WORKSHOP

ON

RESERVOIR SEDIMENTATION ASSESSMENT USING REMOTE SENSING DATA

(May 07 - 08, 1999)

Module 8

Status Paper
on
Reservoir Sedimentation
Assessment
Using
Remote Sensing Techniques

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1 INTRODUCTION

The estimated total capacity of existing water storage reservoirs in the World is between 4,000 Gm3 and 6,000 Gm3. As most of the best locations have already been used, further increase of reservoir storage is limited, with an estimated ultimate limit using all physically possible dam sites of the order of 4-5% of the global fresh water runoff. Reservoir sedimentation and consequent loss of storage capacity affect water availability specially where water is the most scarce - in the arid and semi-arid regions of the world. The loss of water storage by reservoir sedimentation is of the order of 1-2% per year and the lifetime of most reservoirs in the arid and semi-arid realm is of the order of 20 to 30 years, with the exception of some very large reservoirs. The impact of storage depletion is aggravated by the fact, that new dam sites are few, restricted mainly to the upper catchments of a few rivers .

It is thus pressing to preserve existing storage capacity or else, in a foreseeable future, water management in the arid realm will be deprived of storage reservoirs: if this happens, the greater part of renewable resources will be lost, which on its turn, would lead to inevitable over-exploitation and exhaustion of the non-renewable (mainly groundwater) resources

In India, after independence it was realised that for the needs of irrigation, hydro power generation, industry and drinking water of ever increasing population of our country, creation of adequate storage capacity was essential to store the rainfall taking place during the four months of monsoon period only. During the last five decades, a number of large dams, over 4200 nos. apart from tens of thousands of medium/minor dams are constructed/are under construction. The total storage capacity now available is of the order of 174 cu.km. which is only about 10% of the average annual flows in the river. At present capacity of about 77 cu.km. is likely to be added through on-going schemes and addition of another 131 cu.km. capacity is under consideration. The storage capacity available in small ponds/lakes is about 20 cu.km. The completion of all these schemes will enable to create capacity of the order of 400 cu.km in India.

In view of limited good storage sites this is particularly important that storage reservoir should serve the expected functions properly for the whole life span and their life be extended beyond the service period as long as possible, even on a lightly reduced scale of benefits, if necessary. It, therefore, essential to monitor the capacities of the existing reservoirs at regular intervals and taken suitable measures for controlling the sedimentation rate and utilise the findings in the planning of future reservoirs.

2 SURVILLANCE ON SILTING OF RESERVOIR

In some of the reservoirs which have been constructed the rate of sedimentation has been higher than what has been considered at the planning stage. Some reservoirs in the world have been silted up so fast that they have become useless. For example the Yasuka Reservoir in Japan has lost 85percentage capacity in less than 13 years. Many of the reservoirs in India are losing capacity at the rate of 0.5 to 1.5 percent annually. About 40,000 minor tanks in Karnataka have lost more than 50 percent of their capacities. It has ,therefore, been considered necessary to take steps to plan the future projects on a sound basis so that the sedimentation of the reservoirs will not reduce the benefits faster than envisaged.

Ministry of Agriculture and Irrigation (Department of Irrigation), Government of India set up a Reservoir Sedimentation Committee in February 1978 under the Chairmanship of Member (WR), Central Water Commission. The Committee submitted its report in July 1982 and made several recommendations as under :

i) The sediment observation stations in the major streams and important tributaries should be equipped with latest equipment and manned by qualified and well-trained staff.

ii) Capacity surveys on regular intervals of once in 5 years for all major reservoirs should be carried out by the project authorities.

iii) Cultivation in the foreshore is to be prohibited as per existing instructions of Govt. Of India to reduce entry of silt into reservoirs. In any case, ploughing should not be allowed. However, broadcasting can be permitted to a limited extent wherever possible.

iv) There should be a data bank of sediment inflow, outflow and sedimentation of reservoirs at States and Central level with easy accessibility.

3 UTILITY OF SEDIMENTATION ASSESSMENT

At the planning and design stage of every dam & reservoir, provision for sediment storage is kept. This provision is arrived at through observed sediment gauge record (bed load & suspended sediment load) of river at or nearby location where the hydraulic structure would be located. Or for an ungauged site, by modelling sediment yield (using empirical model, physical conceptual model etc.). However, after the construction of dam & impoundment of reservoir a great need arises in continuous monitoring of reservoir to know:

- Quantum of annual actual storage loss in reservoir due to sedimentation for estimating reservoir's effective economic life
- Spatial distribution of sediment deposit in the entire body of the reservoir to identify problem location in reservoir and source of sediment-laden water from tributaries
- Updating stage-area-capacity curve/chart for efficient reservoir operation
- Availability of fresh data to verify and to improve sediment accumulation prediction techniques
- To take up remedial measures, at reservoir (by mechanical means) and in watershed (through soil-water-vegetation conservation planning)

4 CAPACITY SURVEYS

The sedimentation survey of reservoirs in India dates back as early as 1870. In a systematic way they were started only in 1958 when the Central Board of Irrigation and Power undertook a co-ordinated schemes of reservoir sedimentation and entrusted this task to several research stations in the country viz., Karnataka Engineering Research Statin, Directorate of Irrigation Research, Bhopal, Maharashtra Engineering Research Institute, U.P. Irrigation Research Institute, Andhra Pradesh Engineering Research Laboratories etc. Under this schemes 28 major reservoirs have been surveyed.

