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ASSESSMENT OF SEDIMENTATION RATE OF RESERVOIRS USING REMOTE SENSING TECHNIQUES

(SUMMARY OF STUDIES COMPLETED DURING 2002-2007)

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PREFACE

Efficient reservoir management calls for periodic assessment of its capacity. Capacity surveys of reservoirs are important to study patterns and rate of sedimentation for defining appropriate measures for controlling sediment inflow, for managing the available storage in reservoir and for optimum reservoir operation schedule based on realistic assessment of available storage. Data from space platforms can play a significant role in reservoir capacity surveys. In the recent past, satellite remote sensing has emerged as an important tool in carrying out reservoir capacity surveys rapidly, frequently and economically. Multi temporal satellite data provide information on elevation contour areas directly in the form of water spread areas. Any reduction in the water spread area at a specified elevation over a period of time is indicative of sediment deposition at this level. When integrated over a range of water stages, it enables computing volume of storage lost due to sedimentation.

During five years 2002-2007, sedimentation rate in twenty three reservoirs have been quantified using remote sensing techniques. During these five years, studies have been carried out at NIH Head quarters and its regional centres. This summary report describes the results of assessment of sedimentation rate using remote sensing techniques for these reservoirs. The following scientists and scientific staff have carried out the sedimentation study during last five years. Dr. Sanjay K. Jain, Sc. E1; Mr. D.S. Rathore, Sc. E1; Dr. M.K. Goel, Sc. E1; Mr. Y.R.S. Rao, Sc. E1 ; Mr. V.S. Jeyakanthan, Sc.C; Mr. T.R. Nayak, Sc.C ; Dr. B.K. Purendara, Sc. C ; Mr. Ravi V. Galkate, Sc.C; Mr. Dilip Durbude, Sc. B Mr. Rahul K. Jaiswal, Sc.'B', Mrs. Anju Chaudhary, SRA ; Mr. P.K.Agarwal, P.R.A. Mr. D.Mohana Rangan, and Mr. U.V.N. Rao, S.R.A.

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CHAPTER 1

1.0 METHODS OF ASSESSMENT OF SEDIMENTATION IN RESERVOIR

The methods to assess sedimentation in a reservoir can be classified in the following groups:

(a) Inflow-Outflow method,

(b) Capacity survey method, and

(c) Remote Sensing method.

1.1 INFLOW-OUTFLOW METHOD (STREAM FLOW ANALYSIS)

In this method, the sediment inflow into the reservoir including estimated bed load and the outflow from it are measured at all significant points of entry and exit. The difference gives the quantity of sediment deposited during the period of analysis. This analysis is a continuous observation process consisting of measurement of inflows and outflows along with simultaneous measurement of sediment concentration (both bed load and suspended loads are to be measured). A reservoir may have a number of channels draining into it besides the main river and it may not be possible to gauge them all. Depending upon the area drained and sediment transport by these channels and resources available, the gauging network is finalized. The gauging stations should be sufficiently close to the reservoir periphery, keeping in view the fluctuations in reservoir water level. Outflow from the reservoir can take place through spillway, low-level outlets, and irrigation canals. Withdrawal arrangements for municipal water supply take care not to draw turbid water; the outflow of sediments on this count may be negligible. Same is the case for penstocks for hydropower generation. But at times, silt ejectors are installed in the power house intakes and sediment removal through these can be of appreciable quantity and should be accounted for. Particular care must be taken to complete outflow sampling before the outflow meets any erodible channel or a source of sediment downstream.

This method gives quantity of deposit in gravimetric terms and conversion into volumetric unit calls for the estimation of the average unit mass of the deposited sediment material. A direct method of doing this is by collecting systematic samples of the deposit in an undisturbed state from all over the reservoir bed and finding out a correlation between the average dry unit mass and the fractional composition of different grains such as clay, silt and sand.

1.2 CAPACITY SURVEY METHODS

Often called sedimentation or hydrographic survey, it is a direct measurement process to assess the volume of deposit along with its pattern in the reservoirs. Such surveys need to be carried out periodically. Other valuable information gathered in these surveys includes how the sediment deposits are distributed in the reservoir. Sediment data collected during the surveys are analyzed to determine the specific weights of the deposits, their grain size distribution, sediment accumulation rates, and trap efficiency. Note that the maximum information about the reservoir bed profile will be obtained when the reservoir water level is high.

The conventional way of conducting sedimentation surveys in the reservoir involved the use of conventional equipment, e.g. theodolite, plane table, sextant, range finders, sounding rods, echo sounders and slow moving boat etc. Recent advances in technology have considerable reduced the efforts in reservoir surveys and analysis of data.

The frequency of surveying the reservoirs depends on the sediment accumulation rate. Reservoirs that have high accumulation rates are surveyed more often than those with lower rates. The cost of running a survey also plays a critical part in deciding their frequency. Generally the reservoirs are surveyed every 3 to 10 years. Special circumstances may necessitate a change in the established schedule. For example, a reservoir might be surveyed after a major flood that has carried heavy sediment load in the reservoir. A survey may also be run following the closure of a major dam upstream in the same catchment since the reduction in the free drainage area leads to a reduction in the sediment accumulation rate of the downstream reservoir. The volume of the sediment that has accumulated in a reservoir is computed by subtracting the revised capacity from the original capacity at a reference reservoir elevation (usually the FRL). Since this is the difference of two large numbers, an error, even by a few percentages in either of the two numbers will significantly influence the results.

The advantages of reservoir surveys are:

1. The reservoir survey can be less costly than continuous sediment measurement at several locations in the catchment.
2. The accuracy of these surveys is usually very high, particularly if advanced equipment are used.
3. It is possible to estimate the total sediment load (bed and suspended load) being carried by the river.
4. The survey can be carried out at any convenient time to get the total sedimentation after the last survey.
5. The time required for a survey can be considerably shortened with the use of advanced equipment.

There are some limitations of the reservoir sedimentation survey.

a. The unit weight of sediment is required to estimate sediment yield. This weight is estimated using samples from selected locations within the reservoir. If limited samples are taken, spatial variation may not be properly estimated. Further, due to compaction, the weight changes with time and this may introduce errors in the results.
b. Such surveys do not provide any information about the variation of sediment yield with time and give only the total sediments accumulated since the last survey. This information can only be obtained by gauging.
c. This method does not provide sub-catchment wise sediment yield which can be obtained by sediment sampling of different streams.
d. This approach is not very effective where sedimentation is small, as the errors of measurement may mask the true sedimentation rates.
e. To find the total sediment inflow, sediment outflow data is also needed.

It is essential to have accurate map of the reservoir at an appropriate scale, e.g., 1:10,000 scale prior to commencement of the hydrographic survey. The important reservoir features, such as the FRL along the periphery, position of dam, outlets, location of inflowing streams etc. should be precisely marked on the map. Other topographic details, such as position of islands, permanent structures, bridges, roads, villages, etc., are also recorded. Control points should be marked prior to commencement of the survey. Horizontal and vertical control points are fixed at a suitable interval (say 5 km in horizontal and a few meters in vertical) on the circumference of the reservoir. After fixing the control points in the outer boundary of the study reach, x-sections are planned at a suitable interval depending on the reservoir size.

The contour and range methods are two basic techniques of the reservoir survey. In some situations, a combination of both is used. The selection of a method depends on the quantity and distribution of sediment indicated by field inspections, shape of the reservoir, purpose of the survey, and desired accuracy.

Sedimentation rate is computed as the difference between volume measurements from two surveys. The minimum survey interval depends on the precision of the survey technique and the rate and pattern of storage loss. For instance, if a survey technique incorporates an error on the order of 2 percent of the total reservoir volume, and if the reservoir is losing capacity at 0.25 percent per year, a 4-year survey interval may be too short to produce reliable information unless most sediment inflow is focused into a small portion of the impoundment.

(i) Contour methods

Contour surveys use more complete topographic or bathymetric information to prepare a contour map of the reservoir. They are the most accurate technique for determining volume and also provide the most complete information on sediment distribution. Recent advances in automated survey techniques now make hydrographic contour surveying very economical in smaller and midsize reservoirs, which may require only a few days of field time using automated depth measurement and positioning systems to perform the tightly spaced data-collection traverses required by contouring software.

The preferred method for performing reservoir contour surveys is using automated hydrographic surveying equipment. A typical system consists of a real-time positioning system such as the differential Global positioning system (GPS) or microwave equipment.

