REMOTE SENSING APPLICATIONS IN RESERVOIR SEDIMENTATION A CASE STUDY OF SRIRAM SAGAR RESERVOIR

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ABSTRACT

The hydro-geologic processes like erosion, movement and deposition of sediment play a significant role in the planning of reservoir projects. Reservoir silting is an important factor on which depends the life of the reservoir and the long term benefits from the stored water for various purposes viz., domestic water supply, irrigation, power, flood control and other uses. Capacity surveys of reservoirs at regular intervals are considered necessary to evaluate their useful life as well as to assist in optimal reservoir operation. The hydrographic surveys through conventional methods are laborious, time consuming and prone to errors. Remote sensing technique has emerged and established itself as a useful cost effective and efficient tool to estimate capacity loss in reservoir at frequent intervals. This has been demonstrated by a case study in the present paper

1.0 INTRODUCTION

Remote sensing techniques are being increasingly employed to provide cost and time effective estimation of loss in live storage capacity. Multidate satellite remote sensing data provide information on elevation contours in the form of water spread area. Any reduction in reservoir water spread area at a specified elevation corresponding to the date of satellite data is indicative of sediment deposition. The quantity of sediment load settled down over a period of time can thus be determined by evaluating the change in the aerial spread of the reservoir at various elevations. Hence, it helps in determining the new reservoir capacity and establishing new storage-area-capacity curve.

2.0 OBJECTIVES

a) Updation of stage area capacity curve using satellite data for water year 1996-1997.

b) Estimation of storage loss due to sedimentation.

c) Comparison of results with the hydrographic survey.

3.0 STUDY AREA

The total catchment area upto the project site is 91,750 sq.kms. The estimated capacity of the reservoir at FRL 332.537 m is 2796.8 Million m^3. Construction of the reservoir was taken up in 1963 for construction of dam upto 322.48-m elevation (crest of spillway). First impounding in the reservoir was made in 1970 when irrigation benefits started accruing. Subsequently after the Godavari Water Dispute Tribunal Award, the gates on the reservoir were provided and the full reservoir level was raised to 332.537 m. The dam site is located at 18° 58' N-Latitude and 78° 20' E-longitude at a distance of about 200 kms. from Hyderabad city on National Highway no. 7.

4.0 HYDROGRAPHIC SURVEYS

Hydrographic survey in Sriram Sagar reservoir was conducted in 1994. The capacity of the reservoir was computed by the contour area method and by the end area method i.e. taking into consideration the area of the cross sections and the distance in between them. Capacity in the river portion (113.27 Million m^3) has been worked out separately.

According to the above survey, the present gross capacity (without considering the capacity in river portion) of reservoir based on contour method was worked out to 2444.12 Million m^3, whereas the capacity based on end area method was 2377.13 Million m^3. The gross capacity before first impounding was 2796.8 Million m^3. Thus loss in capacity has been found to be of the order of 352.68 Million m^3 (Contour method) in 24 years. This amounted to a siltation rate of 1.6 mm/year .

5.0 APPROACH

Remote sensing technique makes use of water spread of the reservoir between maximum and minimum operating level during the observation period. Since the reservoir levels generally do not go below the Minimum Draw Down Level (MDDL) waterspread observations are not possible below MDDL. The same are to be extrapolated from observed elevation-area curve to find out capacity below MDDL. In the case of Sriram Sagar reservoir, the height difference between FRL (332.54m) and MDDL (324.31m) is 8.23m while the difference between MDDL (324.31m) and average river bed level (310.90m) is 13.41m. Extrapolation for such a large elevation range below MDDL is likely to add considerable subjectivity to the results. Thus the use of satellite remote sensing in the present study has been restricted in live storage zone only.

6.0 DATA USED

6.1 Satellite Data : Table 1 shows date of pass for satellite data corresponding to reservoir

Table 1: Date of pass for satellite data corresponding to reservoir

Path/Row/Quadrant	Sensor	Date of pass
99/59	LISS III	29-Oct-96
26/55/A1&B1	LISS II	8-Jan-97
144/47	TM	27-Jan-97
99/59	LISS-III	26-Feb-97
26/55/A1&B1	LISS-II	15-Mar-97
26/55/A1&B1	LISS-III	6-Apr-97

6.2 Field Data

- Original stage-area-capacity curve
- Reservoir level on date of pass of satellite data.
- Stage-area-capacity data corresponding to previous hydrographic survey.

