Mathematical Representation of Elevation-Area-Capacity Curves for Indian Reservoirs

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ABSTRACT

Elevation-Area-Capacity (EAC) curves of a storage reservoir are among the primary requirements for various kind of reservoir analysis such as reservoir flood routing, reservoir operation analysis, reservoir classification, and reservoir sediment distribution. A river basin may contain a large number of reservoirs/hydraulic structures. Though some of the general details like MDDL, FRL, and storage capacity/reservoir area at FRL and MDDL may be available from various sources (say, web site of India WRIS), it may be difficult to gather EAC tables for various reservoirs.

In this study, an effort has been made to characterize the elevation-area and elevation-capacity curves for Indian reservoirs. The elevation-area-capacity tables of 84 Indian reservoirs have been used to develop such relationships. Depending on the availability of type and range of original and revised EAC tables for different reservoirs, the reservoirs have been classified into four types: Gorge, Hill, Flood plain – foothill, and Lake. Dimensionless plots (relative depth vs. relative area or relative capacity) in the live storage zone of reservoirs in normal and Log scales have been prepared for each reservoir. Such plots have been clubbed for all the reservoirs for deriving representative unique mathematical equations for the area and capacity curves. The methodology has been programmed in MS-EXCEL. From the available plots, average dimensionless curves have been plotted and generalized mathematical equations have been derived which can be used to approximate the elevation-area and elevation-capacity curves within the live storage zone of a reservoir.

In the study, the developed mathematical relationships (within the live storage zone) and the method proposed by J. Mohammadzadeh-Habili et. al (2009) have been used to investigate their applicability for Indian reservoirs. A number of reservoirs, for which the data requirements of the two methods could be met, have been selected and comparative plots of areas and capacities from the two methods have been prepared in conjunction with the original curves. It is seen that the two methods approximate the intermediate areas and capacities quite close to the observed values.

However, the mathematical relationships developed in this study are applicable only in the live storage zone of a reservoir and do not take into account the type of reservoir under consideration. Since average relationships have been worked out, the mathematical relationships may over or under-estimate the intermediate area and capacity values for some reservoirs depending on the location of their dimensionless area and capacity curves with respect to the average curve. On the other hand, method proposed by J. Mohammadzadeh-Habili et. al (2009) provides area and capacity estimates in the full range of the reservoir and also accounts for the characteristics of a reservoir in terms of reservoir coefficient.

The developed equations only approximate the intermediate area and capacity curves of a reservoir. For those analyses which are highly sensitive to the accurate specification of reservoir areas and capacities at intermediate elevations, observed elevation-area-capacity tables may be used.

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CHAPTER - 1
INTRODUCTION

1. General

India is bestowed with rich water resources but more than 80% of the annual rainfall over this country falls in the four monsoon months from June to September. Because of the high time and space variability of rainfall and uncertain nature of monsoon, reservoirs form one of the most important components of water resources development project in India. More than 4500 major and medium dams have already been constructed all over the country to tap the available water resources so that the water can be utilized in accordance with the requirements of mankind.

Any water-related activity that takes place in one part of a river basin may have consequences in the other part. Therefore, effective management of water and related environment in a river basin requires an integrated and co-ordinated planning and utilization within the basin. The efficient use of water resources at the basin scale requires judicious and proper management of various hydraulic structures through their integrated operation so that various demands in the basin can be satisfied to the maximum extent and sustainability of surface and groundwater resources can be maintained. In this context, reservoir operation forms a very important part of the planning and management of water resources system. Reservoir management involves allocating available water among multiple uses and users, minimizing the risks of water shortages and flooding, and optimizing the beneficial use of water. A reservoir operation policy specifies the amount of water to be released from the storage at any time depending upon the state of the reservoir, level of demands and any information about the likely inflows in the reservoir.

Elevation-Area-Capacity (EAC) curves of a storage reservoir are among the primary requirements for various kind of reservoir analysis such as reservoir flood routing, reservoir operation analysis, reservoir classification, and reservoir sediment distribution. A river basin may contain a large number of reservoirs/hydraulic structures. Though some of the general details like MDDL, FRL, and storage capacity/reservoir area at FRL and MDDL may be available from various sources (say, web site of India WRIS), it may be difficult to gather EAC tables for various reservoirs.

In this study, an effort has been made to characterize the elevation-area and elevation-capacity curves for Indian reservoirs and develop generalized mathematical relationships which can be used to approximate the elevation-area and elevation-capacity curves within the live storage zone of a reservoir using the basic details of the reservoir (such as MDDL, FRL, and storage capacity/ reservoir area at FRL and MDDL). Such equations can also be used in the river basin models and reservoir analysis models to approximate EAC relationships, thus reducing the dimensional requirements of such models (though very large dimensional matrices can be handled by present-day high capacity computers). J. Mohammadzadeh-Habili et. al (2009) have also reported such relationships for reservoirs which have been evaluated for 16 reservoirs.

2. Scope of Study

The scope of the present study is to analyze the available elevation-area-capacity curves of some Indian reservoirs and develop the generalized mathematical relationships for the same. The EAC tables of 78 reservoirs, collected from various sources, have been used. In addition, the method proposed by J. Mohammadzadeh-Habili et. al (2009) have also been applied to some reservoirs to find out whether such method can be used for Indian reservoirs.

The data availability is not uniform in all cases. In some cases, original EAC tables (at the time of first impoundment of the reservoir) and revised EAC tables (obtained from capacity surveys) have been available and separate analysis has been carried out for the original and revised conditions. In other cases, reservoir area details are missing and only the original and revised capacity curves are available. Further, in some cases, the EAC details are available from river bed while in other cases, the same are available in the live storage zone (between MDDL and FRL) only. Finally, the density of data points in the EAC tables are also variable.

To account for the varied data availability constraints, a methodology has been formulated for the analysis which is presented in Chapter – 2. Analytical curves for various reservoirs have been prepared and presented in Chapter – 3. Finally, the results of analysis have been detailed in Chapter – 4.

* * *

CHAPTER - 2
DATA AVAILABILITY AND METHODOLOGY ADOPTED

2.1 Data Availability

Capacity tables of 78 reservoirs have been used in the analysis. Original and revised elevation-capacity data of 42 reservoirs in the State of Gujarat, Maharashtra, and Andhra Pradesh have been provided by CWC. The data for 16 reservoirs have been collected from various past studies carried out at NIH.

A weekly newsletter of real-time available water storage in 84 major Indian reservoirs is published by CWC regularly and circulated widely. The elevation – capacity data of these reservoirs has been computerized and based on the variation of water levels in the reservoirs during the past two years, elevation – capacity table has been generated. Out of these 84 reservoirs, data of 20 reservoirs have been used (for other reservoirs, either the range of elevation variation in the live storage zone could not be covered, or the basic information was not available or they were covered from the data from other sources).

For all the reservoirs under consideration, the general details such as MDDL, FRL, year of construction, the name of river on which located, and catchment area have been taken from the web site of India WRIS (http://india-wris.nrsc.gov.in/wrpinfo) under the section of water resources projects.