The general methods of contour surveys are:

(i) Grid contouring

(ii) Radial contouring

(iii) Circular contouring

(iv) Water surface mapping: and

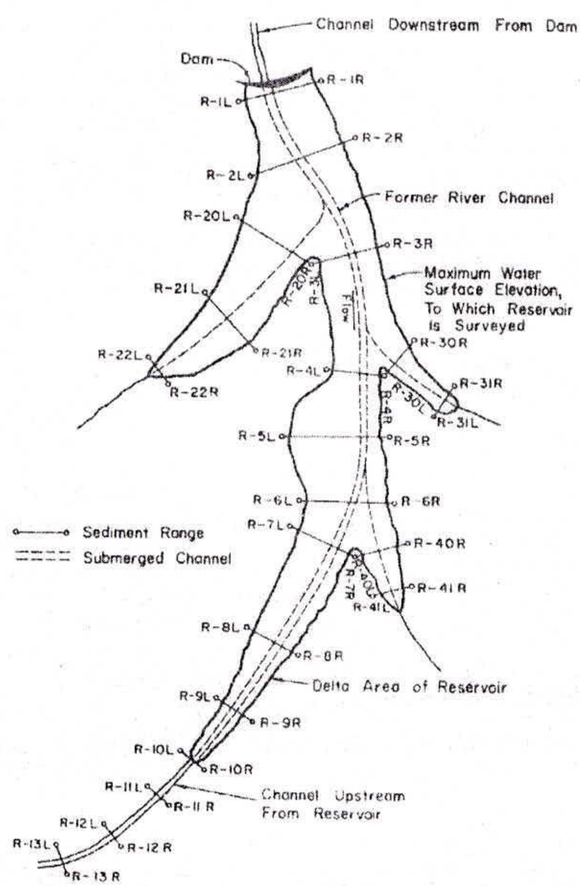
(v) Air surveys

In this method, computation of capacity of the reservoir is based on spot levels taken on grid points over the entire suitable scale and contour interval is prepared from which capacity of the reservoir at the time of survey is computed. The difference in capacity between two surveys indicates the loss of capacity due to sediment deposition during intervening period.

(ii) Range method

In Range method, a survey is conducted along selected range lines across the reservoirs and this form the basis for the computation of cubic contents between ranges. A typical pattern of range locations above the dam is shown in Figure 1. While Contour method of survey is generally applicable for all types of reservoir shapes, use of range method should be limited to relatively straight reaches. A suitable combination may often prove justified in a cost-accuracy trade-off.

Range line method of capacity survey consists of carrying out leveling or sounding along a fixed set of ranges. The objective is to develop the end areas at different cross-sections and carry out volumetric computation on their basis. The range layout must be carefully planned and the reference monuments should be connected with a triangulation network supplemented necessary.



Sounding along the range should be carried out from a raft or a boat of suitable size preferably with echo sounding equipment. The boat should be kept in alignment with the help of range targets and wireless communication providing shore contact. Correction in depth measurements should be applied on account of variation in water temperature and salinity as per the directions of manufacturers of the equipment. The recorded depth from the transducers bottom should be suitably adjusted to give depth below the mean water level of the reservoir.

Where continuous recording is not necessary a visual indicator type echo sounder may be used. The depth limitations in these equipments are about 30 m. The recording type is suitable for larger depth and continuous recording. Proper phase adjustment and recording is to be ensured. The speed of the boat must be kept low (generally below 10 km/hour) while carrying out echo sounding.

1.3 RESERVOIR SURVEYS USING HI-TECH SYSTEMS

An automatic hydrographic data acquisition system consists of mainly three parts:

(i) Positioning system: Sensing Units. This includes Transponder and Remote Depth measuring unit.

(ii) Depth measuring unit: This consists of echo-sounder and Transducer.

(iii)Computer system: including monitor, plotter, printer, disc drive, tape drive, magnetic tape recorder, precision digital electronic clock etc.

The HYDAC system (less remote sensing units) is required to be mounted on a high-speed jet boat having a speed of the order of 23 knots. The high-speed jet boat is necessary since the HYDAC equipment is capable of recording readings at every two seconds. Any compromise in the speed of the jet boat would result in under-utilization of the capacity of the system.

The digital clock provides a time reference to the water level data. The data coupler is the heart of HYDAC system. It is capable of interrogating up to 10 peripheral devices. The coupler temporarily stores the data, inserts housekeeping characters and outputs the results in specified format. The incremental magnetic tape recorder stores the raw data for in-house processing. The line printer of the system provides the hard copy of tape data.

The dynamic positioning of the survey launch is accomplished through two systems of electronic range measuring equipment. Each system consists of a remote unit on shore, a tracking antenna and antenna control, a master unit, and a data line driver on board the survey vessel. The accuracy of the system under dynamic conditions is 1.5 m for a maximum range up to 80 km. The system also has integral duplex radio voice communication, which ensures continuous contact with shore station.

The system uses ultrasonic waves for depth measurement. Short sound pulse in omitted by a transducer in the form of abeam vertically towards the bottom. Part of sound energy 1s reflected from the bed and returns as an echo to the same transducer, which operates both as transmitter and receiver. This eliminates the possibility of angular errors in shallow depths. Depth is computed from the time recorded between omission of pulse and return of its echo. With the help of graphic recorded, a continuous curve presenting a true picture of the bottom is obtained. The range of the system is up to 1500 m and 250 m and its accuracy is ± 5 cm.

1.4 REMOTE SENSING METHOD

The conventional techniques of sedimentation quantification in a reservoir, like the hydrographic surveys and inflow-outflow methods, are cumbersome, costly and time consuming. Further, prediction of sediment deposition profiles using empirical and numerical methods requires large amount of data which are rarely available.

The basic principle of this method is as follows. Due to deposition of sediments, the reservoir water spread area at various elevations goes on reducing. Most reservoirs have annual drawdown and refill cycles. A series of imageries covering a wide range of reservoir water levels are obtained. These imageries are analysed to determine the water spread area of the reservoir at the time of satellite overpass.

The actual water surface elevation in the reservoir at the time of satellite pass can be obtained from the dam authorities. The reservoir capacity between two levels can be computed by the trapezoidal or primordial formula and the elevation-capacity table can be prepared. A comparison of this table with a previous table yields the capacity lost during the intervening period.

Remote sensing approach has the following advantages:

- Satellite data through its spatial, spectral, and temporal attributes, can provide synoptic, repetitive and timely information regarding the revised water spread area in a reservoir.
- By using the digital analysis techniques and GIS in conjunction, the sediment deposition pattern in a reservoir can be determined.
- Remote sensing approach is highly cost effective, easy to use and requires little time for analysis as compared to conventional methods.
- Sedimentation can be easily assessed in reservoirs that are located in areas

that are difficult to access.

There are some limitations of the remote sensing approach:

- The amount of sediments deposited below the lowest observed water level cannot be determined through remote sensing. Thus, it is not possible to estimate the actual sedimentation rate in the whole reservoir.
- Presence of clouds poses a problem in correctly demarcating the reservoir water spread area and hence sedimentation.
- This technique is not suitable for reservoirs that are located in narrow valleys with steep slopes.

1.4.1 Steps of Analysis

The steps of analysis are described below.

a) Selection of Period of Analysis

In general, sedimentation assessment must be made for major reservoirs after a gap of 5 to 10 years. If the analysis is to be carried out for a specified period then the corresponding data has to be used. Otherwise, it is best to use the data of such a period when there is large variation in reservoir water level. If the historical records of maximum and minimum water level in each year are available, the water year of maximum variation can be selected for sedimentation analysis. A wet year followed by a dry year is the best period for such study. The remote sensing data series of the same water year or continuous water years must be selected in sequence to the extent possible. The availability of the satellite data and its cost are additional factors, which govern the selection of period of analysis.

b) Selection of Suitable Satellite and Sensor

Multi-spectral data are required for identification of water pixels and to differentiate the water pixels from the peripheral wetland pixels. A number of satellites are acquiring remote sensing data and the most common among them are listed below along with their sensors and spatial resolution:

a) IRS - 1A/ IRS - 1B [LISS-I (72.5 m) & LISS-II (36.25 m)],

b) IRS - 1C /1D [PAN (5.8 m) & LISS-III (23.5 m)],

c) LANDSAT [MSS (80 m) & TM (30 m)],

d) IRS-P6 (RESOURCESAT-1),

e) IRS-P5 (CARTOSAT-1), and

f) SPOT satellite.

Multi-spectral information is required for the identification of water pixels and for differentiating the water pixels from the peripheral wet land pixels. It is also desirable to use the data of higher resolution for obtaining accurate results. However, the use of PAN sensor data is not usable because it lacks spectral information. IRS-1C satellite was launched in the year 1995 and IRS-1D was launched in 1997. Thereafter, India has launched IRS-P6 and IRS-P5, in which P5 is having even higher resolution of 2.5 m. At present, the remote sensing data of IRS satellites is the best selection in India from the cost and resolution considerations.