The Reservoir Sedimentation Committee under Central Water Commission made certain recommendations in its report (July 1982) for long term measures including that sediment observations in major river systems be carried out with latest equipment, capacity surveys of all major reservoirs be carried out once in five years and cultivation of areas on the periphery of reservoirs be prohibited to reduce silt entry into reservoirs. Maintenance of a data bank of sediment inflow, outflow and sedimentation of reservoirs by State Governments and Central Government was also recommended.

Capacity surveys of reservoirs are carried out for determination of the volume of silt deposited, its distribution, sedimentation rates, updating the elevation-area-capacity relationships. In India, so far conventional methods of hydrographic survey using echo sounder along range lines is adopted. The inflow and outflow method involving measurement of inflows into and outflows from the reservoirs comprising discharges and sediment concentrations is also being used in some cases. Of late use of hi-tech methods has been started in which hydrographic surveys are carried out employing computerised methods both for data collection and analysis. With the advancement in satellite technology, location accuracy of observation points have been greatly enhanced by using Differential Global Positioning Systems (DGPS). Capacity surveys of reservoirs by using remote sensing techniques are also gaining wide acceptance. This method has been found to be very quick and cost effective.

5 Reservoir Sedimentation and Remote Sensing

Remote sensing, owing to the inherent benefits of synoptic coverage, repetivity, cost effectiveness, ability to map inaccessible areas, is gaining use in reservoir sedimentation. Passive remote sensing systems emerges as a useful tool for understanding various facets of reservoir sedimentation. In addition, active remote sensing also seems promising to study few aspects of reservoir sedimentation especially the bed profiling /Bathymetry. Whereas Passive remote sensing system (conventional aerial photographs, IRS-1C/1D (LISS III, PAN, WiFS) LANDSAT TM sensors, for example) are concerned with the detection and imaging of reflected or emitted solar radiation from the water body. In contrast, an active remote sensing system (for example microwave, LIDAR) supplies its own source of energy and receives the reflected signal back from the water body. In terms of loss assessment, quite a few options are available that will be useful to the user of this technology. Application scenario of remote sensing in reservoir sedimentation can be seen in terms of its use to serve the information needs regarding : reservoir water-spreads; reservoir capacity and sedimentation rate; sediment yield from catchment; suspended sediments concentration; reservoir water depth profile / bathymetry etc.

5.1 Reservoir Water-Spread

Water-spread of a water body is probably the easiest earth feature for remote sensing systems to delineate due to its high contrast with surrounding land features in the near-infrared (approximately 0.75 – 1.0 μm) of the electromagnetic wavelength. This is because, water almost totally absorbs near-infrared radiation, whilst surrounding healthy vegetation or bare soil are strong near-infrared reflectors. Therefore, automatic recognition & mapping of reservoir water-spread are possible using computer-processed multi-spectral scanner data. Number of studies have been carried out to estimate reservoir water spreads. The methodologies adopted in such approaches can be classified in three categories

1. *Thresholding*, where a threshold value is adopted to separate out the water body from surrounding soil/vegetation. This is the most commonly used method for reservoir water spread estimation.

2. *Modelling*, Where a model based on multiple conditions is defined to determine weather pixel is water or not. This is useful when thresholding does not give proper results because of confusion pixels. This methodology may involve integrating multi band thresholding, or defining relation between different bands. This methodology was used in most of the case studies to follow.

3. *Classification*, where the image is classified using supervised or unsupervised classification by identified number of training classes of different classes.

5.2 Reservoir Capacity Survey

The conventional methods, the hydrographic surveys are laborious and time consuming. The hydrographic surveys of reservoirs are being conducted at a frequency of 2 to 15 years, though the recommended frequency is 5 years. Remote sensing technique has emerged and established itself as a useful cost effective and time effective tool to estimate capacity loss frequently. The procedure does not call for great expertise. The water spread area can be evaluated by any of the method given in preceding para. With satellite multi-date water-spread estimation, and ground-truth of corresponding dates water stage of the reservoir available from reservoir gauge records, storage capacity of reservoir can be estimated using various mathematical formulae - the most common being Prismodial formula

$C = 1/3\,(H_2-H_1)(A_1+A_2+\sqrt{(A_1*A_2)})$

Where

C = computed reservoir capacity

A_1 = Water-spread area from satellite image corresponding to reservoir stage at H_1

A_2 = Water-spread area from satellite image corresponding to reservoir stage at H_2

By choosing satellite images corresponding to various levels between maximum to minimum reservoir stages, current stage-are-capacity curve can be reconstructed. The comparison of this curve with the original curve, prepared before reservoir impoundment or the ones obtained from subsequent sedimentation surveys, provides a realistic picture of change between two periods and enables computation of total volume of sediment deposited in the reservoir and annual Sedimentation rate. The capacity evaluation is quite accurate for the zone in which reservoir level is varying. The zone above maximum or below minimum water level on available satellite data may suffer from errors as the capacity in these zones is based on extrapolated curve.