2.2 Methodology Adopted

As stated earlier, varied type and range of original and revised EAC tables were available for different reservoirs. The various steps followed in the analysis are enumerated below:

a) Determination of type of reservoir [Gorge (Type-IV), Hill (Type-III), Flood plain – foothill (Type-II), and Lake (Type-I)].

b) Interpolation of the original and revised EAC table at fixed elevation interval (0.5 m) incorporating the values at MDDL and FRL also.

c) Separation of original and revised Elevation-Area and Elevation-Capacity tables in the live storage zone (between MDDL and FRL).

d) Computation of relative depth and relative area (or relative capacity) in the live storage zone in normal and Log scales

e) Plot of dimensionless (relative depth vs. relative area or relative capacity) graphs in the live storage zone of reservoirs in normal and Log scales.

f) Clubbing of dimensionless plots for common type of reservoirs to find their range of variation for representation with unique mathematical equations.

The methodology has been programmed in MS-EXCEL and detailed curves obtained for different reservoirs are shown in Chapter – 3. A few steps are elaborated below.

2.2.1 Determination of type of a reservoir

First, the type of reservoir has been ascertained [Gorge (Type-IV), Hill (Type-III), Flood plain – foothill (Type-II), and Lake (Type-I)] which depends on the shape of the gorge and characteristics of submergence area. The classification is based on the ratio of reservoir capacity to reservoir depth plotted on a log-log scale (as shown in Figure – 2.1).

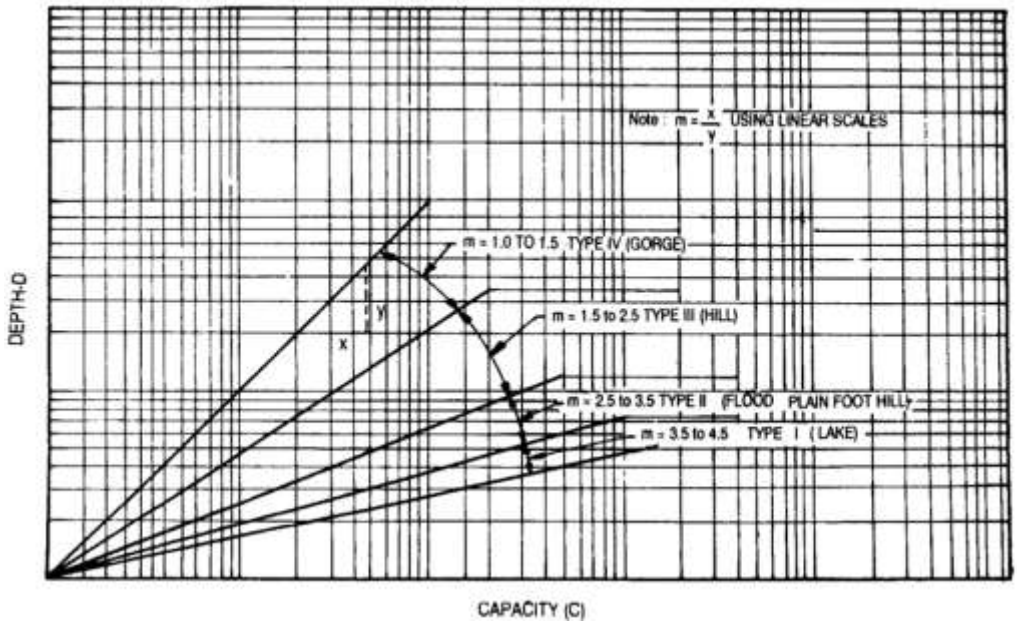


Figure – 2.1: Plot of Reservoir Depth vs Capacity for Classification

For ascertaining the type of reservoir, revised elevation-capacity tables have been used to extent possible. Further, reservoir types could be ascertained only for those reservoirs for which elevation-capacity tables are available from the river bed up to the FRL. For other reservoirs, type of reservoir could not be determined. Computations for a sample reservoir are shown in Table – 2.1. Following steps are followed for determination of type of reservoir:

a) The EAC table is interpolated (described in next section) to have values of area and capacity and regular elevation intervals of 0.5 m above the river bed.

b) The depth (m) of the reservoir above the river bed is computed by subtracting elevation at river bed from a particular elevation (above river bed).

c) Logarithmic values (to the base 10) of the reservoir depth and capacity are computed.

d) A plot is drawn for the Log (relative depth) on x-axis vs. Log (relative capacity) on the y-axis.

e) The slope of the best-fit linear trend line (m) is noted.

f) The value of 'm' for different reservoirs is as follows:

m = 1.0 – 1.5 [Gorge (Type-IV) reservoir]
m = 1.5 – 2.5 [Hill (Type-III) reservoir]
m = 2.5 – 3.5 [Flood plain – foothill (Type-II) reservoir]
m = 3.5 – 4.5 [Lake (Type-I) reservoir]

2.2.2 Interpolation of Elevation-Area-Capacity tables

In the available EAC tables, the area and capacity values have been provided at different non-uniform intervals which results in covering varied range of relative depth vs relative area (or capacity) values when plotted in Log scale. To cover the range uniformly for different reservoirs, EAC values have been interpolated at uniform elevation interval of 0.5 m.

The ***"EAC Interpolation"*** module of ***NIH_ReSyP*** software has been extensively used for the purpose. This module facilitates calculation of intermediate values in the elevation-area-capacity table using linear interpolation. All the available values of EAC table are read as input by the module. The interpolation for any elevation is carried out considering its upper and lower available EAC values.

2.2.3 Dimensionless plots of relative depth vs relative area (or relative capacity)

After computing the EAC values at uniform elevation interval, the EAC values within the live storage zone are segregated and relative depth and relative area (or relative capacity) values are estimated as percentage. The computations for a sample reservoir are shown in Table – 2.2. The computational steps are as follows:

a) The elevation-area-capacity table within the live storage zone is segregated.

b) The depth (m) of the reservoir above the MDDL is computed by subtracting elevation at MDDL from a particular elevation (above MDDL).

c) Similarly, increase in area (and capacity) of the reservoir above the MDDL is computed by subtracting area (and capacity) at MDDL from the corresponding value at a particular elevation (above MDDL).

d) The largest values of depth, incremental area and incremental capacity in live storage zone are determined and relative values of depth, incremental area and incremental capacity are estimated as percentage.

e) Logarithmic values (to the base 10) of relative depth, relative area, and relative capacity are computed.

f) A plot is drawn for the elevation (on y-axis) vs. original and revised capacity (on x-axis) in the live storage zone.