7.0 METHODOLOGY

(a) Data base geo-referencing.

(b) Water spread area estimation.

(c) Estimation of reservoir capacity.

(d) Comparison with Hydrographic survey.

(e) Capacity loss estimation due to sedimentation.

7.1 Data Base Georeferencing

The satellite data corresponding to reservoir area obtained from NRSA Data Center was loaded on the system. The scene of 29th October, 96 was geo-referenced with respect to 1:50,000 Survey of India toposheet. For this GCP Works Module of PCI's EASI/PACE software was used. The geo-referencing was done by the hardcopy map on digitising tablet using second order equation with root mean square error less than 0.5 pixel and nearest neighborhood resampling technique to create a geo-referenced image of pixel size 23.5m x 23.5m. Subsequently other images were also registered with the geo-referenced image using image to image registration techniques.

7.2 Water Spread Area Estimation

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 Colour 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 $D_{n4} > T_{lf4}$ and $D_{n4} < T_{hf4}$ then pixel is in water spread.

Second model equation (using NIR band and ratioed channel)

If $D_{n4} > T_{ls4}$ and $D_{n4} < T_{hs4}$ and $D_{nv} > T_{lv}$ and $D_{nv} < T_{hv}$ then pixel is in water spread.

Where, D_{n4} is digital value in NIR band

D_{nv} is digital value in ratioed image channel

T_{lf4} & T_{hf4} are lower and higher thresholds for the first range of NIR band

T_{ls4} & T_{hs4} are lower and higher thresholds for the second range of NIR band

T_{lv} & T_{hv} 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 water spread. The combined water spread edited to remove the discontinuous water bodies. Masks of the water spread area prepared by modeling have been superimposed on each other and the boundary pixel on the periphery of the reservoir checked and corrected. Tail portion of the reservoir where it merges with river has been removed from the mask.

Water spread area has been calculated by multiplying number of pixels with area of each pixel. Table 2 shows the area for different dates.

Table 2: Water Spread Areas estimated from Satellite Images

Date of pass	Elevation (metre)	Area (Million.m^2)
29 October 1996	332.47	303.27
8 January 1997	330.35	254.59
27 January 1997	329.76	239.06
26 February 1997	328.33	199.40
15 March 1997	327.20	163.58
6 April 1997	325.34	122.08

The water elevation 332.47 m for October 1996 is near to Full Reservoir Level (332.54 m), whereas water elevation 325.34 m for April 1997 is near Minimum Draw Down Level (324.31 m).

7.3 Estimation of Reservoir Capacity

Area elevation curve has been plotted for the water-spread areas for different water level in the reservoir. As water spread areas could not be computed below RL. 325.34 m due to limitation of data availability, the curve has been extended to RL. 324.31 m (MDDL) through extrapolation.

Computation of the reservoir capacity at various elevations have been made using following formula

$$V = h/3\{ A1+A2 + \text{sqrt}(A1*A2) \}$$

where 'V' is the reservoir capacity between two successive elevations h1 and h2

'h' is the elevation difference (h1-h2)

'A1 & A2' are areas of reservoir water spread at elevations h1 & h2.

Table 3 shows the modified elevation – area - live capacity table.

Table 3: Live Storage Capacity of Reservoir at Different Elevations

ELEVATION (m)	SUBMERGENCE AREA (Million m^2)	CUM. CAPACITY (Million.m^3)
MDDL 324.31	99.00	0.00
324.50	104.00	19.57
325.00	115.00	74.29
325.50	125.50	134.40
326.00	136.00	199.76
326.50	147.50	270.61
327.00	158.50	347.10
327.50	171.50	429.58
328.00	188.50	519.54
328.50	205.00	617.89
329.00	218.00	723.62
329.50	232.00	836.10
330.00	245.00	955.34
330.50	258.00	1081.07
331.00	268.00	1212.57
331.50	280.00	1349.56
332.00	291.00	1492.30
332.50	304.00	1641.03
FRL 332.54	305.00	1652.24