It is necessary to ascertain that good quality cloud free satellite data are available. It is also desirable to use high-resolution data for better results. The data of a number of satellites are available these days and a choice is usually made based on the frequency of satellite pass, spatial resolution, and cost considerations. These days, satellite data are mostly supplied on CD-ROM and Internet is being increasingly used for this purpose.

c) Identification of Water Pixels

The basic output from the analysis of remote sensing data is the water spread area of the reservoir. The two techniques of remote sensing interpretation, viz., visual and digital, can be used for water spread delineation. Visual techniques are based purely on the interpretive capability of the analyst and it is not possible to use the information of different bands after the visual product is generated. Around the periphery of the water spread area wetland appears very similar to water pixels and it becomes very difficult for the eye to decide whether a pixel near the periphery is to be classified as water or land. Moreover, in case of clouds or noise in the scene around the periphery, it is not visually possible to distinguish the water pixels. Visual interpretation is rarely used these days.

Using digital techniques, the information of different bands can be utilised to the maximum extent and consistent analysis can be carried out. The information about the features hidden by the clouds can be indirectly obtained using the series of interpreted imageries. The noise in the imagery can be removed using special algorithms. It is also easy to calculate the water spread area. For these reasons, digital techniques are superior and are gaining recognition now-a-days.

In the visible region of the spectrum (0.4 - 0.7 μm), the transmittance of water is significant and the absorptions and reflectance are low. The absorptions of water rises rapidly in the near-infrared region (NIR) (0.77-0.86 μm) where both the reflectance and transmittance are low. Due to transmittance of visible radiation through water, if water depth is shallow, the radiation is reflected by the bottom of the water body, transmitted through water and detected by the sensor. In such situations, it may not be clear from the visible bands whether there is a thin water layer above ground surface. To resolve this, the image in the NIR band must be inspected. In the NIR band, water apparently acts as a black body absorber and the boundary between the water and other surface features is quite prominent.

The reflectance from the wetland along the reservoir periphery may be quite similar to the reflectance from the adjacent shallow water. The reservoir water may be muddy. A pixel at the soil-water interface may represent mixed conditions (some part water and other part soil). To differentiate water pixels from the adjacent wetland pixels, comparative analysis of the digital numbers in different bands is carried out. The behaviour of the reflectance curves of water and soil is different from the blue band (0.53-0.59 μm) onwards. Beyond the blue band, with increase in wavelength, water reflectance curves show downward trend while soil curves show an upward trend. This characteristic can be used to differentiate the water pixels from the peripheral wetland pixels. The variation of soil reflectance with moisture content and the reflectance of water in different conditions is shown in Figs. 1.1 and 1.2 respectively.

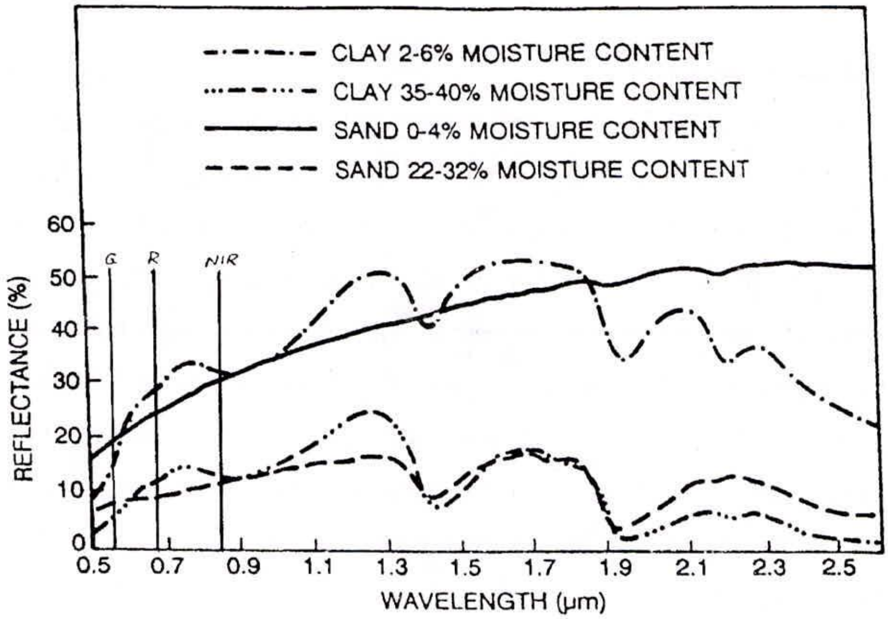


Figure-1.1: Spectral reflectance curves for soils

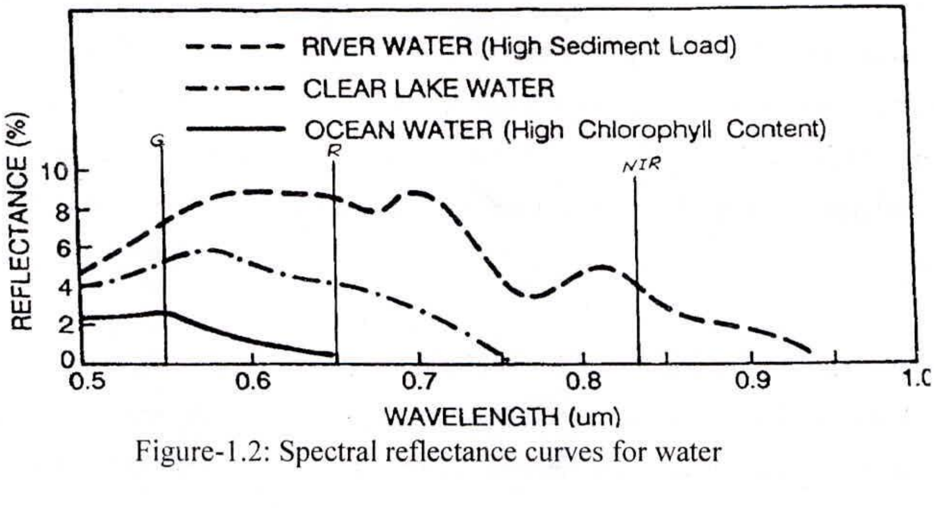


Figure-1.2: Spectral reflectance curves for water

d) Analysis of Imageries

Many commercial software are available for digital image processing. The imagery needs to be imported in the software system before analysis can commence. While using the temporal satellite data of the same area, it is necessary to geo-reference the imageries acquired at different times. Geo-referenced imageries can be overlaid and changes in the water spread area can be detected. Geo-referencing also helps to manipulate the information below the clouds and under the noise pixels. An imagery which is sharp, clear, and cloud- and noise-free is chosen as the base (master). The imageries of other dates are considered slaves and geo-referenced with the master. Although the reservoir area may be covered in a small part of the scene, the full scene should be utilised for geo-referencing to improve accuracy. Clearly identifiable features, such as crossing of rivers, roads or lineaments, sharp turns in the rivers, bridges, the rock outcrops, are selected as control points. At least 10 control points should be selected. The geo-referencing statistics is examined and the points which have generated large errors are edited/deleted/replaced to obtain satisfactory results. Typically, the final error should be less than the size of a pixel.

Depending on the areal extent and spatial resolution, the file size of each scene may be very large. Since the area of interest is only the reservoir area, the reservoir water spread area and its surrounding can be extracted from the full scene before proceeding with analysis. This will result in less consumption of disk space, easy handling of files, and reduction in the analysis time. This will also reduce the efforts for display and editing files. Most image analysis packages contain utilities for this purpose.

e) Accounting for Cloud Effect, Noise and Tails

If the imagery has clouds, their shadows might fall over the reservoir area and its periphery. It is necessary to determine whether the pixels occupied by clouds and shadows correspond to water or not. If clouds and shadows are present over the reservoir area or around the periphery in an imagery taken during the draw-down cycle, the imagery for the next cloud-free date is examined. If the area covered by the cloud in a particular imagery has water at the same location on the next date's imagery, the pixels below the cloud are classified as water pixels. The reason is that the reservoir water surface area decreases with time during the draw-down cycle and so the pixels having water on a given date will necessarily have water on the previous date.

