoff models have been developed to estimate streamflow on daily, monthly and seasonal basis. Remote sensing outputs are widely accepted by many of the hydrological models to compute surface runoff of the watershed. Runoff cannot be directly measured by remote sensing techniques. However, satellite remote sensing data can provide lot of real time information on landuse/landcover, soil moisture, determining watershed geometry, drainage network, and other map-type information in spatial environment for estimating surface runoff more accurately using distributed hydrologic modeling approach.

Topography of the river catchment is a basic need for flood forecasting. Remote sensing can provide quantitative topographic information of suitable spatial resolution to be extremely valuable for model inputs. For example, stereo pair of the satellite remote sensing data can be used to develop a Digital Elevation Model (DEM) with better resolution. Satellite remote sensing can play a major role in rainfall runoff modeling which is a part of the flood forecasting model. Now a day's meteorological satellites are providing valuable information on the real-time rainfall which may be used as an input in the flood forecast models.

### 6.7.3. River Engineering

River migration and river control works form the major elements in the flood plain management Satellite data provides accurate delineation of river configuration and the status of flood/river control works.

Most of the flood prone rivers in India change their course frequently after every flood wave attacking strategic locations at different times. Hence, it is necessary to understand the behaviour of the river and its latest configuration so as to plan the flood control measures effectively. At the same time it is equally important to monitor the existing flood control structures from time to time to avoid breaches in view of the frequent changes in river configuration. For planning flood control works, physical model studies will be conducted for which the latest configuration of the river is required. Every year the banks of the flood prone rivers are subjected to erosion, eating away the fertile land and at times villages on the bank. In order to provide bank protection works, vulnerable areas subjected to bank erosion along the rivers have to be monitored. In this regard latest and temporal information is required. Using conventional techniques to collect the information is not cost effective and time effective. Further, flood hazard zonation maps at large scale are eventually required for planning non structural measures. Hence, the data requirement for flood disaster management is quite complex and need extensive effort to collect especially using conventional techniques. In this regard satellite remote sensing provides an excellent source of information. Remote sensing data coupled with Geographic Information System (GIS) tool proves to be capable of over coming some of the critical limitations that are being faced.

Mapping of river configuration and flood control works of river Kamla Balan in Bihar using satellite remote sensing data was carried out for the years 1991, 1996 and 2001. Mapping of bank lines of Bagmati and Lalbakeya Rivers in Bihar using satellite remote sensing data was carried out for the years 1992, 1996 and 2002. Identification and estimation of River Bank Erosion along Brahmaputra and Barak Rivers in Assam was carried out for the years 1996 and 2002.

### 6.7.4. Urban Flood Management

The primary causes of urban flooding are: 1) extensive concrete surfaces leading to significant proportions of surface runoff with very little in situ percolation 2) inadequate channelization of natural waterways 3) surcharge due to blockage of drains and street inlets. Flooding in urban regions is an inevitable problem for many cities, particularly in cities which are old and have developed according to varying historical needs and visions. The transformation of vegetated land to impermeable surface has gone hand-in-hand with the development of our urban areas over the past two millennia. This has led to a substantial decrease in the proportion of rainfall that infiltrates into the ground and a consequent increase in surface runoff, in terms of both volume and flow rate. One of the typical features of urban flooding is shortening the runoff travel time and making it flash event. Urbanization changed natural runoff pattern and accelerated transport of water, pollutants and sediment from the urban areas. Since urban settlements are undergoing continuous development, data on flow rates, physical and topographical settings require more periodic assessment and monitoring to cope up with storm water flooding. In India the problem of urban flooding is of increasing concern over the years.

Recent advancements in spatial resolutions have greatly enhanced the satellite remote sensing data capabilities in supplementing the data needs for management of urban flooding. High resolution data in the order of few meters provides the accurate layout of existing infrastructure, topographical settings, impervious surface mapping, and helps in preparation of master plans, planning storm water drainage channels. The temporal data sets also help to monitor the growth in urbanization and consequent impacts on storm water flooding. In the past, there are few studies that deal with modelling of urban flooding. With the development in the field of modeling software and availability of software packages like MOUSE, SOBEK, etc., it is feasible at present to model urban flooding with the vital inputs from remote sensing data and this raises new possibilities for managing urban flooding problems.