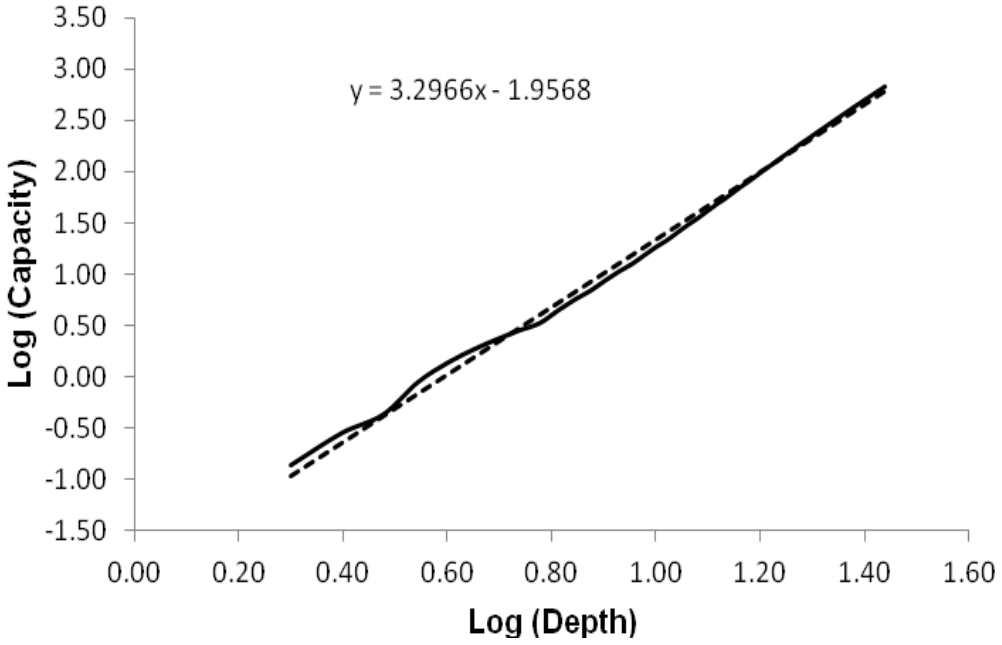
g) Another plot is drawn for the Log (relative area) on y – axis vs. Log (relative depth) on x - axis.

h) Another plot is drawn for the Log (relative capacity) on y – axis vs. Log (relative depth) on x – axis.

i) Separate plots of Log (relative depth) vs. Log [relative area (or relative capacity)] are made for the original and revised EAC tables in the live storage zones of reservoirs.

Table – 2.1
Sample table for computation of type of reservoir

Elevation (m)	Capacity (MCM)	Depth (m)	Log_{10} (Depth)	Log_{10} (Capacity)	Elevation (m)	Capacity (MCM)	Depth (m)	Log_{10} (Depth)	Log_{10} (Capacity)
252.99	0	0	NA	NA	267.49	70.7247	14.5	1.1614	1.8496
254.99	0.1391	2	0.3010	-0.8567	267.99	79.6311	15	1.1761	1.9011
255.49	0.2852	2.5	0.3979	-0.5449	268.49	89.9816	15.5	1.1903	1.9542
255.99	0.4313	3	0.4771	-0.3652	268.99	101.6694	16	1.2041	2.0072
256.49	0.8935	3.5	0.5441	-0.0489	269.49	113.3572	16.5	1.2175	2.0544
256.99	1.3893	4	0.6021	0.1428	269.99	126.4601	17	1.2304	2.1020
257.49	1.8851	4.5	0.6532	0.2753	270.49	141.1485	17.5	1.2430	2.1497
257.99	2.3809	5	0.6990	0.3767	270.99	155.837	18	1.2553	2.1927
258.49	2.8767	5.5	0.7404	0.4589	271.49	171.9008	18.5	1.2672	2.2353
258.99	3.3725	6	0.7782	0.5280	271.99	189.8362	19	1.2788	2.2784
259.49	4.4775	6.5	0.8129	0.6510	272.49	207.7716	19.5	1.2900	2.3176
259.99	5.7275	7	0.8451	0.7580	272.99	227.011	20	1.3010	2.3560
260.49	6.9774	7.5	0.8751	0.8437	273.49	248.4196	20.5	1.3118	2.3952
260.99	8.7658	8	0.9031	0.9428	273.99	269.8283	21	1.3222	2.4311
261.49	10.7243	8.5	0.9294	1.0304	274.49	292.5706	21.5	1.3324	2.4662
261.99	12.6828	9	0.9542	1.1032	274.99	318.0528	22	1.3424	2.5025
262.49	15.4234	9.5	0.9777	1.1882	275.49	343.535	22.5	1.3522	2.5360
262.99	18.4807	10	1.0000	1.2667	275.99	370.2152	23	1.3617	2.5685
263.49	21.538	10.5	1.0212	1.3332	276.49	399.985	23.5	1.3711	2.6020
263.99	25.6729	11	1.0414	1.4095	276.99	429.7547	24	1.3802	2.6332
264.49	30.3542	11.5	1.0607	1.4822	277.49	460.4762	24.5	1.3892	2.6632
264.99	35.0355	12	1.0792	1.5445	277.99	494.359	25	1.3979	2.6940
265.49	40.8598	12.5	1.0969	1.6113	278.49	528.2419	25.5	1.4065	2.7228
265.99	47.3979	13	1.1139	1.6758	278.99	562.9205	26	1.4150	2.7504
266.09	48.74467	13.1	1.1173	1.6879	279.49	601.1415	26.5	1.4232	2.7790
266.49	53.936	13.5	1.1303	1.7319	279.99	639.3625	27	1.4314	2.8057
266.99	61.8184	14	1.1461	1.7911	280.42	672.4164	27.43	1.4382	2.8276