Some pixels may be affected by noise in the data and are edited in a similar way using the imagery of previous or subsequent date. Due to the presence of local depressions around the reservoir periphery, a few water pixels might be present near the reservoir area. Such pixels that do not form part of the continuous water spread should be removed. Many streams join the reservoir from different directions around the periphery. Beyond a certain point, these do not form a part of the reservoir. The imagery is edited to suitably remove such tails.

f) Demarcation of Waterspread Area

Many techniques are available to demarcate water pixels. Density slicing of the NIR band is one such method. Although most of the water pixels can be separated out by density slicing, it may fail under certain conditions. The sliced pixels may include some saturated soil pixels also since the reflectance value of the saturated soil is very low in the NIR band. Supervised classification is another approach. Although clearly distinguishable water pixels could be easily separated out by this technique, sometimes it is difficult to provide accurate training sets for peripheral pixels. Depending on the area covered by the water or soil in a mixed pixel, classification of some pixels as pure water and some as pure soil can mutually counterbalance the effect of misclassification to some extent. Nevertheless, the objective should be to do as correct as possible. Another approach is to apply a model that uses multi-spectral data and tests multiple conditions to ascertain whether a pixel represents water or not. Most modern packages have a provision to write algorithms to differentiate water pixels by processing the data of multiple bands.

After the water spread area is separated out, the resulting imagery can be compared with the NIR imagery and the standard FCC. Note that the estimation of sedimentation by remote sensing is highly sensitive to determination of the water spread area. The data of high-resolution sensors helps to reduce the error in remote sensing analysis.

g) Calculation of Revised Capacity

After finalizing the water spread areas of all the images, the histograms are analyzed and the water pixels in each image are recorded. Revised water spread area at any elevation is obtained by multiplying the number of water pixels by the size of one pixel. The reservoir elevation at the time of satellite pass is obtained from the reservoir authorities. The reservoir capacity between two consecutive reservoir elevations (ΔV) is computed using the prismoidal formula:

$$\Delta V = \Delta H\,(A_1 + A_2 + \sqrt{A_1 * A_2})\,/3 \qquad (1)$$

where ΔV is the volume between two consecutive elevations 1 and 2; A_1 is the contour area at elevation 1; A_2 is the contour area at elevation 2 and ΔH is difference between elevation 1 and 2. The revised volume can be compared with the original volume in each zone (obtained from the original elevation-capacity table) and the difference between the two represents the capacity loss due to sedimentation. The contours can also be used to prepare the DEM of the area. The DEM of two different dates can be compared to determine the depth of sediment deposition at various points.

CHAPTER 2

2.0 CASE STUDIES

During the period of five years (2002-2007), sedimentation rate assessment of 23 reservoirs using remote sensing method was completed at NIH. This report presents a summary and analysis of the results of the various studies. Before discussing the results, a brief description of the reservoirs is given.

2.1 GHATPRABHA RESERVOIR

The Ghatprabha River with its main tributaries viz., the Hiranyakeshi, the Taamraparani, and the Markandeya, is one of the principal rivers of the Northern part of the Karnataka State. It is one of the major inter-state tributaries of the Krishna River. The total catchment area of Ghataprabha and its tributaries is 8829 sq. km (3.41 percent of the area of the Krishna basin).

Remote sensing data of IRS-1D satellite and LISS-III sensor was acquired for the year 2000-2001 and the estimated water spread area was extracted. The original elevation-area-capacity curve and the reservoir levels on these years for the dates of pass of satellite were obtained from CWC. Using the trapezoidal formula, the estimated capacity in between the maximum and minimum observed levels was obtained. For the year 2000-2001, the estimated capacity (1114.3 M m^3) was subtracted from the original capacity (1230.22 M m^3) and the loss in capacity (115.90 M m^3) was attributed to the sediment deposition in the zone of study (660.99 m to 629.26 m) of the reservoir. Thus, the average rate of loss of capacity in this zone came out to be 4.45 M m^3 per year.

The hydrographic survey of the reservoir was carried out in the year 2000. As per the results of this survey, annual sedimentation rate for the period 1974-2000 comes out to be 4.443 M m^3 which is comparable with the above rates. CWC (2002), using satellite imagery estimated the sedimentation rate as 5.662 M m^3 and 4.631 M m^3 for the period 1974-90 and 1974-97 respectively. However, it should be noted that in our case the sedimentation rate is only for live zone and the rate given in CWC report is for the total storage.

2.2 GANDHISAGAR RESERVOIR

The Gandhisagar reservoir, one of the first major reservoirs of the State of Madhya Pradesh (M.P.), is the uppermost dam in a series of three dams (Gandhisagar, Rana Pratap Sagar, and Jawahar Sagar) and a barrage (Kota barrage) of Chambal Valley Project. The dam was a joint venture of the States of M.P. and Rajasthan and was completed in the year 1960. It is the main storage dam constructed across river Chambal, intercepting a catchment area of about 23025 km^2. The dam serves as a backup storage for power generation in the three dams and irrigation through canal systems taking off from Kota Barrage.

The analysis with hydrographic survey (2001) shows that the revised capacity at highest observed elevation (398.58 m) comes out to be 6377.798 MCM and the available capacity in the zone of analysis (398.58 m to 380.57 m) comes out to be 5875.778 MCM using remote sensing method. The difference between the results of hydrographic survey (HS) and remote sensing analysis in terms of the available capacity in the zone of study comes out to be 94.943 MCM which is about 1.61% of the available capacity in this zone.

The original capacity in the zone of study was 6117.789 MCM and the revised capacity as per remote sensing analysis is 5970.7216 MCM. So, 147.0674 MCM of sediments have been deposited in the zone in the span of 41 years. This gives the rate of sedimentation as 1.5579 ham/100 sq. km/year in the zone of study. It is observed that though the capacity estimation in whole of the study zone of reservoir by the two techniques is quite close, yet remote sensing method estimates lesser available capacity in the lower portion of the reservoir (below elevation 394 m) and greater available capacity in the upper portion of the reservoir (above 394 m).

2.3 VAIGAI RESERVOIR

The Vaigai reservoir lies in the middle of the Vaigai River basin, which is one of the seventeen river basins of Tamil Nadu. As per the hydrographic survey the revised capacity of the reservoir at elevation 279.026 m is 163.32 MCM whereas using remote sensing analysis it comes out to be 152.78 MCM.

To know why there is a difference between the HS and RS survey, an analysis on the prior five hydrographic surveys (1958-2000) has been worked out. Until 2000 hydrographic survey the average rate of loss of capacity of the reservoir/year is around 0.94 Mm^3 result obtained by remote sensing methodology, i.e. 1.00 Mm^3 is in agreement with this, whereas the hydrographic survey-2000's result 0.75 Mm^3 is far less than the average value. This shows that the results arrived through remote sensing data are more reliable than the hydrographic survey results.

2.4 TANDULA RESERVOIR

Tandula dam is situated in Durg district of Chhattisgarh state. The Tandula reservoir is constructed at the confluence of rivers Tandula and Sukha. Also, some small streams join directly to the main body of the reservoir forming very small tails in the perimeter of the reservoir at FRL. Tandula and Sukha Rivers carry most of the sediment into the reservoir. The satellite data used for this study belongs to IRS 1C/1D, LISS-3 sensors, which has high spatial resolution of about 24 m pixel size. The water spread area at FRL (332.18 m) is covered by 73133 pixels having periphery of 60.106 km and at elevation of 320.96 m it is covered by 10686 pixels having 31.5 km. Numbers of pixels along the periphery at FRL and elevation 320.96 m is 2504 and 1312 respectively.

From the analysis of remotely sensed data, it has been found that the live storage of Tandula reservoir has reduced by 2031.085 ha-m in the 80 years (1922-2002). More loss in the live storage has been found in the zone between 320.96 m to 324.07 m, it may be due to accumulation of sediments in the lower zone. Annual rate of silting is estimated to be 28.056 ha-m /year since impoundment of reservoir in 1922. This comes out to be about 0.1 % reduction in live storage capacity every year.

2.5 LINGANAMAKKI RESERVOIR

The Karnataka Power Corporation Limited has constructed a composite dam across the river in 1964 near Linganamakki, which is at present one of the oldest Hydro electric power projects in India. The dam is located at about 14°41'24" N latitude and 74°50'54" E longitude with an altitude of 512 m. The total capacity of the reservoir is 4417.51 M. cum. It has a catchment area of nearly 1991.71 km^2. The water from Linganamakki dam flows to Talakalale balancing reservoir through a trapezoidal canal with a discharge capacity of 175.56 cumecs. The length of this channel is about 4318.40 m with a submersion of 7.77 km^2. It has a catchment area of about 46.60 km^2 and the gross capacity of the reservoir is 129.60 cu m. The salient features of Linganamakki Dam are given in Appendix II.