## 6.8. Environmental Impact Support

(Hydro-power development, Water Quality, Climate Change)

### 6.8.1. Hydro-Power Development

Power is a critical infrastructure for socio-economic development. Hydroelectricity is clean energy and its generation is not linked to issues concerning fuel supply, especially the price volatility of imported fuels. It enhances our energy security and is ideal for meeting peak demand. Industrialized countries harness over 80% of their economically-viable hydropower potential, in India the figure is quite low, despite the fact that the Indian electricity system is in desperate need of peaking power and the Himalayan hydropower sites are, from social and environmental perspectives, among the most benign in the world. Less than one fourth of the vast hydel potential of 1,50,000 MW has been tapped so far. In India, the share of hydro generation has gradually declined during the past 25 years. Consequently, thermal generation, which should generally be used for base load operation, is also being used to meet peaking requirements. As against the desirable hydro share of 40 per cent, the current share is only about 25 per cent in India.

Hydropower projects submerge vast areas of natural resources and satellite data is being extensively used for generating inputs for pre-feasibility analysis and also for carrying out environmental impact analysis. Space technology plays a very important role in terrain mapping and scientific assessment of the ground conditions with minimum time and manpower is ideally suitable for inaccessible mountainous regions where majority of these balance hydro-electric dam / diversion sites are located.

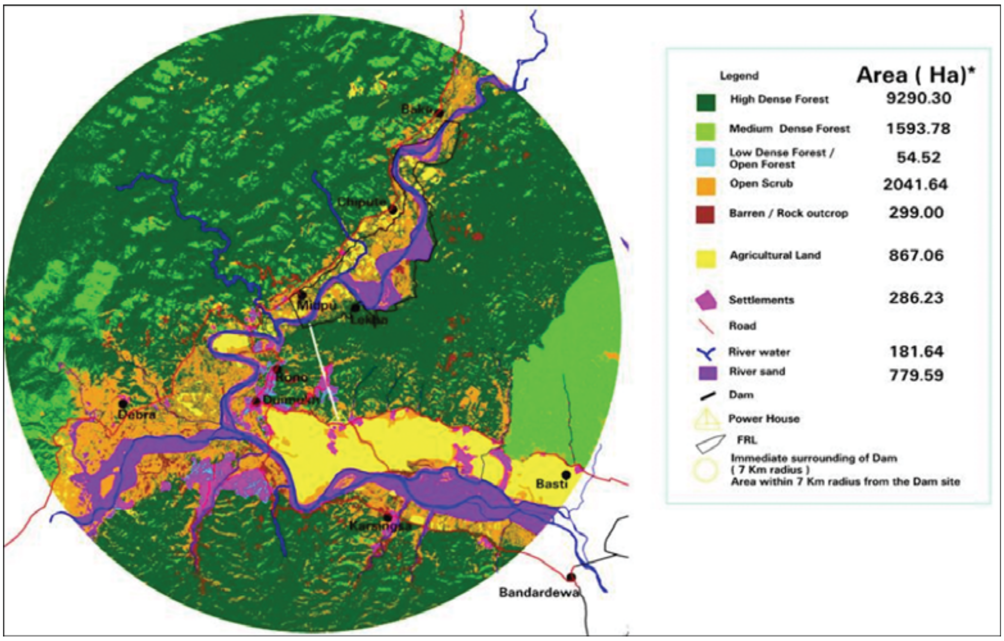


*Figure 6.15: Submergence area analysis of proposed hydro-power site*

The central electricity authority (CEA) in consultation with the States, Department of Space, Ministry of

Environment & Forests, CWC and Geological Survey of India, has initiated a basin wise ranking study of all the balance hydro sites with a view to identify those hydro projects which could be taken up first so that hydro power development is taken up in an appropriate sequence. The objective was to optimally utilize the potential of feasible hydro projects in the country over the next few decades.