The stage capacity curves have been revised in a number of reservoirs namely Hirakud, Tungabhadra, Bhadra, Malampuzha, Ghataprabha, Sriramsagar, Himayat sagar, Osman sagar, Nizam sagar, Ukai, Bajaj Sagar, Kadana, Konar, Tilaiyia and many other reservoirs across the country using remote sensing to reflect realistic storage condition. A list of some case studies of reservoir sedimentation surveys conducted by various agencies along with the brief results is given in Annexure - I

5.2.1 Case Studies of Satellite Based Reservoir Sedimentation

Tungabhadra Reservoir

Tungabhadra reservoir located at Munirabad about 5 Kms from Hospet town in Karnataka is a multipurpose reservoir. The maximum water spread area of reservoir at FRL 497.738m is 378.99 sq.kms with a gross storage capacity of 3751.17 Million m^3. A siltation rate of 0.429 mm/year was adopted in the design of the project. The water in the reservoir was first impounded in the year 1953. For conducting the above study through satellite remote sensing

IRS-1B LISS-I&LISS-II (27/57&27/58) and LANDSAT-TM (145/49&145/50) data for seven different dates spreading over different water levels ranging from 497.54 m to 478.133 m for the year 1994-95 was used.

For estimating water spread area NIR band and ratioed image {(NIR-Red)/(NIR+Red)}was used. The ratioed images was thresholded into three ranges in increasing order of ratioed value. First range that contains all water pixels is then verified by consulting standard FCC. The next two ranges containing mostly boundary pixels at the periphery of the reservoir. First these two range masks were evaluated for the correctness of the range limits by consulting FCC. But, in most of the cases the criterion of thresholding ratioed image has not yielded satisfactory results in identifying the correct water pixels due to shallow depth of water at some of the locations along the periphery and at the tail portion of the reservoir. Hence, actual water pixels in these two range masks were estimated using either threholding NIR or GREEN band. The total water spread area is estimated by adding the water spread masks under the three range masks.

Annual rate of siltation is found to be 0.7618 mm/year since impoundment of reservoir in 1953 to 1995. The live and gross storage capacities of the reservoir is estimated to be 2849.8372 Million m^3 during 1995, since the dead storage has been estimated as zero from 1978 onwards. Loss in gross storage works out to be 0.57 % per year. Graph showing storage capacities from 1952 to 1995 of Tungabhadra reservoir is given at Fig. 1.

Hirakud Reservoir

Hirakud dam has been built across the river Mahanadi 15 Kms upstream of town Sambalpur in Orissa. Hirakud is a composite dam with a length of 4803m and height of about 60m at its deep channel bed. The dam has been built immediately downstream of the confluence o0f the river Mahanadi with its tributary Ib. The full reservoir level (FRL) and minimum draw down level (MDDL) of the dam are El. 192.02 & El. 179.83m respectively. The reservoir water spreads over an area of 727 sq. km. at FRL. At the time of construction of the project the capacities of the reservoir at FRL and MDDL were estimated to be 8105 and 2262 Million m^3. The water in the reservoir was first impounded in 1957. For conducting the above study through satellite remote sensing IRS-1B LISS-II (22/53/A1&B1) data for six different dates spreading over different water levels ranging from 192.02 m to 183.30 m for the year 1994-95 was used.

For estimating water spread area NIR band and ratioed image {(NIR- Red)/(NIR+Red}was used. Different slicing threshold values for NIR band and ratioed images for different dates were obtained by analysing the histograms and viewing pixel values by moving the cursor along the periphery of the reservoir, in False Color Composite(FCC) mode. After selecting these threshold values, model with following equation has been run to extract the reservoir water spread areas.

First model equation (using NIR band only)

If Dn4 > Tlf4 and Dn4 < Thf4 then pixel is in water spread.

Second model equation (using NIR band and ratioed channel)

If Dn4 > Tls4 and Dn4 < Ths4 and Dnv >Tlv and Dnv <Thv then pixel is in water spread.

Where

Dn4 is digital value in NIR band

Dnv is digital value in ratioed image channel

Tlf4 & Thf4 are lower and higher thresholds for the first range of NIR band

Tls4 & Ths4 are lower and higher thresholds for the second range of NIR band

Tlv & Thv are lower and higher thresholds for ratioed image

Water pixels from the result of second model were added to first model to find out the total water spread area of the reservoir. The derived elevation-area – Capacity curve is shown in Fig 2.

Average rate of sedimentation is estimated to be 0.618-mm/year upto 1995 since first impoundment of the reservoir. Percent loss of gross storage per annum is 0.64 %.The modified live capacity and gross capacity of the reservoir has been worked out as 4934.53 Million m^3 & 6145.74 Million m^3 respectively.