The original elevation-capacity and the reservoir levels on all dates of satellite pass were obtained from KPCL. Using the prismoidal formula, the revised capacities in-between the maximum (548.78m) and minimum (532.20m) levels were obtained. The revised capacities in the zone of reservoir levels (533.05m to 548.78m) for the year 1989-1990 is found as 2837.84 M. cum and for the year 2001-20002, it is found to be equal to 2207.95 M cum in the zone of 532.20m to 545.91m of reservoir levels, while the original capacities for the year 1989-1990 was 2896.75 M. cum and 2283.25 M. cum for the year 2001-2002 as reported during the survey in the year 1957. Based on these results, the sedimentation rates in the zone (533.05m to 548.78m) come out to be 8.96 ha-m/100 km^2/year and for the zone (532.20m to 545.91m) is 8.57 ha-m/100 km^2/year. The total sediment deposition in the zone (533.05m to 548.78m) during the period 1957 to 1989 comes out to be 58.91 M. cum, while during the period 1957 to 2001, it is 74.94 M cum. The sediment deposit during the year 1989-2001 is found to be 16.03 M cum. As per results obtained through the sediment assessment during the period 1957 to 1989 and 1957 to 2001, it is found that the results are comparable and the uniform sediment rate of 8.57 ha-m/100 km^2/year can be considered for the present study. No hydrographic survey has yet been carried out for this reservoir. Under these circumstances, the results obtained in this study can be serve as a guide to the operating authorities for considering the actual available capacity in planning the operation of this reservoir.

2.6 RAMGANGA RESERVOIR

Ramganga reservoir had been created in 1974-75 by constructing a 125 m high and 595 m long dam across Ramganga River. Ramganga dam is located in Uttarakhand state. The main tributaries of the Ramganga River at dam site are Mandalti and Sona rivers. The catchment area of Ramganga River and its tributaries up to the dam site is 3134 km^2. The reservoir has a spread area of 78.31 km^2 at full reservoir level of elevation 365.3 m. The dam was fully filled for the first time in 1975.

The Ramganga River transports a lot of silt, which is detrimental to the life of reservoir. The silt contribution is largely due to unprecedented deforestation, over-grazing in the pasturelands, unscientific agricultural practices, indifferent contour terrace farming, absence of effective afforestation programs and other development activities undertaken in the catchment area, including mining activities, road construction etc.

Sedimentation assessment for the Ramganga session was carried out for the year 2000-01. In the year 2000, maximum level at 364.4 m was observed on 28th September 2000. The reservoir level gradually fell to the minimum level of 339.05 m on 2nd May 2001.

In the present study, the analysis has been carried out for the year 2000-01. The results show that the volume of sediment deposition during 1988 to 2000-2001 (12 years) between the maximum and minimum observed levels (364.4 m and 339.05 m) is 50.8 Mm^3. If the uniform rate of sedimentation is assumed, then for the year 2000-2001, the sedimentation rate in the zone (364.4 m and 339.05 m) is 4.23 M m^3 per year.

As per the IRI report, the results are as follows.

Capacity of reservoir in Mm^3				Sedimentation Rate (Mm^3/year)			
1974	1988	1997	2000	1974-1997	1988-1997	1988-2000	1974 - 200
2590.72	2508.01	2480.25	2463.64	4.80	3.08	3.70	4.23

The dead storage of the reservoir was 210.11 Mm^3 and the live storage was 2270.14 Mm^3 the year 1997. At the gross sedimentation rate of 4.23 Mm^3/year, it will take approximately 500 years for this live storage to completely fill up if the sedimentation continues at the current rate.

2.7 RIHAND RESERVOIR

Rihand Dam was constructed on Rihand River in Distt. Sonbhadra of Uttar Pradesh in the year 1962. The objective of the project was to provide water mainly for generation of hydro-power necessary for speedy development of agriculture and industry in the backward areas of Eastern and South- Eastern parts of the State of Uttar Pradesh. Rihand River is a tributary of the Sone River. The river and its tributaries arise in the hills in Madhya Pradesh and flow in the northern direction through this state and also through the district of Sonbhadra in Uttar Pradesh.

The reservoir can attain a maximum level of 271.52 m during the passage of PMF of 13,339 cumec. The reservoir has a designed dead storage of 1628.38 Mm^3 below R.L. 236.22 m and a live storage of 8979.94 Mm^3 between R.L. 236.22 m and the FRL. Its water spread is 469.45 sq. km at FRL. The water spread area lies in both Uttar Pradesh (347 sq. km) and Madhya Pradesh (122 sq. km).

Based on the availability of satellite data and the water level variation in the Rihand reservoir during the period 1999-2001, the study was carried out for the zone of the reservoir lying in-between the elevations 258.78 m and 267.31 m. The available capacity in the reservoir in-between 258.78 m and 267.31 m comes out to be 2585.223 Mm^3. This capacity excludes the capacity of ash dykes and water pools created around the reservoir for various thermal power plants.

In comparison to the results of original survey or the hydrographic survey, the estimates of waterspread areas at different elevations by the remote sensing technique comes out to be very less. Probably, the most important reason for the same is the consideration of waterspread areas of the surrounding ash dykes and water pools. In the present analysis, these have not been taken into account because of the fact that, though constructed within the water spread of the reservoir, their capacities no longer contribute to the capacity of the reservoir. Further there may not be much deposition of silt in these ponds. As a consequence, the capacity of the reservoir in the zone of study comes out to be 3011.507 Mm^3 by the hydrographic survey method while the same from the original survey is estimated to be 3466.1 Mm^3.

Since the details of hydrographic survey concerning the consideration of capacity of surrounding water pools is not known, the sediment deposition in the zone of study can not be estimated. Similarly, the original survey included the capacities of surrounding water pools. Hence, it is not advisable to compare the results of remote sensing with the original survey.

2.8 TUNGABHADRA RESERVOIR

The Karnataka State Irrigation Department has constructed a composite dam across the Tungabhadra River near Mallapur village in Hospet Taluka of Bellary District of Karnataka State. Located at about 15^0 15' 0'' N latitude and 76^0 21' 0" E longitude, the dam is about 69.25 km from Bellary city. The Tungabhadra dam was completed in 1953 and its catchment area is 28,180 sq. km. The total length of the dam is 2.4 km. The water-spread area of the reservoir is 378 km^2 having maximum width of 15.30 km near dam and a fetch of 85.34 km. The storage capacity of the reservoir is 3751 MCM.

The results show that the revised capacity in the zone under consideration (up to 494.79m) is 1915.97 MCM, while the original capacity was 2256.85 MCM. Thus, it can be inferred that the volume of sediment deposition in the zone under study for the period 1981 to 2002 is (2259.83 MCM – 1915.97 MCM) 343.86 MCM. If a uniform rate of sedimentation is assumed in 21 years up to 2002, then the reservoir sedimentation rate is 5.81 ha-m/100 km^2/year. The estimated rate of sedimentation is found higher than the design rate of sedimentation (4.29 ha-m/100 km^2/year). It calls for urgent precautionary and remedial measures to prevent the further siltation of reservoir.

2.9 BARNA RESERVOIR

Barna dam has been constructed on a tributary with the same name in the Narmada basin. The main dam is a 432 meters long masonry structure with maximum height of 48 meters above foundation. The spillway is 115 meters long with crest 35 meters above foundation level. Over the crest, there are eight radial gates. The lake formed behind the dam has a live storage of 45,560 ha-m with submergence area of 7,700 ha.

The loss in the live storage capacity (455.8 MCM) of Barna reservoir has been estimated to be 79.766 MCM i.e., 17.5 % of the live storage. Further, by extrapolating the revised elevation-capacity curve, silting in the dead storage capacity (83.200 MCM) comes out to be 25.311 MCM. Hence total loss in the gross storage capacity (539.000 MCM) has been estimated to be 105.077 MCM in last 27 years.

Based on the analysis, it has been observed that 105.077 MCM of gross storage capacity has been lost due to sedimentation in a period of 27 years (1975 – 2002). If we assume a constant rate of sedimentation over the period of 27 years, it comes out to be 3.891 MCM/year or 389.1 ha-m. The catchment area of Barna reservoir being 1176 sq. km, the silting rate in more common unit is computed to be 33.09 ha-m/100 sq. km/year.

2.10 SOMASILA RESERVOIR

Somasila reservoir is located on the river Pennar that flows through the Nellore district in Andhra Pradesh. The reservoir is at a distance of about 80 km from the Nellore town, which is also the district capital. Location of the dam site is 79^0 18' 25" E and 14^0 29' 15" N and it is covered in the SOI toposheet No. 57N/7. The designed FRL of the reservoir is 94.488 m and the storage capacity of this level is 2208.71 mcm respectively. Riverbed level is at 67.056 m. MDDL & dead storage of the reservoir is 82.296 m and the dead storage capacity is 214.27 mcm.