The potential of this technology was demonstrated in the preliminary ranking study of the 81 proposed hydro- power sites located in Indus River Basin for the CEA executed by National Remote Sensing Centre in October 2001. Subsequently NRSC carried out the initial environmental assessment of 45 proposed (prioritized) hydro-power sites as part of preparation of pre-feasibility reports (PFRs) in different river basins of India during 2003 for NHPC and HPSEB. The high resolution satellite data (IRS 1C/1D PAN+LISS-III merged data) was used to estimate the Land use / Land cover area in the proposed dam submergence area and its immediate environs of hydro-power sites mostly located in inaccessible areas. Also, identification of the infrastructure details like roads, bridges, settlements etc., was carried out. Initial environmental assessment using submergence area statistics covering rehabilitation & relocation aspects and impact of proposed hydro-electric projects on national parks and sanctuaries using proximity analysis was carried out. Recently, NRSC carried out a similar study for the proposed Tamanthi hydro-electric project on Chindwin river in Myanmar, which is a bilateral project between Indian and Myanmar. A sample, Submergence area analysis of proposed hydro-power site is shown in figure 6.15.

### 6.8.2. Water Quality

With the rapid increase in the population of the country and the need to meet the increasing demands of irrigation, human and industrial consumption, the water resources in many parts of the country are polluted and the water quality has deteriorated. Many surface water resources are polluted due to the discharge of untreated sewage and industrial effluents. Groundwater quality problems have reached to a cause of concern throughout the country. Some of the major concerns in water pollution are due to rapid industrial revolution, over exploitation of agriculture fields with extensive usage of chemicals (i.e., pesticides and manures etc.,) and rapid growth of cities and depriving of vegetative cover over land surface in all over the world.

Water quality is a descriptor of water properties in terms of physical, chemical, thermal, and/or biological characteristics. Spectral properties of water vary with wave length not only due to molecular nature of water but also depend upon the impurities present with water body. Constituents in water influence its spectral and backscattering characteristics. Remote sensing techniques for monitoring water quality depend on the ability to measure these changes in the spectral signature backscattered from water and relate these measured changes by empirical or analytical models to water quality parameters. Major factors affecting water quality are suspended sediments, algae, chemicals, dissolved organic matter (DOM), thermal releases, aquatic vascular plants, pathogens, and oils. Some of these parameters like suspended sediments, algae, DOM, oils, aquatic vascular plants, and thermal releases directly influence the energy spectra and hence can be measured by remote sensing techniques (table 6.3). Most chemicals and pathogens do not directly affect or change the spectral or thermal properties of surface waters; they can only be inferred indirectly from measurements of other water quality parameters affected by these chemicals.

Visible and infrared (reflected) regions of EMR are useful for detecting indicators of water quality. Thermal infrared is also used for measuring water quality but it uses a direct measure of emitted energy. Microwave region is not particularly useful for determining water quality parameters but it is useful for detecting oil slicks or other surface contamination. In general, relationship between water quality parameter and the reflectance need to be established. As the reflectance changes with the modified value of water quality parameter, an empirical relationship can be established between reflectance and water quality parameter. This empirical relationship may not be valid for different times because the type of constituent in water may not remain constant. Sun elevation angle as well as composition of the atmosphere changes with time and year will also affect this relationship. Thermal infrared region 8 - 14 µm will be helpful due to its atmospheric window as well as maximum radiant emittance of most earth features in this range. Effluent dispersion patterns from industries and from other sources are easily identifiable due to varying nature of temperature differences. Point source identification calls for high resolution satellite data. Regional models of non-point source pollution loading is arrived based on remote sensing derived inputs on land use - land cover, supported by sample ground data collection. In general, remote sensing techniques can be successfully applied in all environments where there is a change in colour, temperature or turbidity of water bodies.

**Table 6.3: Remote Sensing Techniques in Water Quality Monitoring**

| S. No. | Water Pollution/ Quality parameter | Spectral Region | Remarks |
|---|---|---|---|
| 1 | Total suspended solids (TSS) | Visible spectral region of EMR | Reflectance increases with the increase in sediment concentration. Empirical relationships could be developed for TSS estimation |
| 2 | Temperature | Thermal infrared and passive microwave | Infrared radiometers (8-14 µm region) based on Aircraft/satellite can be used to estimate the temperature. The temperature variation is function of nature of pollutants and effluents |
| 3 | Agriculture runoff | B&W and colour infrared photography | Change in vegetation can be identified & monitored through colour infrared. B & W IR image also can be used to identify the sources of agriculture pollution |
| 4 | Eutrophication | Colour Infrared (CIR) | Monitoring of floating algae can be done with CIR data<br>Identification & defining of potential areas of algal blooms<br>Water transparency, colour, chlorophyll, algal blooms, aquatic vegetation of eutrophication can be monitored |
| 4 | Oil Pollution | Ultraviolet<br>Thermal infrared / Passive microwave | Good weather and low level flying is required to monitor oil pollution. Limited to day time monitoring<br>Day/night capability |
| 5 | Water depth | Blue/green regions of visible spectrum<br>Aerial /Laser profile | In clear water blue light penetrates upto 15 to 20 meters, & Green light penetrates upto 5 - 7 meters.<br>Lidar systems can be used to be measure accurate profiling of water depths |
| 6 | Municipal & Industrial discharge | Satellite/ airborne thermal infrared | Temperature difference between the effluents and the receiving waters can be identified and monitored |
| 7 | Colour/ material insolation | Laser spectrometers | May not be possible to detect through satellite techniques. However ground based laser spectrometers are used for identification of chemical composition |