Konar Reservoir

Konar dam was constructed in 1955 on River konar near village Jari Kunda in Hazribagh district, which is a tributary of river Damodar to supply cooling water to Bokaro Thermal Power Station. The dam is of composite (earth and concrete) type 3682.9m long. The full reservoir level (FRL) and minimum draw down level (MDDL) of the dam are El. 425.8m & El. 410.56m respectively. The original gross capacity of the reservoir is 281.35 Million m^3. For conducting the above study through satellite remote sensing IRS-1C LISS-III (105/54), IRS-1B LISS-II (21/51/A1) & LANDSAT TM (140/43/Q3) data for eight different dates spreading over different water levels ranging from 425.52 m to 415.17 m for the year 1996-97 was used.

For estimating water spread area NIR band and ratioed image (NIR- Red)/(NIR+Red}was used. Different slicing threshold values for NIR band and ratioed images for different dates were obtained by analysing the histograms and viewing pixel values by moving the cursor along the periphery of the reservoir, in False Color Composite(FCC) mode. After selecting these threshold values, model similar to the one used in Hirakud reservoir study has been run to extract the reservoir water spread areas.

Average siltation rate in gross and live storage of the reservoir for the period (1955-96) has been observed as 1.302 mm/year and 0.624 mm/year. Loss in gross storage is found to be 0.46 % per year. The modified gross capacity of the reservoir has been worked out as 228.13 Million m^3 giving a percentage loss of 18.92%. The results matches well with the Hydrographic survey carried out by RITES in same period (Fig 3).

Tilaiya Reservoir

Tilaiya reservoir on River Barakar which is a major tributary of river Damoda was constructed in 1953. The dam is of concrete gravity type, with total length at top as 365.76m. The full reservoir level (FRL) and minimum draw down level (MDDL) of the dam are El. 368.81m & El. 363.32m respectively. The original gross capacity of the reservoir is 215.88 Million m^3. For conducting the above study through satellite remote sensing IRS-1C LISS-III (105/54) & IRS-1B LISS-II (21/51/A1&B1) data for seven different dates spreading over different water levels ranging from 369.8 m to 363.08 m. for the year 1996- 97 was used.

For estimating water spread area NIR band and ratioed image {(NIR-

Red)/(NIR+Red}was used. Different slicing threshold values for NIR band and ratioed images for different dates were obtained by analysing the histograms and viewing pixel values by moving the cursor along the periphery of the reservoir, in False Color Composite(FCC) mode. After selecting these threshold values, model similar to the one used in Hirakud reservoir study has been run to extract the reservoir water spread areas. The modified Elevation Area Capacity curve is given at Fig.4.

It is found from the study that original elevation-area-capacity table being furnished by project authorities is not correct. Hence sedimentation rate could not be worked out. The elevation-area-capacity curve has been updated

Ukai Reservoir

The Ukai is the largest multipurpose project so far completed in Gujarat state. The Ukai dam is located across river Tapi near village ukai of Fort-songadh taluka in district surat in Gujarat state. The total catchment area of the ukai reservoir is 62,225 sq. km. which lies in the Deccan plateau.The reservoir impounds a live storage capacity of 0.71 Million Hectare meter at FRL 105.156m. The minimum draw down level (MDDL) of the reservoir is 82.296m. The ukai headworks were completed in a construction period of seven years, ending in the year 1972. For conducting the above study through satellite remote sensing NIH used IRS-1B LISS-II (30/53/A1) data for eight different dates spreading over different water levels ranging from 104.446 m to 92.196 m for the year 1993-94.

For estimating water-spread area a algorithm was developed for differentiating the water pixels using the information of different bands. The algorithm check for one condition for each pixel and if a pixel satisfies the condition, then it is recorded as a water pixel, otherwise not. The condition states that "If the DN value of NIR band of the pixel is less than the DN value of the band 2 and band3, then it must be classified as water otherwise not"

The revised capacity in between the maximum (104.446m) and minimum(92.196m) observed levels was worked out as 4467.3 Million m^3 whereas the original capacity in this zone of study was 4791.94 Million m^3 (Curve at Fig. 5). The average rate of loss of capacity in this zone came out to be 15.46 Million m^3/year.

5.3 Sedimention Yield from catchment

The quantity of sediment that may reach the reservoir from the catchment depends on factors such as hydrometeorology, topography, land use and lithology. Remote sensing provides such information for use in many empirical models such as Universal Soil Loss Equation (USLE) or Garde's model for estimating the average annual soil loss. Similar empirical formulae have also been developed in Madhya Pradesh State and elsewhere. While simulation models such as the Colorado State University Model are more rational and physically based, calibration and use of such models have limited capability to accept remotely sensed information inputs. Number of studies have been carried out to assess the sediment by using different models such as emperical model by Guruswamy et. al , Chokraborty , SYPE by Baldev Sahai et. al., Musgrave model, USLE

The watershed priortisation can also be done using these quantitative models as well as qualitative models. This can help the authorities to undertake suitable remedial measures more effectively. However these models are effective only if the soil or physiography is not changing much with small distances..