To calculate the prevailing water spread area of 2002, seven different elevations have been selected which vary from 82.3 m (MDDL) to 94.488 m. The dam has been constructed up to the designed FRL 100.584 m but the maximum reservoir level is being kept at 94.488 m due to non-completion of land acquisition in the foreshore submersible area).

The revised capacity of the reservoir at the lowest observed level (83.17 m) was estimated at 255.35 MCM. The difference between the original (1975) and revised cumulative capacity (2002) represents the loss of capacity due to sedimentation. The results show that the volume of sediment deposition is 23.96 MCM (1158.12 – 1134.16) for the period 1987 to 2002. If a uniform rate of sedimentation is assumed in 15 years of occurrence of the reservoir then the sedimentation rate is 1.597 MCM per year.

It is to be noted that the Somasila project was initiated during 1975. The gauge was erected during 1987. Prior to this for few years water was stored up to spillway crest level (86.868 m). Hence the deposition of sedimentation was considered from the year 1987 onwards.

2.11 MATATILA RESERVOIR

Matatila Dam was constructed in the year 1956 across river Betwa that is tributary of the Yamuna River. The dam lies at 25^O 6'15" North Latitude and 78^O 23'00" East Longitude. It is located at Matatila in District and Tehsil Lalitpur of U.P., which is 56 km from Jhansi. It is situated 4.8 km southwest of Basai railway station on the left bank of Betwa River, and 11.25-km northwest of Talbehat railway station on the Right Bank. It has designed dead storage of 113.30 MCM below RL 295.66m and a live storage of 1019.40 MCM between RL 295.66m and FRL of 308.46m. The total capacity of the reservoir is thus 1132.70 MCM at FRL 308.46m with water spread area of 142.43 sq. km. It provides facilities for irrigation, power generation, water supply and fish cultivation. The dam was completed in 1956 with the spillway up to the crest level at RL 301.45m. The spillway gates were erected later and the reservoir could be filled up to the FRL for the first time in 1964.

The results show that the volume of sediment deposition during 1962 to 2001-2002 (39 years) in-between the maximum and minimum observed levels (308.46 m and 298.60 m) is $292.63*10^6$ m^3. If the uniform rate of sedimentation is assumed, then as per the 2001-2002 analysis, the sedimentation rate in the zone (308.46 m and 298.60 m) is $7.51*10^6$ m^3 per year. Besides the hydrographic surveys of this reservoir out by Irrigation Research Institute (IRI) Roorkee, a study using remote sensing in the year 1998-99 was carried out by CWC, New Delhi. As per the hydrographic survey between 1962 to 1990, sediment deposition during 28 years comes out to be 236.99, which gives sedimentation rate of $8.46*10^6$ m^3 per year. As per CWC study in the year 1998-99, the sediment deposition between 1962 to 1998-99 (36 years) comes out to be 283.38 $*10^6$ m^3, which gives sedimentation rate of $7.87*10^6$ m^3 per year. These results are presented in Table 2.1.

Table 2.1: Silting rate in Matatila reservoir

Year of impoundment	1962
FRL (m)	308.46
MDDL (m)	295.66
Gross capacity in 1962 (Mm^3), (308.46-298.60 m)	985.71
Gross capacity in 1998-99 (CWC) (Mm^3), (308.46-298.60 m)	702.33
Gross capacity in 2001-02 (NIH) (Mm^3), (308.46-298.60 m)	693.09
Silting rate (CWC) (ha-m/ 100 km^2/year)	3.69
Silting rate (NIH) (ha-m/100 km^2/year)	3.56

Thus the results of hydrographic survey and remote sensing techniques are in close agreement.

2.12 HIRAKUD RESERVOIR

The Hirakud dam is built across Mahanadi River 15 km away from Sambhalpur town. The reservoir is located in Jharsuguda, Bargarh and Sambhalpur district of Orissa in India. The reservoir is situated between latitudes 21° 28′ and 21° 50′ N and longitudes 83° 16′ and 84° 04′ E. Dam has composite structure of earth, concrete and masonry. The main dam is 4.8 km in spans and is located between Lamdungri and Chandili Dunguri. The earthen dykes are 21 km in length. The reservoir water spread area at full reservoir level (FRL) is 743 sq. km. The catchment is 83400 sq. km. The reservoir volume is 5818 MCM (utilizable) and 8136 MCM (gross).

The elevation- area- capacity table of present and past surveys reveals following details:

- The elevation- area table using remotely sensed data prepared presently and that in past are comparable, where as the table prepared using hydrographic table and remotely sensed data have large differences. Thus, the results obtained from remotely sensed data can only be compared to those from other such surveys for the present reservoir.
- Two remote sensing data based surveys do not compare well for lower elevations. The reason for this could be lowest level for which water-spread area available using remotely sensed data in past survey (1995) is 183.3 m, which is 3.468 m above MDDL. In year 2001 lowest level surveys is 180.68 m (0.848 m above MDDL).

2.13 TAWA RESERVOIR

The Tawa project is one of the major irrigation projects in Narmada river valley as well as in Madhya Pradesh. The dam is constructed on the confluence of Tawa and Denwa River at village Ranipur of Hoshangabad district of M.P. It is located at 22-°33'40" N latitude and 77°58'30"E longitude. The catchment area of the river up to dam site is about 5983 sq. km. The construction of the dam was completed in the year 1978.

The total loss in the live storage capacity (1943.941 MCM) of Tawa reservoir has been estimated to be 350.852 MCM i.e., 18.05 % of the original live storage. Further, by extrapolating the revised elevation-capacity curve towards lower limit (MDDL), silting in the dead storage capacity (367.572 MCM) comes out to be 117.623 MCM.

Based on the analysis, it has been observed that 468.475 MCM of gross storage capacity has been lost due to sedimentation in a period of last 25 years (1978 – 2002). If we assume a constant rate of sedimentation over the period of 25 years, it comes out to be 18.739 MCM/year or 1873.9 ha-m/year. The silting rate in commonly used unit is computed to be 31.32 ha-m/100 km^2/year. The silt rate estimated from the river water sample collected in the years 1953 and 1958 was 16.19 ha-m/100 km^2/year, which is nearly half of the present silting rate in the reservoir.

2.14 LOWER MANAIR RESERVOIR

The reservoir was constructed across Manair River at its 110^{th} km and it is at confluence of Mohedamada River. Its co-ordinates are $18^0$8'24" N latitude and $79^0$8'6" E longitude respectively. The reservoir was taken up for construction during 1976 and completed in 1985. The total drainage of the river up to the confluence is 129.50 sq. km. The catchment area at the lower Manair dam site is 64644.64 sq. km, out of which 1797.46 sq. km is from catchment and the rest of 4667.18 sq. km is intercepted.

The gross capacity of the reservoir was 680.648 MCM. The sill level of the off-take sluice is 266.09 m and the MDDL is 276.94 m. The capacity of the reservoir below the sill level of the off-take is 2.096 TMC, which is kept for silting. Hydrographic surveys were conducted during 1991 and it was found that the rate of siltation is 3.42 ha-m/100 sq. km/year. (It is clear from the chart that the inflow from river is in the decline trend and after the year 2001, there is very negligible contribution of inflow to reservoir from river flow).

2.15 NAGARJUNASAGAR RESERVOIR

Nagarjunasagar Dam is the main dam constructed across river Krishna, intercepting a catchment area of about 215185 Sq. Km. resulting in gross storage of about 11553 MCM. Out of total catchment area, free catchment downstream of Srisailem reservoir is 9340 sq. km. The Nagarjunasagar dam is the first highest manually built masonry dam in the country providing annual irrigation to 12.88 lakh ha area and power generation with installed capacity of 810 MW. The dam site is located about 2.4 km downstream of Nandikonda village in Miryalaguda Takul of Nalgonda district about 149 km from Hyderabad.

Hydrographic survey of the Nagarjunasagar reservoir was carried out in the year 2001. As per the hydrographic survey the revised capacity of the reservoir at elevation 175.32 m is 8108.33 MCM whereas using remote sensing analysis it comes out to be 8149.19 MCM. It is seen from the analysis that there is considerable agreement between the remote sensing results and conventional method of hydrographic survey.

The capacity loss in live storage is 637.37 MCM in 35 years. Current rate of silt deposition in the live storage is 20.35 MCM/year.

2.16 RAVISHANKAR SAGAR RESERVOIR

The Ravishankar Sagar dam is situated in Dhamtari district of Chhattisgarh State. The dam is constructed on river Mahanadi. The Ravishankar Sagar dam is one of the major dams of Multipurpose Mahanadi project, which consists of Pairi, Ravishankar Sagar, Moorumsilli, Dudhawa, Sondur and Sikasar reservoir.