## 6.9. Future Trends / Prospects

### 6.9.1. Water Resources Information system

The investments in Science & Technology, the communication facilities, the satellite technology and the computer capabilities that have increased manifold since our independence, have resulted in an explosion of the quantum of data. In a country like India adopting welfare concept in its constitution, the information that has been generated with national inputs should be used for developmental purposes for social benefits. The widely scattered large amount of information generated through various efforts have to be properly coordinated, coded and preserved using an Information system. The need of creating water data bases are imminent and we can hardly afford to delay the matter. National Resources Information System (NRIS), NR Census and (NRC) National Spatial Data Initiative (NSDI) initiatives go a long way in addressing the data related issues that emerge while preparing the road map for implementation of many water resources projects including inter linking of rivers.

The National Water Policy stipulates that the prime requisite for resource planning shall be a well developed information system consisting of scientifically designed data bases for improving both the quality of data and the data processing capabilities. Towards this, a national level water resources information System (WARIS) is being formulated and designed using geo-spatial and conventional field data. It is essentially an interactive computer based system that incorporates capabilities for efficient data input, storage and retrieval, information processing and analysis capabilities and user friendly data (acquisition, management and processing), models (development, analysis, prediction and decision guidance) and interfacing (for interactive applications). The application package 'WARIS' will be developed by ISRO and collaborating partners and will be installed at CWC, New Delhi (Figure 6.16).

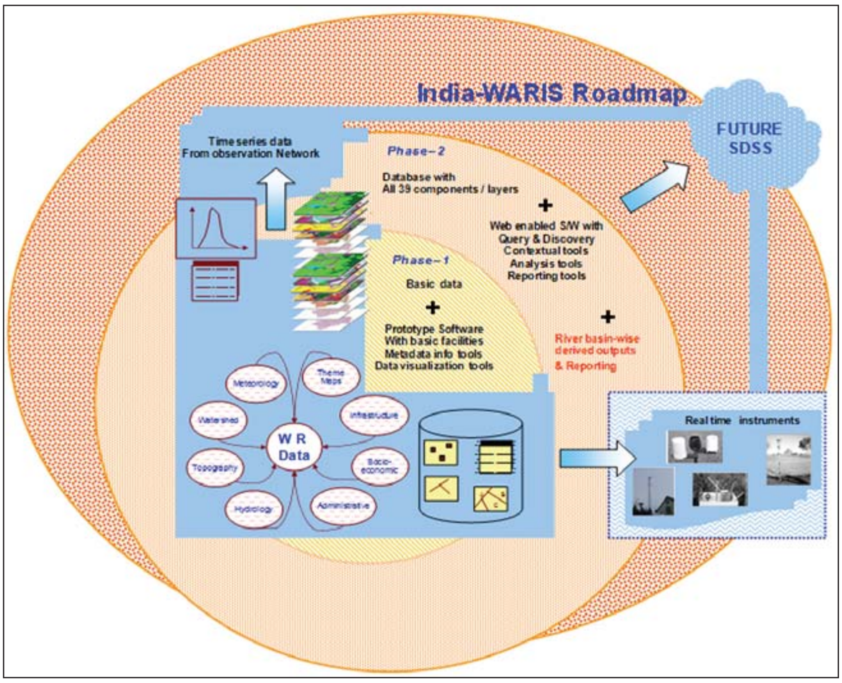


*Figure 6.16: Conceptual frame work of WARIS*

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