5.4 Estimation of Suspended Sediments

A specific remote sensing application in reservoir is the detection and monitoring of suspended sediments in water. The presence of suspended sediment increases the reflectance in the visible regions of electromagnetic spectrum. A number of studies have been conducted using aircraft & satellite multi-spectral scanner data to relate suspended sediment concentrations to reflectance measurements. The relations are developed based on the observation of sedimentation concentration at the time of satellite pass and measured reflectance. Various authours such as Chakraborty(Upper Lake, Bhopal), Khorram et. Al., Whitlock, Pramanik. Ainai & Jing, V.K. Choubey etc have given different relationships.

Advantages of this approach are:

- The distribution of the sediment can be mapped spatially.
- When suitable calibration data is available, iso-concentation lines can be plotted using image processing & GIS systems.
- Localised high sediment concentrations would pinpoint contributing sediment-laden

inflow tributaries & upstream watershed where erosion problems are present.

- Enables future monitoring of reservoir, as increase or decrease of sedimentation, can be identified using reflectance-suspended sediment concentration data and its relationship.

However, present day space-borne sensors limits this approach to the detection and monitoring of suspended sediments at or near below reservoir surface waters as these sensors are capable of detecting suspended sediments not deeper than about 1 metre, at the most,.

5.5 Water Depth Profile /Bathymetry

The aerial measurement of water depth can either be absolute, using direct measurement technique like 'laser profiling', or it can be inferred by estimating reflected radiation from the clear water body using passive imaging system like multi-sprectral scanner. Once the accurate depth information on spatial scale is available, reservoir bathymetric map can be constructed.

5.5.1 Water Depth Profile /Bathymetry by Multispectral Imaging System

Sunlight (solar radiation & diffuse sky radiation) entering a water body is subjected to depletion as a result of i) absorption & scattering by the pure water. ii) scattering defraction & reflection by suspended particles in the water. The penetration of radiation into pure water is described by means of an extinction coefficient, 'k', which takes into account the effects of both scattering & absorption.

An indication of the relationship between wavelength and the potential for determining water depth from satellite altitude has been shown earlier in some of the results with LANDSAT MSS data, specially in clear, relatively shallow water of depths less than 5 - 15 metre.

Keeping these earlier results elsewhere in the world in view, it should be possible for LISS sensors in IRS-series with first two spectral bands in the region of 0.45 to 0.52 um and 0.52 to 0.59 um to provide equally good results, if not better. Some studies in bathymetry in coastal shallow waters of India have been conducted. Research, however, needs to be directed in reservoir waters with varied water depth & turbidity regimes.

5.5.2 Water Depth Profile /Bathymetry by LIDAR System

Accurate profiling of water depth can be accomplished by LIDAR system. A pulsed, coherent laser light source is pointed downwards from the sensor platform so as to strike the water surface at right angles. A strong reflected light signal is received from the water surface, followed closely by a weaker reflected signal from the floor of the water body. The calculation of water depth is a function of time of travel of a given pulse of light for the round trip from the laser gun to water bed and back to the detector head, minus the round trip time from the sensor to the water surface and back. The depth to which the laser beam can effectively penetrate obviously depends on the water clarity, atmospheric attenuation, laser strength and frequency, but in clear waters, depth measurements down to about 50 metre should be feasible from aircraft and to about 20 metre from satellites. The use of scanning LIDAR system would be most useful for rapid water depth profiling of a large reservoir.

6 Cost of Sedimentation surveys:

It is said that the Remote Sensing is cost effective. Question arises what is the cost of sedimentation survey. A typical sedimentation survey by remote sensing will take 2 to 4 Months and cost could be as follows

S. No.	Item	Cost in Rs. Thousand	
		Small Reservoir	Large Reservoir
1.	Satellite Data cost	100	200
2.	Satellite Data Analysis	100	150
3.	Ground truth data Collection	50	50
4.	Consumables and Report Generation	50	75
	Total Cost	300	475

7 Future Directions

1. Satellite remote sensing based survey gives the information on the capacities in the water level fluctuation zone only, which generally lies between MDDL and FRL of the reservoir. Below MDDL the information on the capacity could be taken from the most recently conducted hydrographic survey. Use of Satellite Remote Sensing technique enables a fast and economical estimation of live storage capacity loss due to sedimentation. A number of studies have been shown that results are comparable with hydrographic surveys. It is now required to operationalise the use of remote sensing based surveys for major reservoirs. It would be appropriate if hydrographic surveys are conducted at longer interval and the remote sensing based sedimentation surveys are carried out at shorter interval to make both surveys complementary to each other.
2. Remote sensing has provided very useful information for watershed prioritization, especially at reconnaissance or primary level, through qualitative and quantitative methods. However there is need for more research to improve the quantitative methods for use in detailed watershed prioritization and estimation of Silt yield from catchment at the time of planning reservoirs.
3. Estimation of Suspended sedimentation in shallow reservoir needs more work to build the confidence for application of the same in operational manner.
4. Research needs to be done for application of Microwave remote sensing and LIDAR data in reservoir capacity estimation under cloud conditions, Bathymetry and Suspended Sedimentation concentrations and sediment distribution pattern under Deep reservoirs.
5. For achieving synergic benefit from these research activities there is need for close cooperation within different agencies in the field such as CWC, NIH, State water resources departments, NRSA, SAC, Regional/state remote sensing centres, Research Institutes and Educational Institutes.