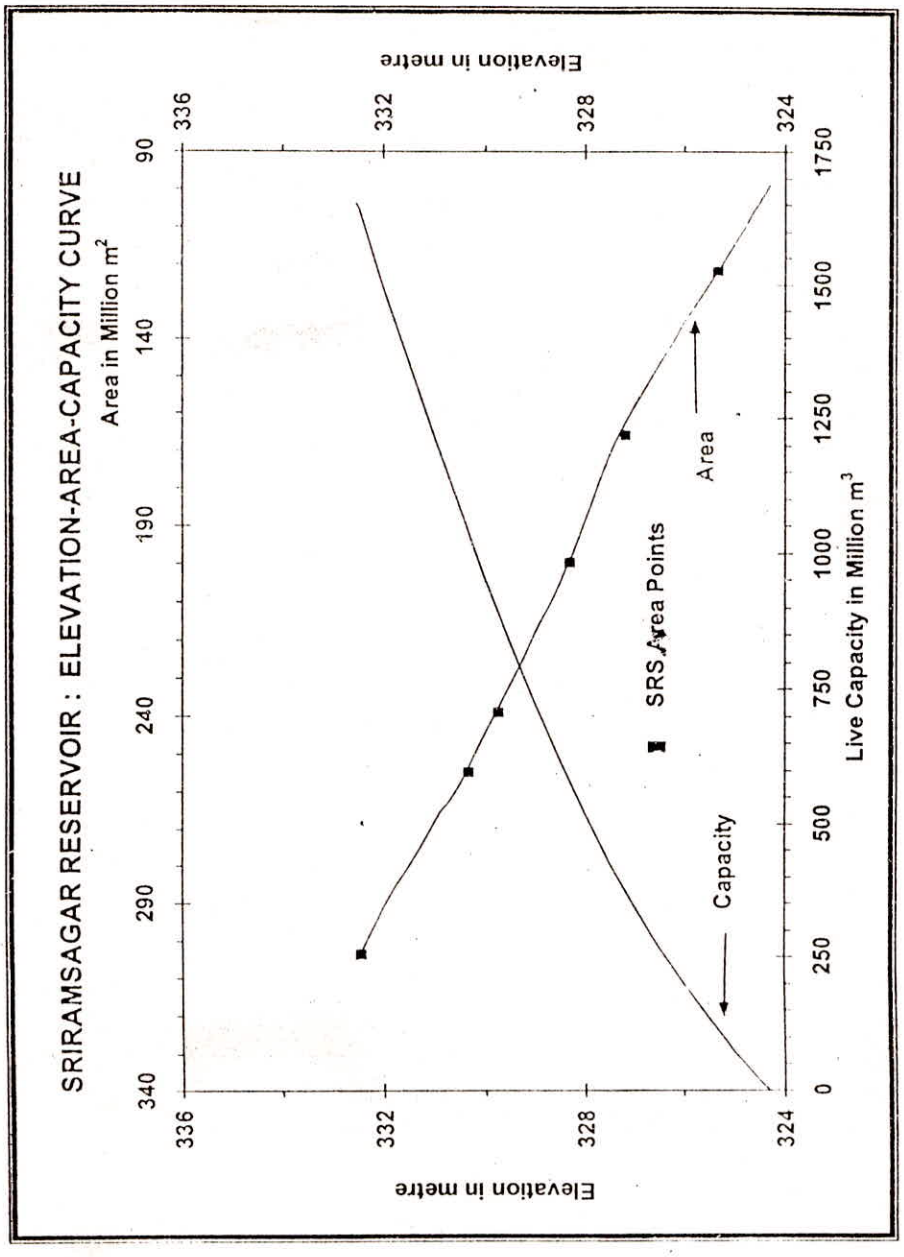

Fig. 1: Elevation – Area Capacity Curve from Sriram Sagar Reservoir

It is found that there is an increase of submergence area in between RL 326.00 m & 329.00 m. Increase in submergence area shows the erosion instead of sedimentation in between these reservoir elevations. Again in between RL 329.50 m & 331.00 m there is no change in submergence area, showing no sedimentation. Above RL 331.00 m upto FRL (332.54 m) there is a little reduction in submergence area. A close observation of the results of the hydrographic survey data and consequent revised original reservoir area data in between RL 326.00 m & 329.50 m shows some discrepancy in the concluding results as there may be still some errors in arriving at the revised original reservoir area data.