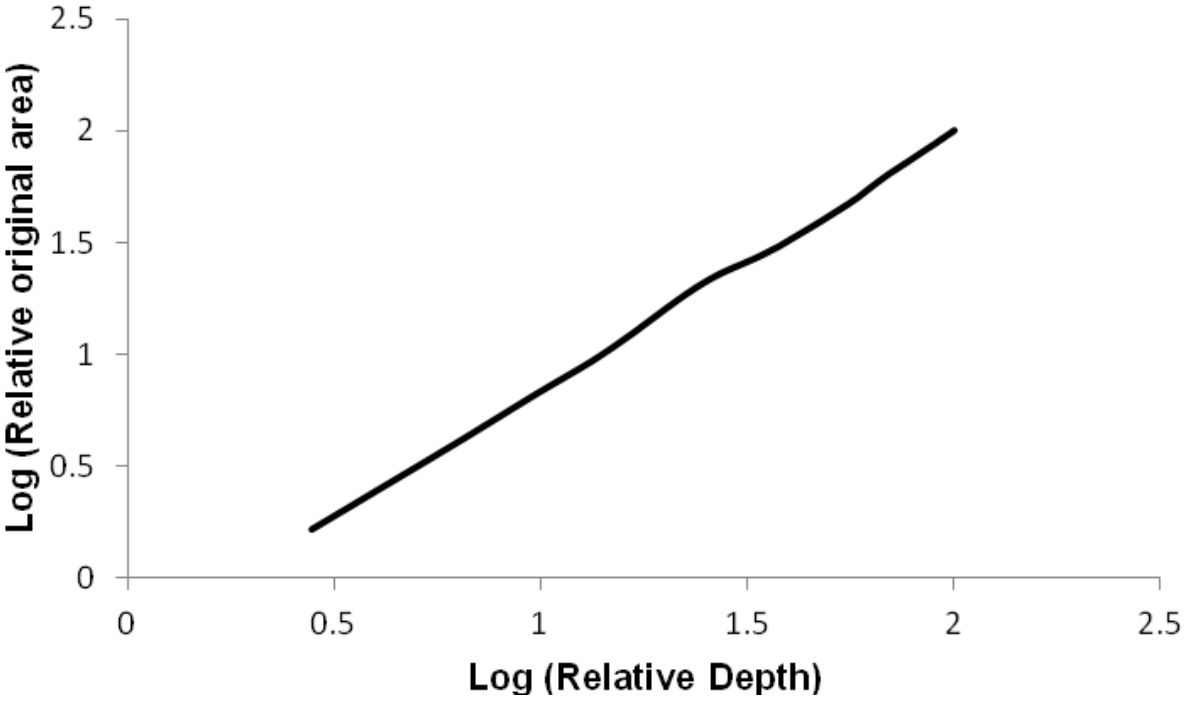
m - 3.2966

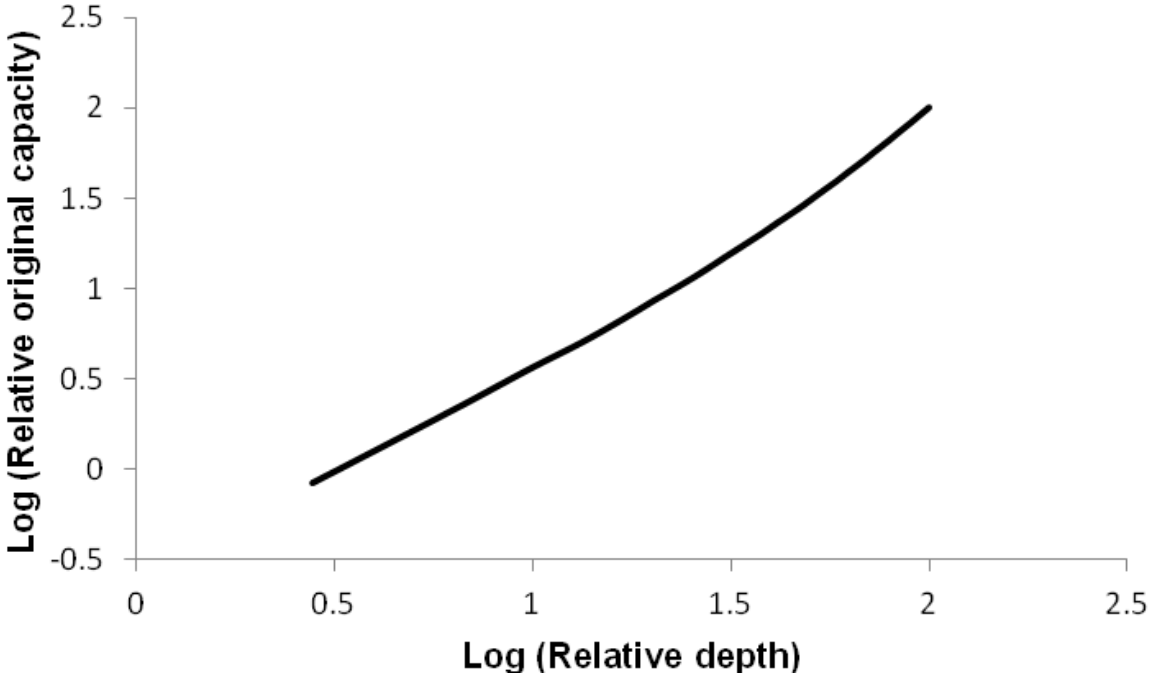
Type of Reservoir - Type-II (Floodplain - foot hill)

Table – 2.2

Sample computations of relative area (or relative capacity) with relative depth in the live storage zone of a reservoir

Elevation (m)	Area (M sq m)	Capacity (MCM)	Depth (m)	Incremental area (MSM)	Live Capacity (MCM)	Relative values as percent			Logarithmic values (to base 10)		
						Depth	Area	Capacity	Relative depth	Relative area	Relative capacity
266.09	13.92	51.11	0.00	0.00	0.00	0	0	0	NA	NA	NA
266.49	15.04	56.45	0.40	1.12	5.34	2.79135	1.66620	0.84847	0.44581	0.22173	-0.07136
266.99	16.65	64.54	0.90	2.73	13.43	6.28053	4.07117	2.13307	0.79800	0.60972	0.32901
267.49	18.42	73.66	1.40	4.50	22.55	9.76971	6.70994	3.58220	0.98988	0.82672	0.55415
267.99	20.19	82.79	1.90	6.27	31.67	13.25890	9.34872	5.03134	1.12251	0.97075	0.70168
268.49	22.33	93.38	2.40	8.42	42.26	16.74808	12.54272	6.71366	1.22397	1.09839	0.82696
268.99	24.82	105.33	2.90	10.91	54.21	20.23726	16.25099	8.61189	1.30615	1.21088	0.93510
269.49	27.31	117.28	3.40	13.39	66.16	23.72645	19.95925	10.51011	1.37523	1.30014	1.02161
269.99	29.37	130.71	3.90	15.46	79.59	27.21563	23.03389	12.64316	1.43482	1.36237	1.10186
270.49	30.96	145.79	4.40	17.04	94.68	30.70482	25.39862	15.03930	1.48721	1.40481	1.17723
270.99	32.55	160.88	4.90	18.63	109.76	34.19400	27.76351	17.43543	1.53395	1.44347	1.24143
271.49	34.35	177.18	5.40	20.43	126.07	37.68318	30.44996	20.02602	1.57615	1.48359	1.30159
271.99	36.45	195.16	5.90	22.53	144.05	41.17237	33.57438	22.88127	1.61461	1.52601	1.35948
272.49	38.54	213.13	6.40	24.63	162.02	44.66155	36.69880	25.73652	1.64993	1.56465	1.41055
272.99	40.71	232.58	6.90	26.80	181.47	48.15073	39.92916	28.82545	1.68260	1.60129	1.45978
273.49	43.00	254.47	7.40	29.08	203.36	51.63992	43.33567	32.30312	1.71299	1.63685	1.50924
273.99	45.28	276.37	7.90	31.37	225.25	55.12910	46.74232	35.78078	1.74138	1.66971	1.55365
274.49	47.79	299.50	8.40	33.87	248.38	58.61828	50.47591	39.45484	1.76803	1.70308	1.59610
274.99	50.75	325.16	8.90	36.83	274.05	62.10747	54.88142	43.53239	1.79314	1.73943	1.63881
275.49	53.70	350.83	9.40	39.79	299.72	65.59665	59.28692	47.60991	1.81688	1.77296	1.67770
275.99	56.57	377.69	9.90	42.65	326.58	69.08583	63.55235	51.87666	1.83939	1.80313	1.71497
276.49	59.19	407.63	10.40	45.27	356.51	72.57502	67.45657	56.63134	1.86079	1.82902	1.75306
276.99	61.81	437.56	10.90	47.89	386.45	76.06420	71.36093	61.38603	1.88118	1.85346	1.78807
277.49	64.45	468.42	11.40	50.54	417.30	79.55338	75.30524	66.28760	1.90066	1.87683	1.82143
277.99	67.19	502.35	11.90	53.27	451.23	83.04257	79.38276	71.67708	1.91930	1.89973	1.85538
278.49	69.92	536.27	12.40	56.01	485.16	86.53175	83.46013	77.06658	1.93718	1.92148	1.88687
278.99	72.69	571.00	12.90	58.78	519.89	90.02094	87.58459	82.58269	1.95434	1.94243	1.91689
279.49	75.60	609.27	13.40	61.68	558.16	93.51012	91.91842	88.66243	1.97086	1.96340	1.94774
279.99	78.51	647.55	13.90	64.59	596.44	96.99930	96.25210	94.74218	1.98677	1.98341	1.97654
280.42	81.02	680.65	14.33	67.11	629.54	100.00	100.00	100.00	2.00000	2.00000	2.00000