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CASE STUDIES OF SATELLITE BASED RESERVOIR SEDIMENTATION SURVEYS

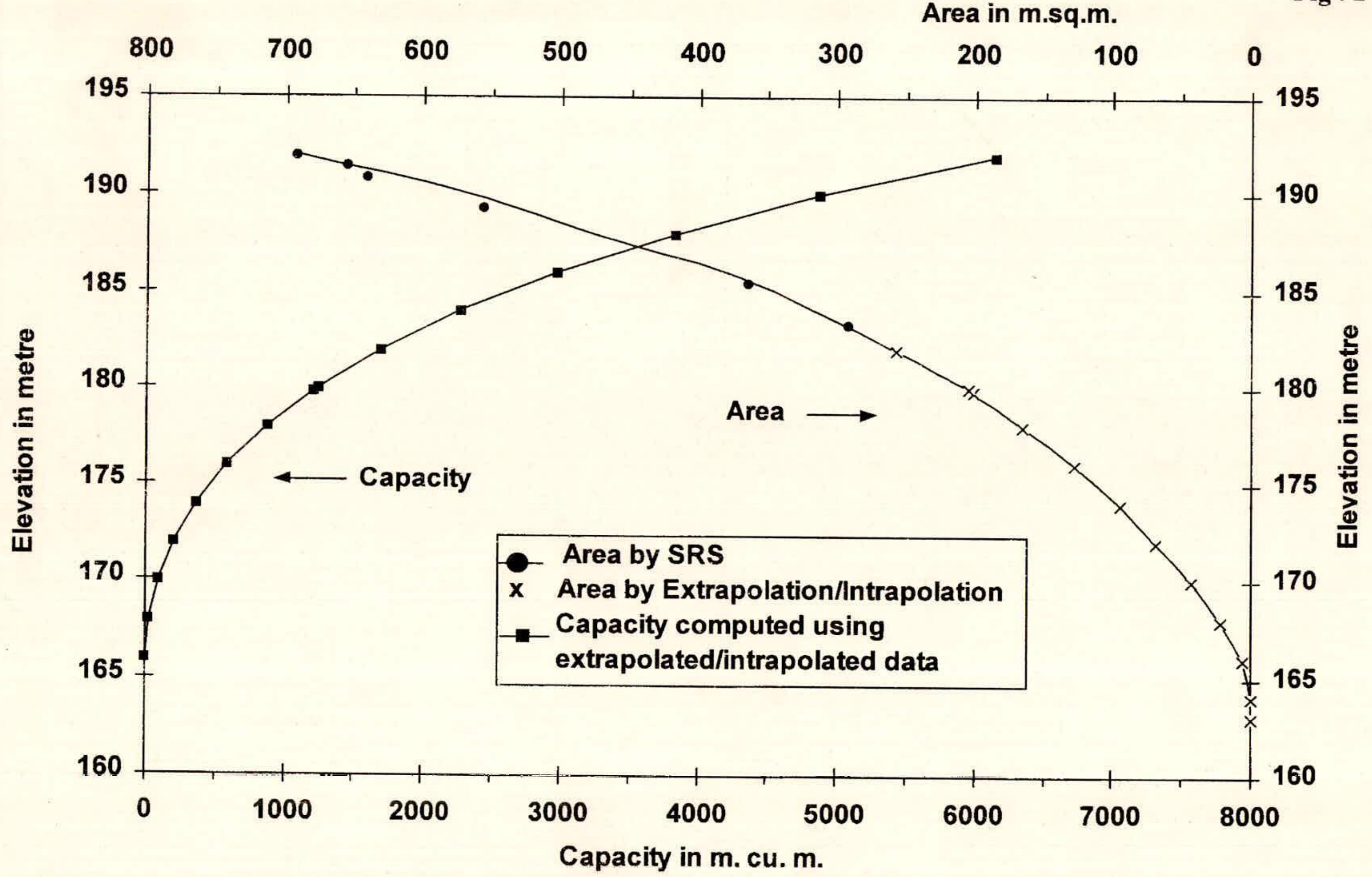
Sl.No.	Reservoir	Year of Satellite Survey	By whom	percent storage loss per year	Period	Remarks
*1.	Bhadra	1986	KERS	0.25	1964-86	
*2.	Ghatprabha	1989-90	RRSSC (B) & KERS	0.57	1974-89	
*3.	Malaprabha	1988-89	-do-	0.24	1972-88	
*4.	Krishnaraja sagar	1988-89	-do-	0.03	1932-88	
5.	Tungabhadra	1994-95	NRSA	0.59	1953-95	
*6.	Nath sagar	1991-92	-do-	0.48	1976-92	
*7.	Ujjani	1991-92	-do-	1.18	1976-92	
*8.	Ukai	1984-85	SAC			comparable capacity as that of hydrographic survey
*9.	Osman sagar	1986-89	APERL	0.489	1927-86	
*10.	Nizamsagar	1990-92	-do-	0.195	1930-90	
*11.	Sriram sagar	1982-84	-do-	1.85	1970-84	
12.	Himayat sagar	1986-89	-do-	0.472	1927-86	
13	Kaddam	1987-90	-do-	1.142	1965-87	