7.4 Comparison With Hydrographic Survey

Table 4 shows the comparison of submergence areas among original survey, hydrographic survey and SRS survey at a regular interval of 0.5 m.

Table - 4: Comparison of Submergence Area of Reservoir

ELEVATION (m)	SUBMERGENCE AREA (Million m^2)		
	Original (1970)	Hydrographic Survey (1994)	SRS (1997)
MDDL 324.31	159.00	135.30	99.00
324.50	163.50	140.00	104.00
325.00	168.50	151.50	115.00
325.50	174.00	163.50	125.50
326.00	180.50	176.50	136.00
326.50	186.50	189.50	147.50
327.00	192.50	203.50	158.50
327.50	200.50	218.50	171.50
328.00	212.00	229.00	188.50
328.50	225.00	239.00	205.00
329.00	242.50	247.50	218.00
329.50	258.50	258.50	232.00
330.00	271.00	271.00	245.00
330.50	284.00	284.00	258.00
331.00	293.50	293.50	268.00
331.50	305.00	301.50	280.00
332.00	319.50	311.00	291.00
332.50	333.00	329.00	304.00
FRL 332.54	334.80	334.10	305.00

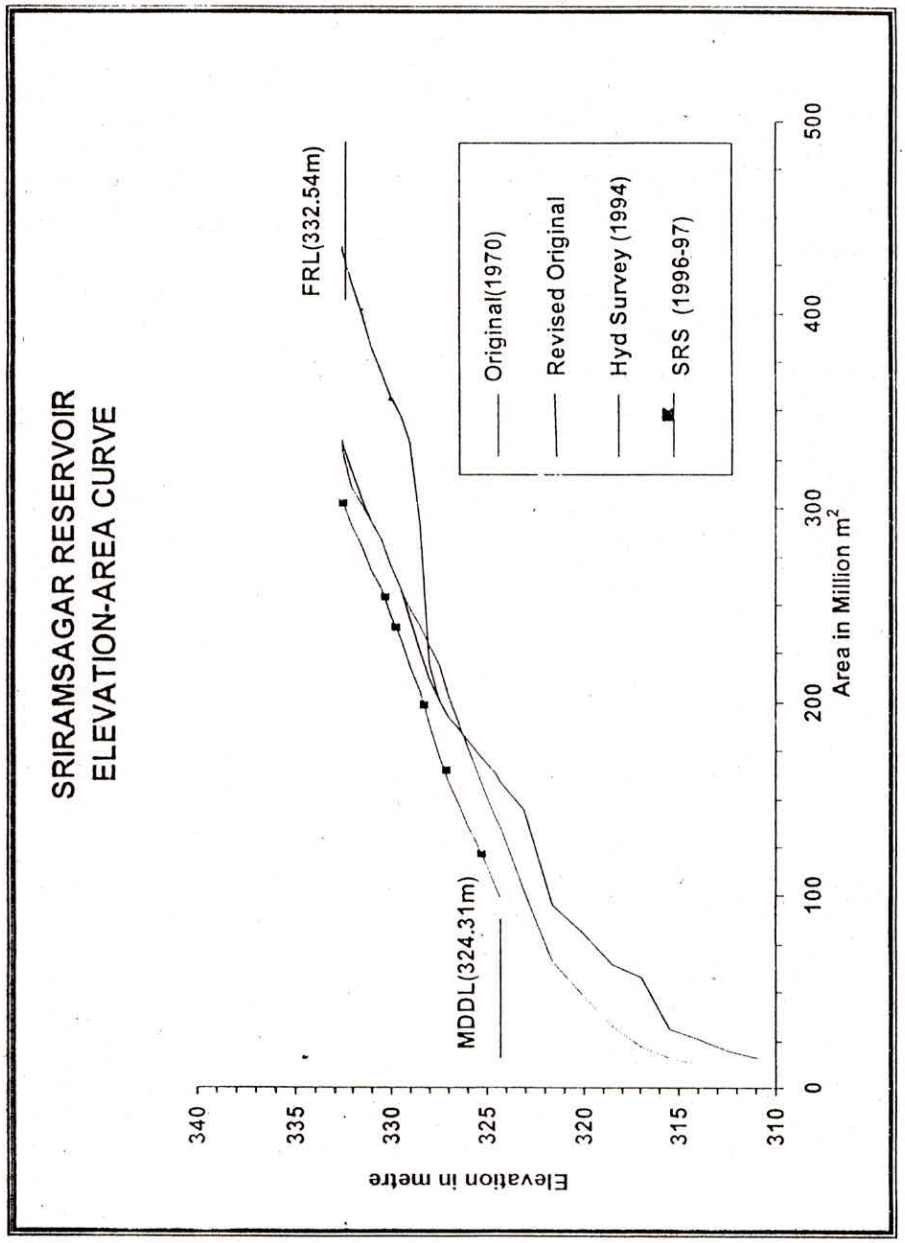

Fig. 2: Elevation – Area Curve for Sriram Sagar Reservoir

Table 5 shows the comparison of present live storage capacity with the original capacity as well as capacity of hydrographic survey.

Table 5: Comparison of Live Storage Capacity of Reservoir

ELEVATION (m)	Live Storage Capacity (Million m^3)		
	Original (1970)	Hydrographic Survey (1994)	SRS (1997)
MDDL 324.31	0.00	0.00	0.00
324.50	31.09	25.91	19.57
325.00	114.08	100.38	74.29
325.50	199.71	181.48	134.40
326.00	288.33	262.07	199.76
326.50	380.07	359.85	270.61
327.00	474.82	456.89	347.10
327.50	573.06	561.38	429.58
328.00	676.17	672.38	519.54
328.50	785.41	788.20	617.89
329.00	902.25	907.98	723.62
329.50	1027.48	1037.39	836.10
330.00	1159.85	1169.63	955.34
330.50	1298.58	1301.87	1081.07
331.00	1442.95	1447.98	1212.57
331.50	1592.57	1597.95	1349.56
332.00	1748.68	1746.72	1492.30
332.50	1911.79	1902.47	1641.03
FRL 332.54	1923.81	1914.16	1652.24