Log (Relative original area)
2.5
2
1.5
1
0.5
0
0
0.5
1
1.5
2
2.5
Log (Relative Depth)


Log (Relative original capacity)
2.5
2
1.5
1
0.5
0
-0.5
0
0.5
1
1.5
2
2.5
Log (Relative depth)

* * *

CHAPTER - 3
ANALYSES OF VARIOUS RESERVOIRS

3.1 Presentation of Analysis for a Reservoir

The presentation of analysis for a reservoir includes the general details of the reservoir, plot of original and revised elevation – capacity curves in the live storage zone of reservoir, plot of depth vs. capacity (on Log-Log scale) for computation of 'm', and plots of original and revised relative depth vs. relative area (and/or relative capacity based on data availability) in the live storage zone of reservoir. The general details include the State and river in/on which the reservoir is located, the catchment area, MDDL and FRL and original capacities at MDDL and FRL, year of first impoundment, year of revised capacity survey, value of 'm' and classification of reservoir. Some of general details have been obtained from the web site of India WRIS (http://india-wris.nrsc.gov.in/wrpinfo).

3.2 Analysis of CWC/State Data – Reservoirs in Gujarat

From the EAC table data received from CWC/State for reservoirs in Gujarat State, a total of 23 reservoirs have been selected for the present analysis. In most of the cases, the original and revised Elevation - Capacity tables were available for the entire range of reservoir depth (river bed to FRL) which enabled the determination of type of reservoirs. However, original and revised areas at different elevations were not available and therefore, plots of relative depth vs. relative area corresponding to original and revised conditions could not be made.

3.3 Analysis of CWC/State Data – Reservoirs in Maharashtra

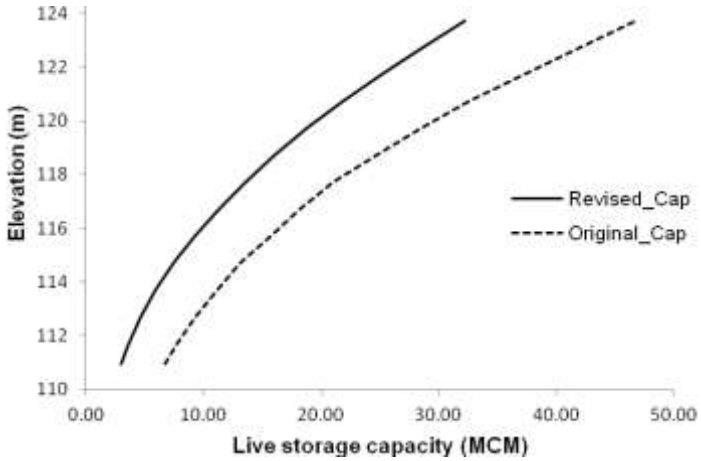
From the EAC table data received from CWC/State for reservoirs in Maharashtra State, a total of 11 reservoirs have been selected. The data availability varies widely for the reservoirs in this State. However, in most of the cases, the Elevation – Area – Capacity tables were available for the entire range of reservoir depth (river bed to FRL). The availability of Elevation – Capacity values for entire range enabled the determination of type of reservoirs. Depending on the availability of data, plots of relative depth vs. relative area (and/or relative capacity) corresponding to original and revised conditions have been prepared.

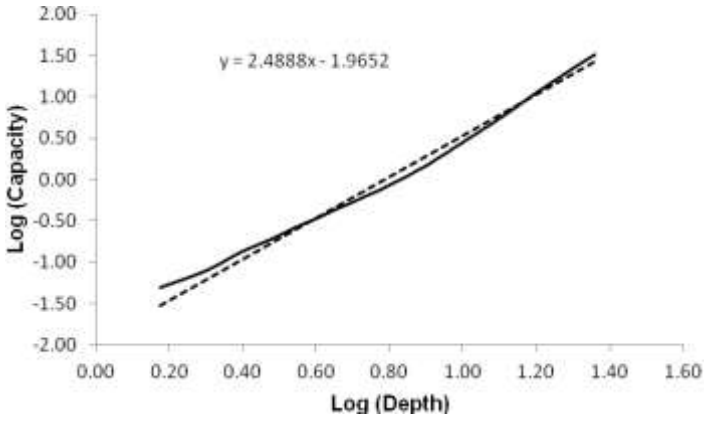
3.4 Analysis of CWC/State Data – Reservoirs in Andhra Pradesh

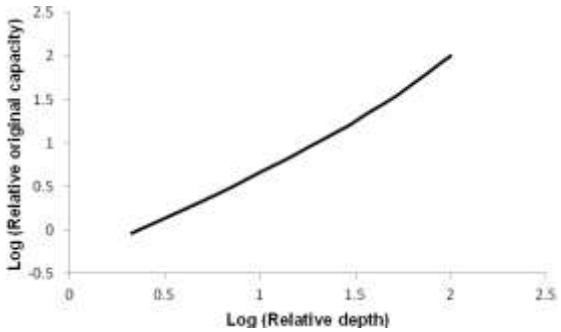
From the EAC table data received from CWC/State for reservoirs in Andhra Pradesh State, a total of 14 reservoirs have been selected for the present analysis. In most of the cases, the original and revised Elevation - Area - Capacity tables were available for the entire range of reservoir depth (river bed to FRL) which enabled the determination of type of reservoirs. Depending on the availability of data, plots of relative depth vs. relative area (and/or relative capacity) corresponding to original and revised conditions have been prepared.

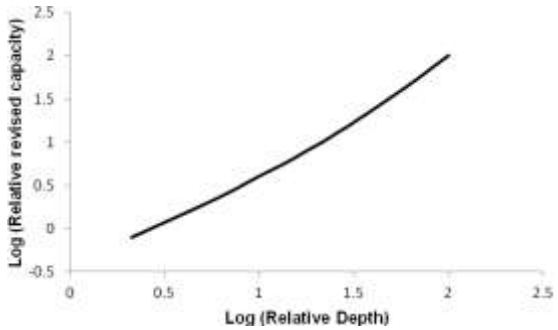
Bhadar Project

State – ***Gujarat***				
River	***Bhadar***		Catchment Area	***407***
MDDL (m)	***110.95***		Original capacity (MCM) at MDDL	***6.70***
FRL (m)	***123.72***		Original capacity (MCM) at FRL	***46.72***
Year of first impoundment	***1983***		Year of capacity survey	***1999***
Value of 'm'	***2.48***		Type of reservoir	***Type-III***