From the analysis of the results, it has been observed that 45.93 M. cum of gross storage and 31.00 M. cum. of live storage have been lost in last 24 years (1979 to 2003). If the rate of sedimentation in the reservoir is assumed as constant over the period of 24 years, the rate of silting may come out as 1.91 M. cum/year or 191 ha-m/year. The catchment area up to the dam site of the Ravishankar Sagar reservoir being 3670 sq. km, the silting rate in commonly unit is computed to be 5.20 ha-m/100 km^2/year. It has been observed that the present rate of sedimentation is higher than the adopted rate of Mahanadi project that is 3.4 ha-m/100 km^2/year. In Mahanadi project report, it has been assumed that the 4.5% of the live storage may be lost in 50 years due to sedimentation. The live storage of the dam is 766.32 M. cum. The sedimentation in 50-years may be computed as 34.48 M. cum. The present study shows that in the last 24 years, 31.00 MCM which is 4% of live storage has been lost due to sedimentation, therefore it is necessary to take corrective measures in the catchment area to reduce entry of silt in the reservoir.

2.17 LOWER BHAWANI RESERVOIR

The Bhavani River is an important tributary of the Cauvery River which is one of India's largest rivers. The Bhavani River originates in the upper regions of the

Nilgiris of the Western Ghats. It is one of the two perennial rivers of water deficient Tamil Nadu. It crosses three districts in the Nilgiris.

Among the 16 irrigation reservoirs in the Tamil Nadu State, Lower Bhavani reservoir is second largest reservoir after Mettur reservoir. Bhavanisagar dam is constructed on the river Bhavani at 11°30'N latitude below its confluence with the river Moyar in the Cauvery basin in the Periyar district. This reservoir is formed by the impoundment of two rivers, Bhavani and Moyar, below their junction near the village Poongar, 37 km from Mettupalayam. Both these rivers have their origin in the Nilgiri Hills above an elevation of 1525 m. The main catchment (80 %) area of the reservoir lies in the Nilgiri Hills with cold climate and only 20% lies in the plains. The length of the main rivers and streams up to the dam is 112 km.

The reservoir has a maximum waterspread of 7 876 ha at FRL which is 280.2 m above the MSL, and its net capacity is 814 million m^3. The average reservoir area is 3695 ha. The revised capacity in the zone of reservoir levels for the year 2004-2005 is found 428.45 M. cum, while the original capacity was 593.46 M. cum as reported during the survey in the year 1953. Based on these results, it is found that the revised capacity reduced by 28% (165.01 m cum.). The estimated rate of sedimentation is found very high (13.22 ha-m/100 sq. km/year) as compared to original/assumed rate of sedimentation (0.44 mm/year) and RS survey carried out by CWC in the year 1977 (3.56 ha-m/100 sq. km/year).

2.18 SINGOOR RESERVOIR

The river Manjira takes its origin near Bhir in Maharashtra State in Balaghat hills and joins Godavari River about 54 km upstream of Sriramsagar Dam. The Singoor dam is constructed across Manjira at its 490^{th} km.

The year 2005 was selected for analysis based on the recent availability of water year that includes near FRL and near MDDL. To calculate the prevailing water spread area of the year 2005, six different elevations have been selected which varies from 512.51 m to 523.49 m. The actual MDDL and FRL of the reservoir are 510.6 m and 523.6 m respectively. Water spread areas for the years 1987 and 1997 against the selected elevations are drawn from the elevation area Tables. From the known values of original (1987) and revised (2005) water spread areas at different elevations the corresponding original and revised capacities/volumes were worked out using trapezoidal formula. The cumulative capacity of the reservoir at the lowest observed level (512.51 m) was drawn from the 1987 capacity area table (48.86 Mm^3) obtained from the dam authority. The result reveals that the volume of sediment deposition is 145.53 M.cu.m during the period 1987 to 2005 and 102.70 M.cu.m during 1997 to 2005. If a uniform rate of sedimentation is assumed from 1987 to 2005 and 1997 to 2005, the reservoir sedimentation rates are 8.085 M. cm/yr or 9.312 ha.m/100sq.km/yr and 12.83 M.cu.m/yr or 14.78 ha.m/100sq.km/yr respectively. The loss of live capacity of the reservoir from 1987 to 1997 and 1997 to 2005 are 5.05% and 17.18% respectively as compared with original capacity (847.02 M.cu.m) The activities in the catchment of Singoor reservoir are to be investigated to identify the reasons for increase in rate of sedimentation during the period 1997-2005.

2.19 SALANDI RESERVOIR

Salandi River originates from the Meghasani Hills of the Similipal massif in Keonjhar district. Salandi an east-flowing medium river in the State of Orissa, India with a length of 144 km and has a catchment area of 1793 km^2. The fertile lands are flood prone as the river in the coastal zone has a ridge profile and spills extensively in the lower 50 km reach because of the high monsoon rainfall (June-October) in the range of 1200 to 1500mm. The basin is drought prone because of erratic trend of monsoon in September -October. For stable agriculture through irrigation to 91,000ha and protecting almost 70,000 ha of low land from flood, a dam intercepting 673 km^2 of basin and a pickup barrage were built in 1970. In the worst drought year of 1987, the basin yield was only 22.646 ha-m. The river below the dam has gone into distress as the channel has deteriorated to a 30-40m width and 3-4m depth from the original bankfull width and depth in the range 100-150m and 6-10m respectively The dam is located 90 km upstream of the confluence of Salandi and Baitarani, a major deltaic river which spills a large 2000 m^3/sec into Salandi over the right bank.

The satellite data for the years 2004-2005 have been used for computation of sedimentation rate. The results show that the volume of sediment deposition during 1962 to 2004-2005 (42 years) in-between the maximum and minimum observed levels (308.46 m and 298.60 m) is (985.71-693.09) = 292.63 Mm^3.

2.20 UPPER KOLAB RESERVOIR

The Upper Kolab reservoir is located in Kolab sub basin of Godavari basin. It is located in Koraput district of Orissa. Power station is located 5 km from Jeyapore town. Preliminary investigations were conducted as early as 1936. Detailed investigation was completed in 1961. Planning commission approved the project in 1976. Dam was built in 1990. The project is a multipurpose project. It derives hydroelectric power, irrigation and water supply benefits. Hydroelectric generation is 320 MW. Water is supplied to Damonjodi, Koraput, Sunabeda and Jeypore from the project.

The reservoir is situated between latitudes 18° 31′ and 18° 49′ N and longitudes 82° 34′ and 82° 53′ E. Dam has masonry gravity dam. The dam is 630.5 m in spans. Its height is 54.5 m. The cost of project is nearly Rs 74.63 crore. The reservoir volume was 935 MCM (utilizable) and 1215 MCM (gross). The reservoir water spread area at full reservoir level (FRL) was 114.32 sq. km. The catchment is 1630 sq. km.

Elevation-area-capacity table for live storage region is obtained using remotely sensed data for year 2004- 05. Reservoirs sedimentation rates are classified as severe, significant and not significant based on loss of gross storage capacity more than 0.5, between 0.5 to 0.1 and less than 0.1 %. This concept may as well be extended with respect to percent loss in live storage capacity in terms of original live storage capacity. Yearly 0.06 % loss in live storage capacity in Upper Kolab reservoir may be classified as not significant as it is less than 0.1%. For minor catchments (catchment area less than 2600 sq. km.), observed sedimentation rates varied from 3.80 to 12.80 ha m/ 100 sq. km/ year (Khosla, vide Sadhu 2005). Sedimentation rate in Upper Kolab reservoir (3.16 ha m/ 100 sq. km/ year) may be assumed to be low and does not require elaborate measures to control the sedimentation rates. Design yearly gross sedimentation rate was 70 ha m. The estimated value for live storage alone is 52 ha m.

2.21 BHAKRA RESERVOIR

The Bhakra reservoir, named as Gobindsagar, has an enormous spread of water extending over 168.35 sq km at full reservoir level of 515.11 m. The Satluj River transports a lot of silt detrimental to the life of reservoir.

The data of LISS-III sensor of IRS – 1D satellite, which is having good resolution of 23.5 m, was used. The remote sensing data of following dates was procured:

08/10/2005, 22/11/2005, 16/12/2005, 10/02/2006, 07/03/2006 and 26/04/2006.

From the original elevation-area table, the original areas at the intermediate elevations (reservoir elevations on the dates of satellite pass) were obtained. The cumulative estimated capacity of the reservoir at the lowest observed level (484.10 m) was assumed to be the same as the original cumulative capacity (5597.76 Mm^3) at this elevation before the construction of the dam. The results show that the volume of sediment deposition during 1965 to 2005-2006 (41 years) in-between the maximum and minimum observed levels (512.27 m and 484.10 m) is 821.27 Mm^3. If the uniform rate of sedimentation is assumed, then as per the 2005-2006 analysis, the sedimentation rate in the zone (512.27 m to 484.10 m) is 20.07 M m^3 per year.