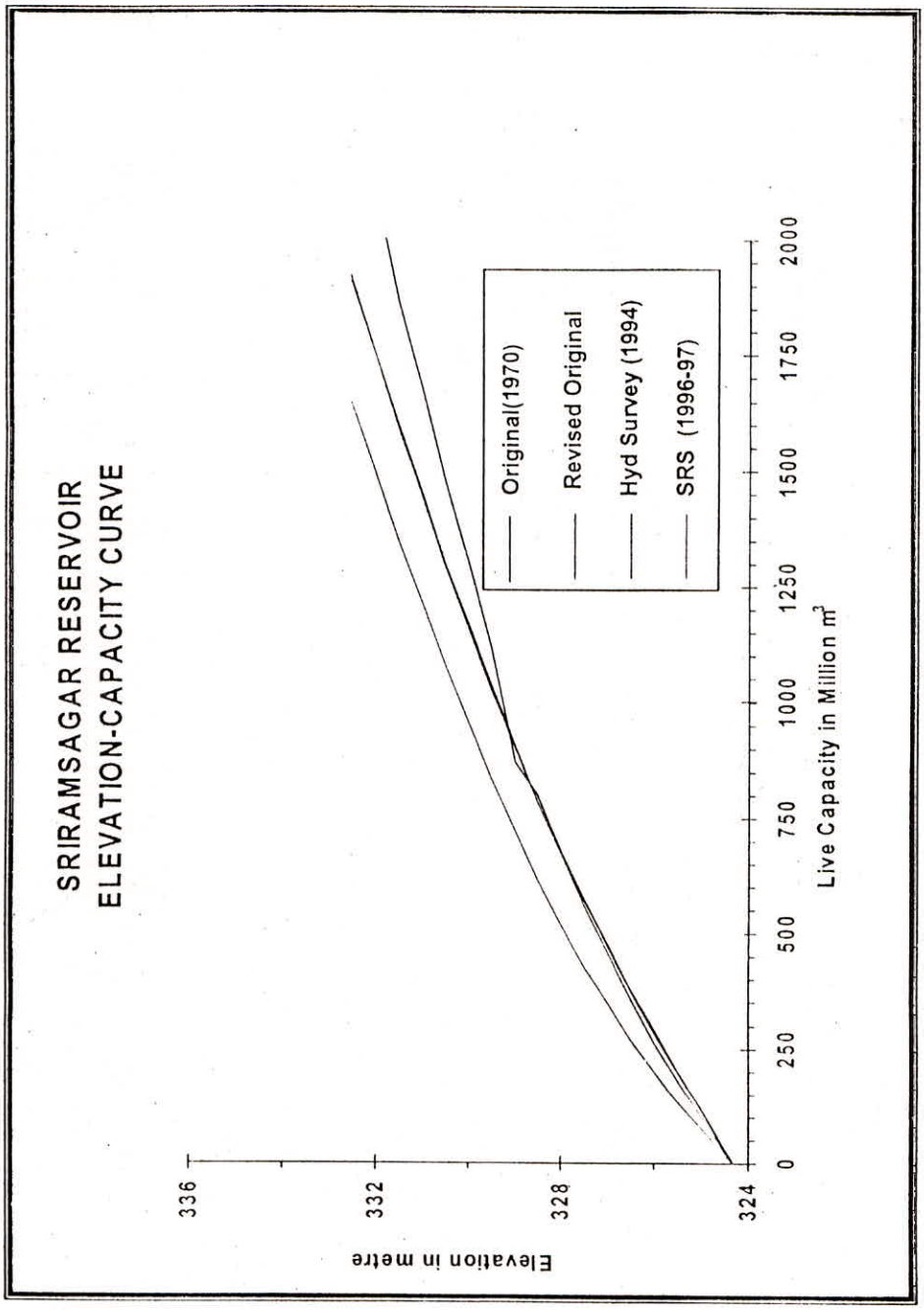

Fig. 3: Elevation Capacity Curve for Sriram Sagar Reservoir

7.5 Capacity Loss Estimation Due To Sedimentation

Table 6 shows the loss in live capacity at different elevations

Table 6: Live Capacity loss due to sedimentation at different elevations

ELEVATION (m)	Live Capacity In (Million m3)		Live capacity loss In (Million m^3)
	Original	SRS	
MDDL 324.31	0.00	0.00	0.00
324.50	31.09	19.57	11.52
325.00	114.08	74.29	39.79
325.50	199.71	134.40	65.31
326.00	288.33	199.76	88.57
326.50	380.07	270.61	109.46
327.00	474.82	347.10	127.72
327.50	573.06	429.58	143.49
328.00	676.17	519.54	156.63
328.50	785.41	617.89	167.52
329.00	902.25	723.62	178.63
329.50	1027.48	836.10	191.38
330.00	1159.85	955.34	204.51
330.50	1298.58	1081.07	217.51
331.00	1442.95	1212.57	230.39
331.50	1592.57	1349.56	243.01
332.00	1748.68	1492.30	256.38
332.50	1911.79	1641.03	270.76
FRL 332.54	1923.81	1652.24	271.57

8.0 RESULTS AND DISCUSSIONS

1. Sediment deposition in 27 years (1970-97) carried out by present study and as pe hydrographic survey is given below.

Table 7: Summary of results

Capacity	Original (1970)	Hydrographic (1994)			SRS (1997)		
Storage	Original capacity	Estimated capacity	Loss in capacity	% loss (annual)	Estimated capacity	Loss in capacity	% loss (annual)
Live Storage	1923.81	1914.16	9.65	0.021	1652.2	271.57	0.522

2. The live storage capacity of Sriram Sagar reservoir as per present study is found to be 1652.20 Million m^3 for the year 1996-97. As per the hydrographic survey conducted in 1994 the live storage capacity is 1914.16 Million m^3. Modified elevation-area-capacity table worked out by the present study is given at table 3.