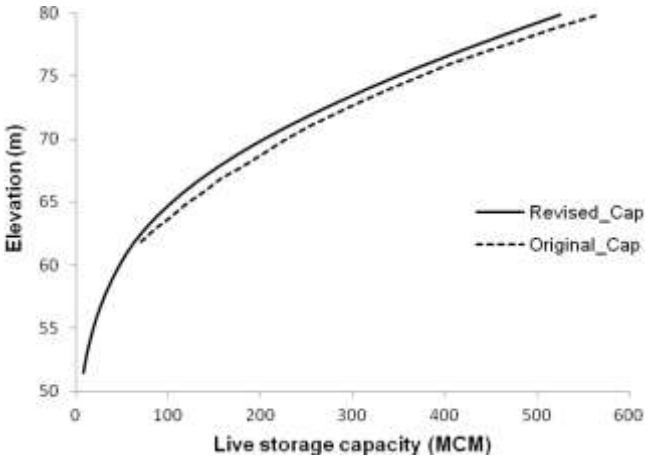


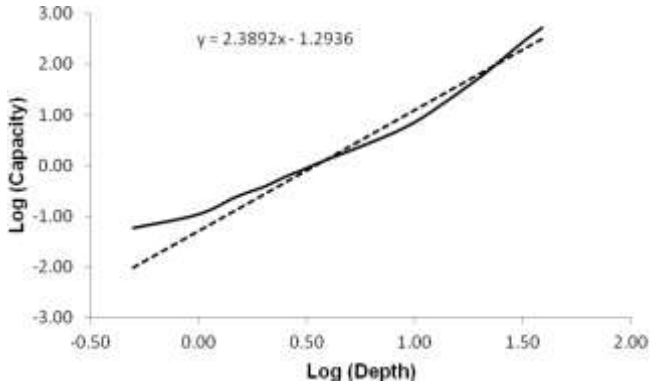


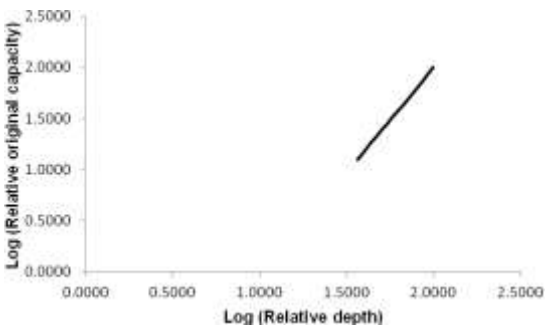


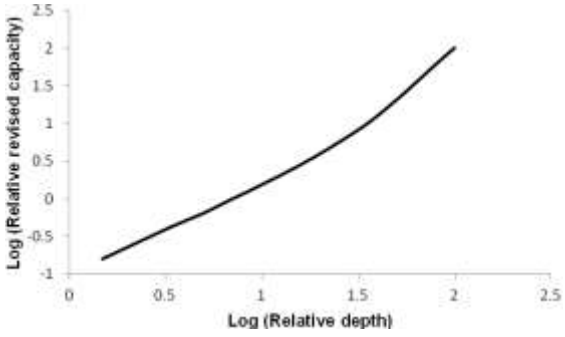
Damanganga Project

State – ***Gujarat***				
River	***Damanganga***		Catchment Area	***1813***
MDDL (m)	***51.44***		Original capacity (MCM) at MDDL	***NA***
FRL (m)	***79.86***		Original capacity (MCM) at FRL	***567***
Year of first impoundment	***1983***		Year of capacity survey	***1999***
Value of 'm'	***2.39***		Type of reservoir	***Type-III***



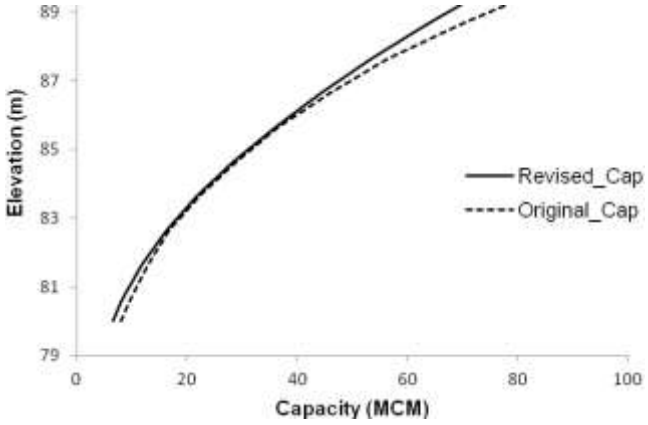


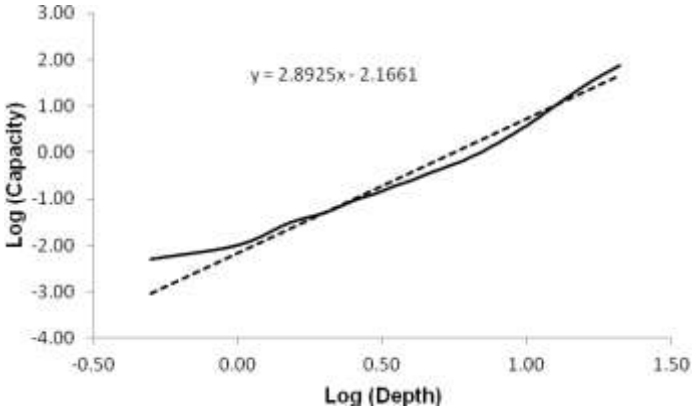


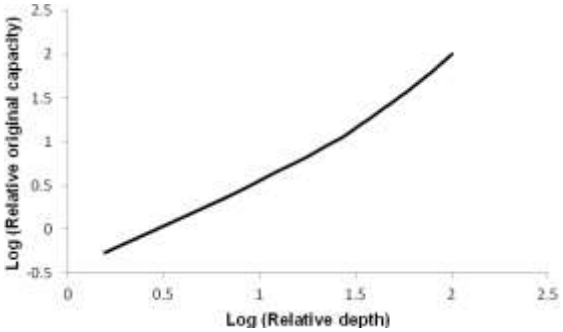


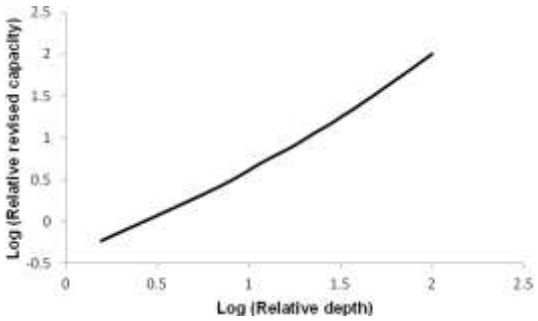
Deo-II Project

State – ***Gujarat***				
River	***Deo***		Catchment Area	***259***
MDDL (m)	***80.00***		Original capacity (MCM) at MDDL	***7.99***
FRL (m)	***89.65***		Original capacity (MCM) at FRL	***84.09***
Year of first impoundment	***1986***		Year of capacity survey	***1998***
Value of 'm'	***2.89***		Type of reservoir	***Type-II***