2.22 NIZAMSAGAR RESERVOIR

The Nizamsagar is located on Manjira a major right bank tributary of Godavari. The reservoir was constructed during 1923 to 1930. Original capacity of the reservoir was 841.18 MCM. From hydrographic survey conducted during 1967, the capacity was estimated to be equal to 402.91 MCM. This indicated a loss of 52.1 % capacity. In order to compensate the loss of storage, FRL of the reservoir was raised by 1.37 m i.e. from 426.87 m to 428.24 m in the year 1978 to increase the capacity by 150 MCM. The capacity of reservoir increased to 496.70 MCM.

As per remote sensing based study of sedimentation of Nizamsagar, storage up to 427.30 m is 414.81 MCM. Up to original FRL (426.87 m), the original and revised gross capacities are 841.18 and 375.55 MCM respectively. As per 1992 hydrographic survey, the dead storage capacity was only 1.13 MCM and thus assumed to be zero for remote sensing based revision. Thus, loss in gross storage up to original FRL was 465.63 MCM and 6.13 MCM year $^{-1}$ over 76 years period percentage loss in gross capacity was 55.4 and annual percentage lose was 0.73 year^{-1}(Table 2.2). Since, percent yearly loss in storage capacity lies between 0.5 and 1.0, the sedimentation is serious. Silt index was 2.82 Ha m (100 km^2 year)$^{-1}$. Nizamsagar reservoir was one of the first major reservoirs to come up in the sub basin. This is one of the reasons for higher rate of yearly storage loss due to sedimentation. Design sedimentation rate was 1.16 MCM year^{-1}. Thus, actual sedimentation rate was nearly six times the design rate.

Table 2.2 Reservoir sedimentation rate

Sedimentation of gross storage in units of	1930- 2006
MCM	465.63
MCM $year^{-1}$	6.13
% of gross storage	55.4%
% of gross storage $year^{-1}$	0.73%
Ha m $(100\ km^2\ year)^{-1}$	2.82

2.23 SHETRUNJI RESERVOIR

The Shetrunji reservoir is one of the multipurpose medium projects in Kuchh of Gujrat. The dam is situated on river Shetrunji near Rajasthali village of Palitana block of Bhavnagar district. The dam is located on 21^0 28'N longitude and $71^0$52'E latitude. The catchment area of river Shetrunji up to dam site is about 4317 sq. km. The Dead storage level (DSL) and Full supply level (FSL) of Shetrunji reservoir are 45.17 m and 55.53 m respectively. The gross storage and dead storage capacity as per the project report are 415.44 M. cum and 41.03 M. cum respectively. The construction of dam started in the year 1955-56 and completed in the year 1959-60. The construction of canal system was completed in the year 1965. The first year of impoundment of Shetrunji dam is 1965.

From the analysis of the results, it has been observed that 120.66 MCM of gross storage and 97.17 MCM of live storage have been lost in last 42 years (1965 to 2007). Assuming constant rate of sedimentation over a period of 42 years, the rate of silting may come out as 2.87 MCM/year or 287 ha-m/year. The catchment area up to the dam site of the Shetrunji reservoir being 4317 sq. km, the silting rate in common unit is computed to be 6.66 ha-m/100 km^2/year. The present remote sensing survey indicated that present capacity at D.S.L. is 17.54 m. cum. It indicates that the 23.49 M. cum space in dead zone of Shetrunji reservoir has already been silted up and if the current rate of silting continues, the whole dead storage zone may be silted up in next 31 years. The silt surveys in the year 1978, 1986 and 1996 have been conducted to estimate the revised capacity of the reservoir. The results obtained from the present remote sensing survey have been compared with the silt surveys and the dead storage, live storage, gross storage and rate of silting in different periods have been given in table 6. From the analysis of this table, it may be concluded that the rate of siltation in the live storage varies from 2.04 M. cum/year to 2.70 M. cum/year with an average rate of 2.31 M. cum/year (1965 to 2007).

CHAPTER 3

3.0 SUMMARY AND CONCLUSIONS

The sedimentation surveys of reservoirs in India although dates back to early as 1870, the systematic surveys started only in 1958 when the Central Board of Irrigation and Power undertook a coordinated scheme of reservoir sedimentation and entrusted this task to several research stations in the country viz. Karnataka Engineering Research Station, Directorate of Irrigation Research, Bhopal, Maharashtra Engineering Research Station, U. P. Irrigation Research Institute, Andhra Pradesh Engineering Research Lab. etc. Under the scheme 28 major reservoirs have been surveyed. During the VIII five-year plan period, Central Water Commission also formulated a scheme for carrying out capacity survey of thirty important reservoirs in the country through consultants available in the field.

In the last five years, 23 reservoirs have been studied and sedimentation rate for these reservoirs have been computed using remote sensing techniques. The results of all the reservoirs are given in table 1. In this table zone of assessment, gross storage, sedimentation rate and capacity loss etc. have been given. As per this analysis, capacity loss per year varies from 0.95% to 0.027%. It was observed that reservoirs in South and central India are losing capacity at high rate in comparison to Northern Rivers. Among the reservoirs studied, Nizam sagar reservoir has lost more than half of its storage. It was contradictory to the belief that the reservoirs located in Himalayan region are having more sedimentation rate because of heavy soil erosion in Himalayan region.

Nagarjuna Sagar which has the largest storage capacity in India has lost more than 20% of storage; it has the highest absolute sedimentation rate. Sedimentation rate per unit catchment area for reservoir in Narmada basin is the highest and is close to 10 times of the rates of many other reservoirs.

Large reservoirs (capacity more than 1000 Mm^3) are losing storage at the rate of about 9% per year.

Table 3.1 Sedimentation rate of reservoirs

Reservoir	Period	Live Zone	Zone of assessment (m)	Gross Storage (Mm^3	Sedimentation rate (Mm^3/yr)	Sedimentation rate Mm3/100 sq km/year	Capacity loss (%)	% capacity loss per year
Nagarjunasagar	1967-2002	149.0-179.83	152.28-175.32	10286.98	64.14	0.298	21.82	0.62
Hirakud	1957-2001	179.83-190.00	180.68-185.80	82136.0	21.88	0.263	11.83	0.027
Gandhinagar	1960-2001	381.0-400	380.57-398.58	7746.0	3.58	0.156	1.0	0.046
Tungabhadra	1981-2002	477.01-497.74	477.45-494.79	3751.0	16.37	0.581	9.16	0.44
Linganamakki	1957-2001	522.73-554.43	532.20-548.78	4417.5	1.70	0.857	1.7	0.038
Tawa	1978-2002	330.9-357.57	338.84-355.12	2311.51	18.74	3.13	19.46	0.81
Ramganga	1974-2001	324.6-365.3	339.05-364.4	2590.72	4.23	1.349	4.57	0.163
Ghatprabha	1974-2001	629.69-662.94	631.1-658.6	1434.14	4.45	3.165	7.75	0.31
Matatila	1962-2002	295.66-308.46	298.6-308.46	985.71	7.51	0.356	38.26	0.76
Somasila	1987-2002	67.05-94.49	83.17-94.39	1158.12	1.60	0.0764	2.07	0.138
Lower Manair	1983-2001	270.09-280.42	271.97-276.83	680.65	5.46	0.047	14.45	0.80
Barna	1975-2002	338.1-348.55	338.69.00-348.55	539.00	3.89	3.309	19.48	0.72
Vaigai	1983-1999	257.56-279.19	264.95-279.03	194.78	0.99	0.142	8.24	0.51
Upper Kolab	1990-2005	844.0-858.0	848.38-855.88	1215.0	0.515	0.316		0.042
Ravi shanker Sagar	1979-2005	336.21-348.70	337.59-348.72	909.32	1.91	0.520	5.4	0.21
Lower Bhawani	1953-2005	266.0-280.20	266.28-275.47	814	0.76	0.181	5.0	0.093
Singur	1987-2005	510.6-523.60	512.51-523.49	847	8.08	0.668	17.17	0.95
Bhakra	1965-2006	445.62-515.11	484.10-512.27	9373.06	20.07		8.77	0.21
Nizamsagar	1930-2006	415.57-428.24	415.80-427.30	841.18	6.13	0.366	55.3	0.73
Tandula	1922-2001	320.45-332.18	320.8-332.18	3122.5	0.28			
Shetrunji	1965-2007	45.17-55.53	46.57-55.32	24.90	2.87	0.666	32.36	0.77