3. Results of capacities assessed through hydrographic surveys conducted in 1994 and satellite remote sensing survey in 1997 vis a vis original capacity are shown in table 5.

4. Rate of silting of reservoir as per surveys done so far has been computed for live storage and results obtained are summarised below.

Table 8: Average rate of siltation for capacity surveys in mm/yr.

Storage	Hydrographic Survey (1994)	SRS Survey (1997)
Live Storage	0.044	1.1

5. In the report of hydrographic survey, capacity in the river portion (113.27 Million m^3) has been worked out separately. As for making comparison (of water spread area and capacity) of Hydrographic survey with present SRS, water spread area and capacity data of reservoir corresponding to different elevation of reservoir covering live storage should be available. Water spread area and capacity data for this river portion is not available in the desired format. So for comparing the results of present study with that of hydrographic survey the capacity of river portion has been deducted from the given gross capacity in the report of hydrographic survey.

6. The loss in gross capacity with and without considering river portion capacity is of the order of 239.22 Million m^3 & 352.5 Million m^3 respectively. This amounted to a siltation rate of 1.1 mm/year & 1.6mm/year respectively. The loss in live capacity with and without considering river portion capacity is of the order of -103.63 Million m^3 (negative value) & 9.65 Million m^3 respectively. This amounted to a siltation rate of -.47 mm/year & 0.044 mm/year respectively. Comparison of the submergence area of hydrographic survey

with original survey shows an increase of submergence area in between RL 326.00 m & 329.00 m (Table-4). Increase in submergence area indicates the erosion instead of sedimentation in between above mentioned reservoir elevations. Again in between RL 329.50 m & 331.00 m there is no change in submergence area, showing no sedimentation. Above RL 331.00 m upto FRL (332.54 m) there is a little reduction in submergence area. A close observation of the results of the hydrographic survey data and consequent revised original reservoir area data in between RL 326.00 m & 329.50 m shows some discrepancy in the concluding results as there may be still some errors in arriving at the revised original reservoir area data.

9.0 LIMITATION/OBSERVATION

- The reservoir capacity estimation using satellite remote sensing technique has been made between MDDL and FRL as for this region only the satellite data is available.

- Ground truth verification of boundary pixels is not possible due to continuos variation in reservoir levels which prevents correlating field observation of reservoir boundary with satellite data.

10.0 CONCLUSIONS

1. According to the reservoir sedimentation data available with CWC, it is estimated that the average losses of capacity in gross storage, live storage and dead storage are about 0.5%, 0.35% and 1.13% respectively.

2. The live storage capacity of Sriram Sagar reservoir has been found to be 1652.20 Million m^3 in 1997.

3. Capacity loss of 14.12 % was observed in live storage, in a period of 27 years (annual loss 0.523 %) since the first impounding of the reservoir in 1970, whereas estimated capacity loss by hydrographic survey (1994) in live storage is 0.50 %.

4. Average rates of siltation are 1.1 mm/yr and 0.044 mm/yr in regard of Satellite remote sensing based survey (1997) and hydrographic survey (1994) respectively.

5. A close observation of the results of the hydrographic survey and consequent revised original reservoir area data (Table-4) in between RL 326.00 m & 329.50 m shows some discrepancy in the concluding results as there may be still some errors in arriving at the revised original reservoir area data. Further more visual observation of Elevation-Area Curve indicates the correctness of SRS curve.

6. 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.

SALIENT FEATURES OF SRIRAM SAGAR DAM RESERVOIR

Location	Pochampad Village, Nizamabad District, Andhra Pradesh
Purpose	Irrigation and Hydro Power
River	Godavari
Area of catchment	91,750 sq.km
Year of commencement	1963
Year of first impounding	1970
Reservoir	
Area at F.R.L.	334.823 sq.km
Gross storage capacity	2796.80 Million m^3
Effective storage capacity	1923.81 Million m^3

REFERENCES

2000, Report on Reservoir Sedimentation study of Sriram Sagar Reservoir, CWC.