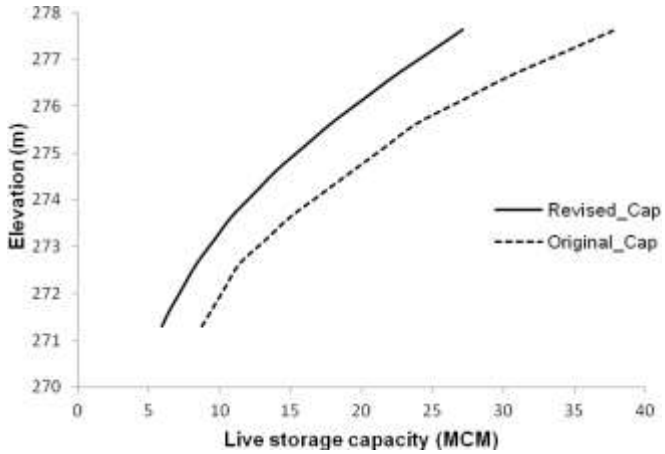


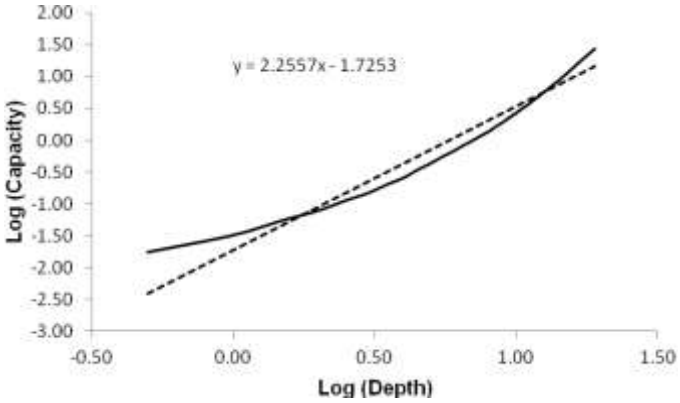


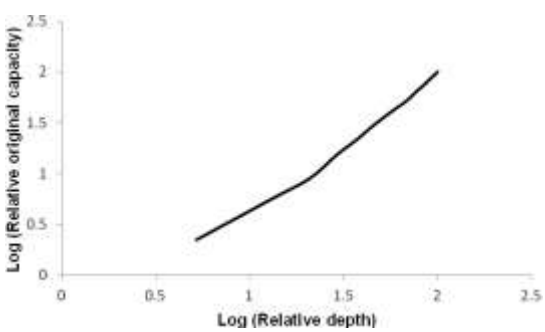


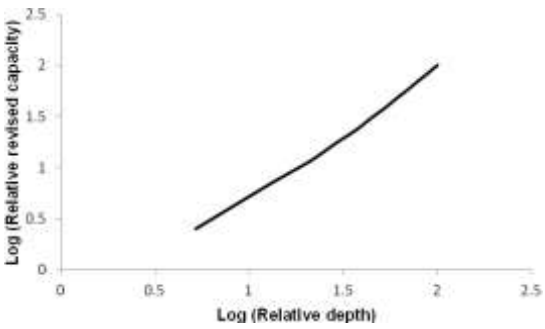
Machhan Nala Project

State – ***Gujarat***				
River	***Machhan***		Catchment Area	***245***
MDDL (m)	***271.31***		Original capacity (MCM) at MDDL	***8.77***
FRL (m)	***277.64***		Original capacity (MCM) at FRL	***37.91***
Year of first impoundment	***1982***		Year of capacity survey	***1999***
Value of 'm'	***2.25***		Type of reservoir	***Type-III***



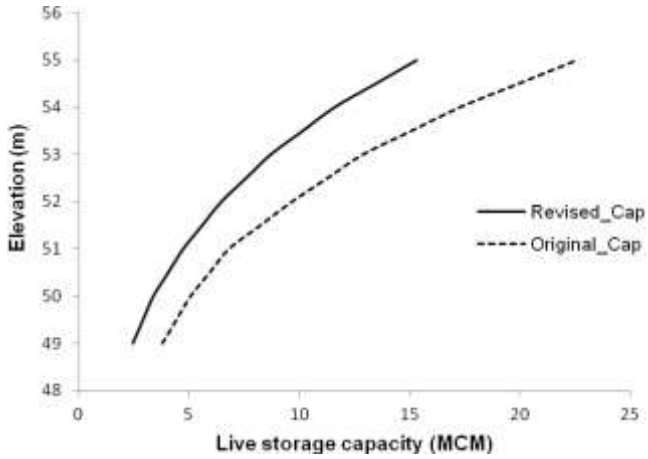


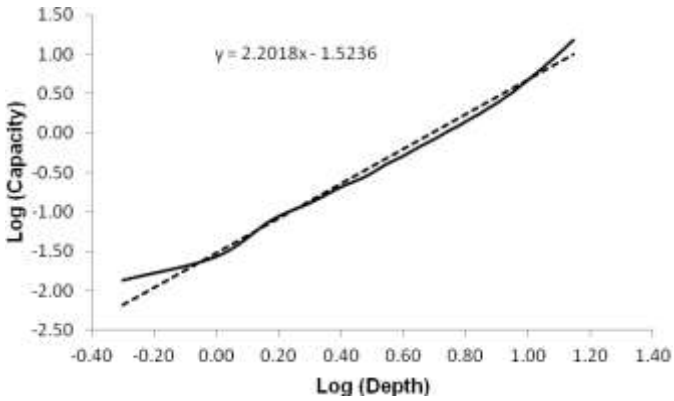


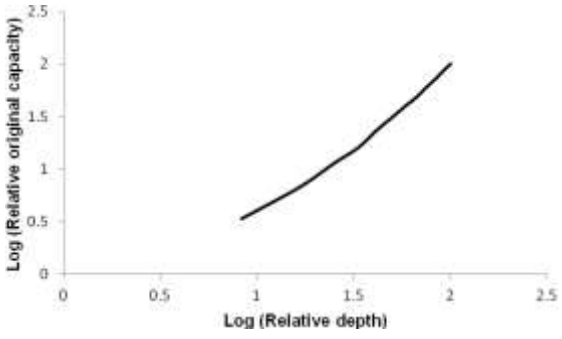


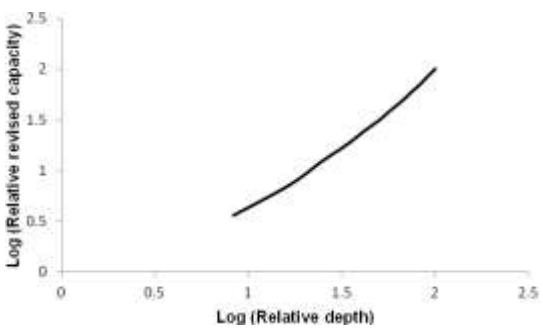
Venu-II Project

State – ***Gujarat***				
River	***Venu***		Catchment Area	***751***
MDDL (m)	***49.00***		Original capacity (MCM) at MDDL	***3.78***
FRL (m)	***55.00***		Original capacity (MCM) at FRL	***22.58***
Year of first impoundment	***1989***		Year of capacity survey	***1999***
Value of 'm'	***2.20***		Type of reservoir	***Type-III***