Sl.No.	Reservoir	Year of Satellite Survey	By whom	percent storage loss per year	Period	Remarks
14	Lower Manair	1987-90	-do-	0.324	1982-87	
15	Hirakud	1976-77	ORSAC			comparable capacity as that of hydrographic survey
16	Hirakud	1994-95	CWC	0.64	1957-95	
17	Kadana	1994-96	CWC	0.54	1977-96	
18	Mahi Bajajsagar	1993-94	CWC & RRSSC-J	1.23	1983-94	
19	Konar	1995-96	CWC	0.46	1955-96	
20	Tilayia	1995-96	CWC	-	-	It is found from the study that original elevation-area-capacity table being furnished by project authorities is not correct. Hence sedimentation rate could not be worked out
*21	Ukai	1993-94	NIH	-	-	The revised capacity in between the maximum (104.446m) and minimum(92.196m) observed levels was worked out as 4467.3 Million m^3 whereas the original capacity in this zone of study was 4791.94 Million m^3.

- Full live storage is not covered by satellite data

HIRAKUD RESERVOIR - ELEVATION-AREA-CAPACITY CURVE

Fig : 2



KONAR RESERVOIR
ELEVATION-CAPACITY CURVE

Fig : 3

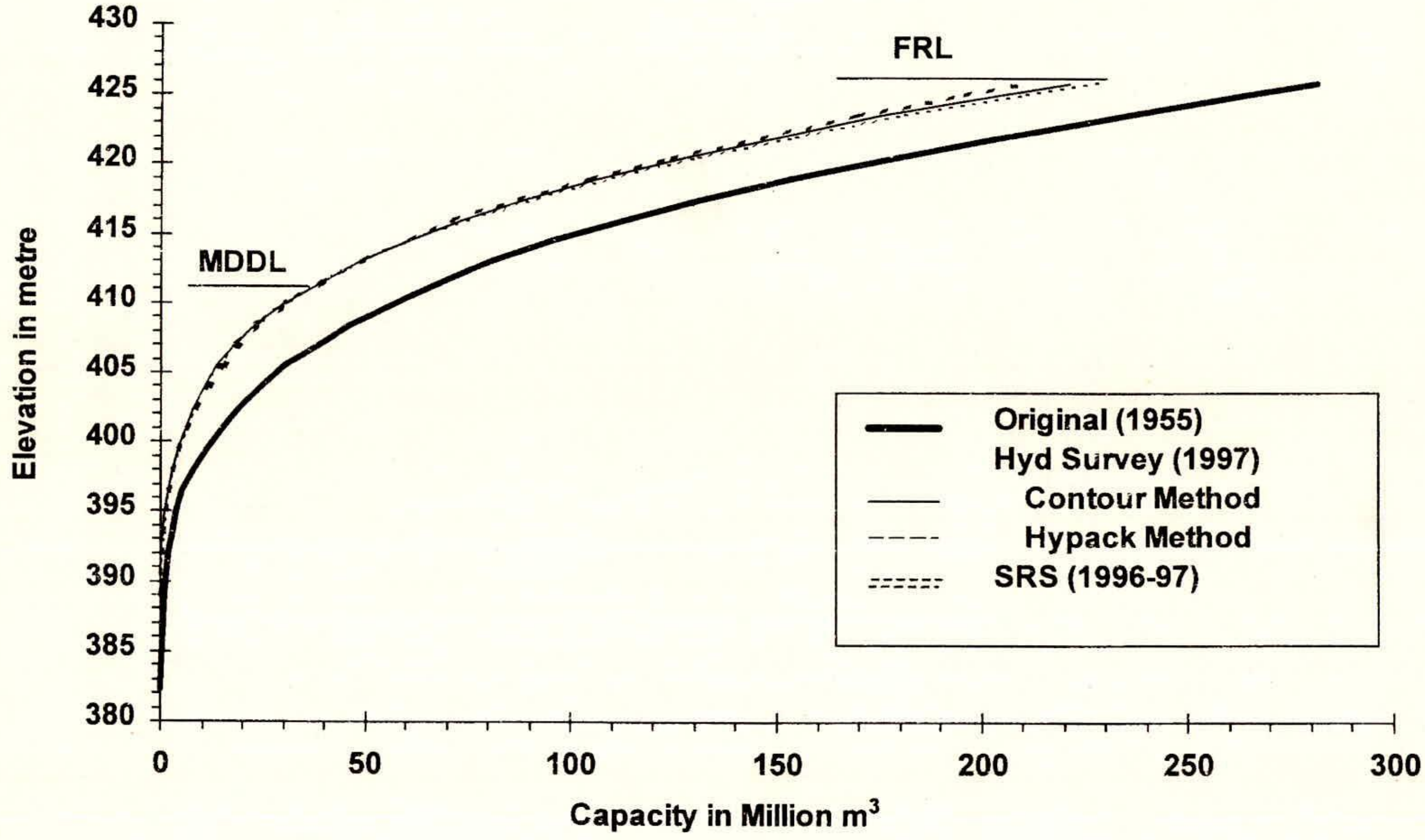
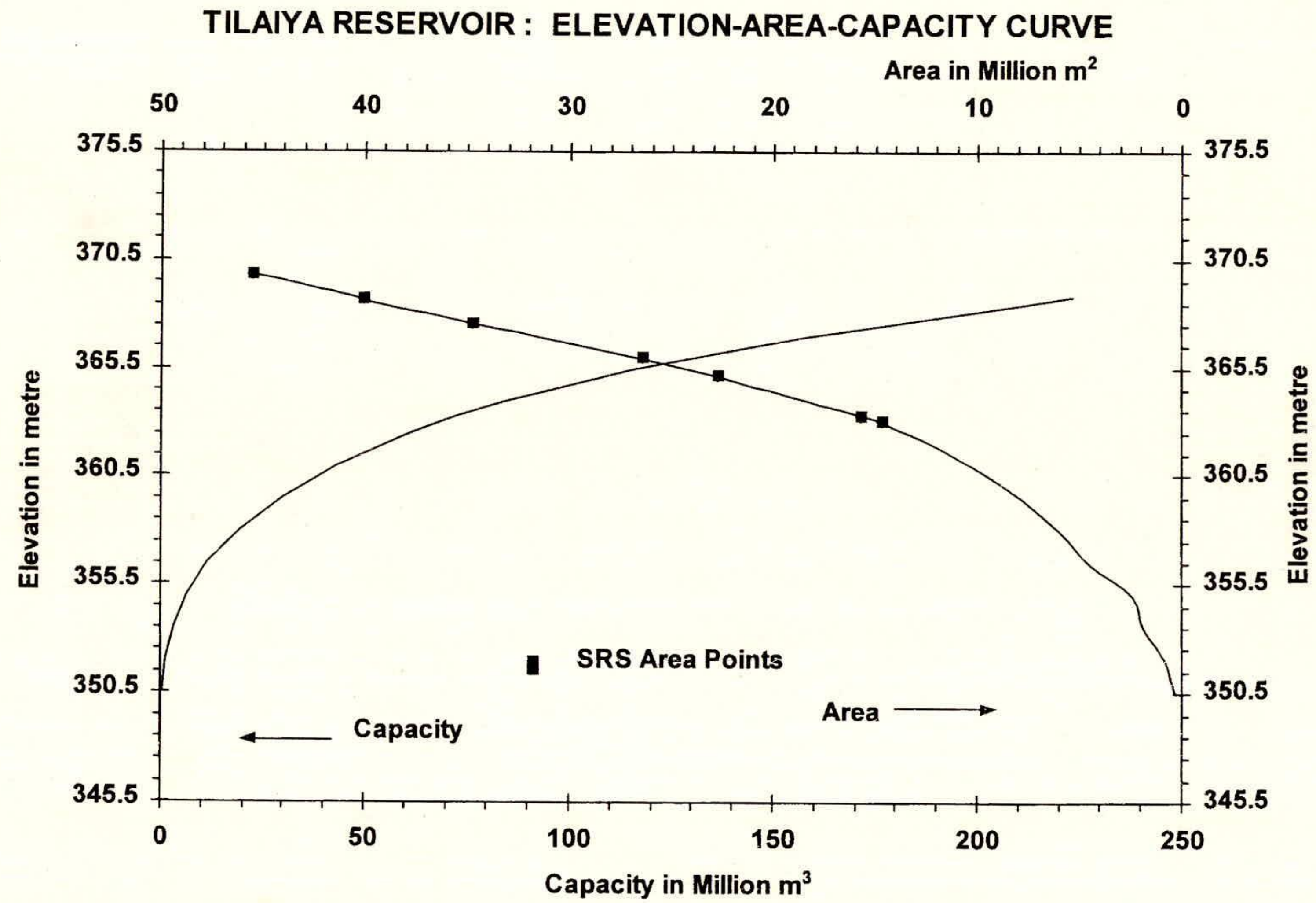


Fig: 4


TILAIYA RESERVOIR : ELEVATION-AREA-CAPACITY CURVE
Area in Million m²
50
40
30
20
10
0
375.5
370.5
365.5
360.5
355.5
350.5
345.5
Elevation in metre
SRS Area Points
Capacity
Area
0
50
100
150
200
250
Capacity in Million m³