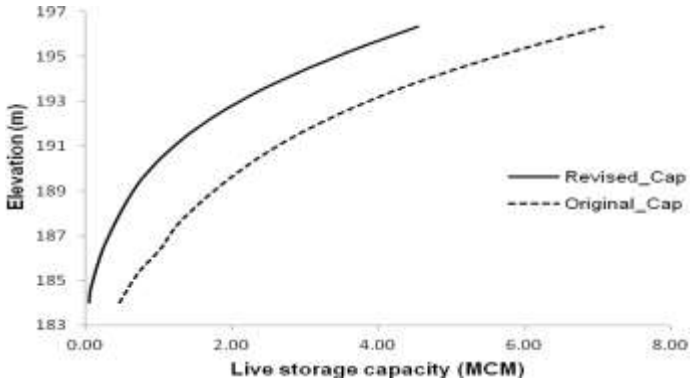


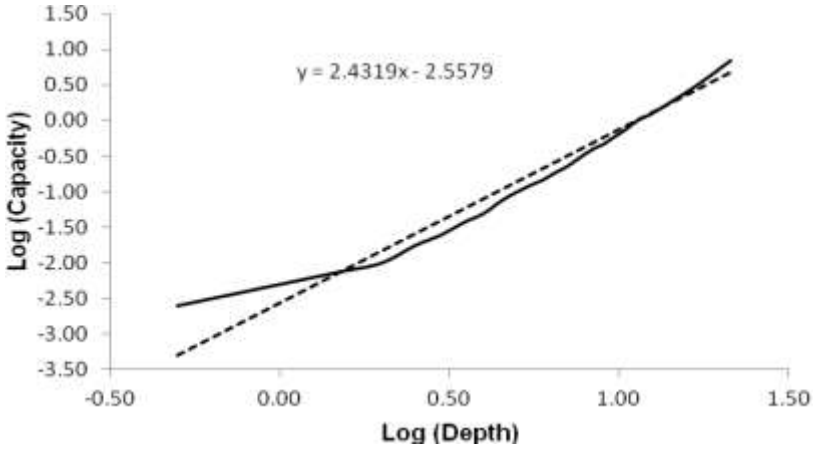


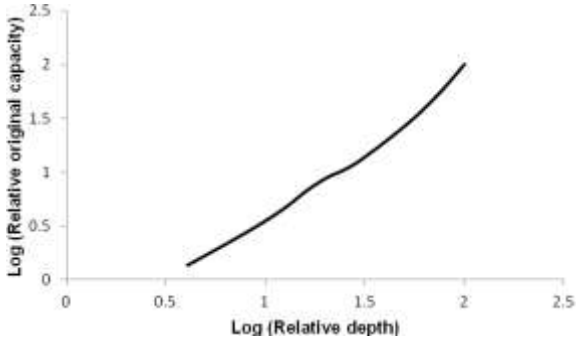


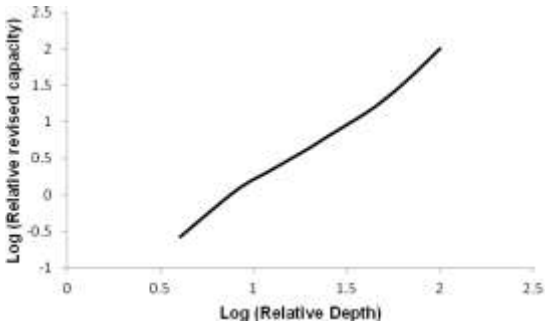
Rami Project

State – ***Gujarat***				
River	***Rami***		Catchment Area	***25***
MDDL (m)	***184.00***		Original capacity (MCM) at MDDL	***0.47***
FRL (m)	***196.35***		Original capacity (MCM) at FRL	***7.08***
Year of first impoundment	***1983***		Year of capacity survey	***1999***
Value of 'm'	***2.43***		Type of reservoir	***Type-III***



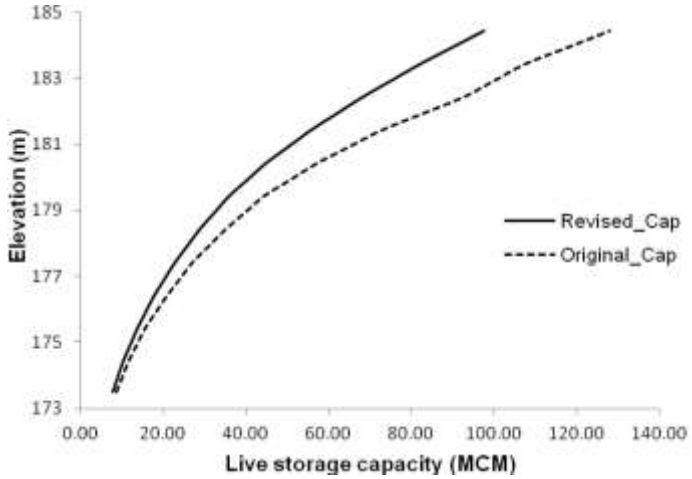


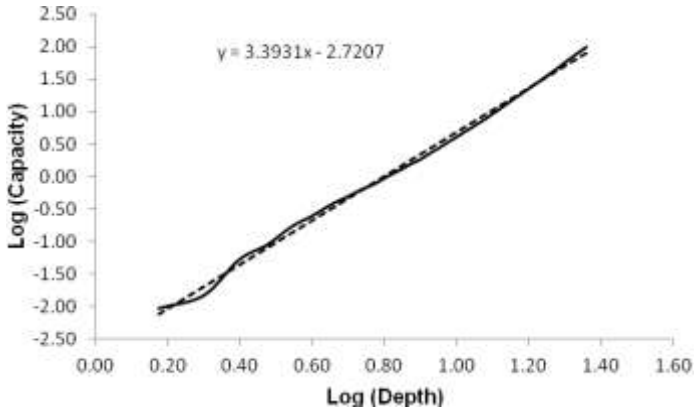


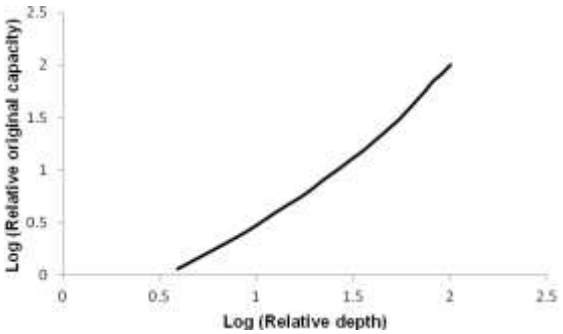


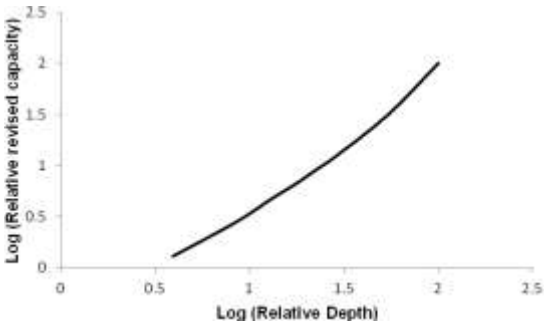
Sipu Project

State – ***Gujarat***				
River	***Sipu***		Catchment Area	***122***
MDDL (m)	***173.50***		Original capacity (MCM) at MDDL	***8.72***
FRL (m)	***186.43***		Original capacity (MCM) at FRL	***177.80***
Year of first impoundment	***1992***		Year of capacity survey	***1998***
Value of 'm'	***3.39***		Type of reservoir	***Type-II***



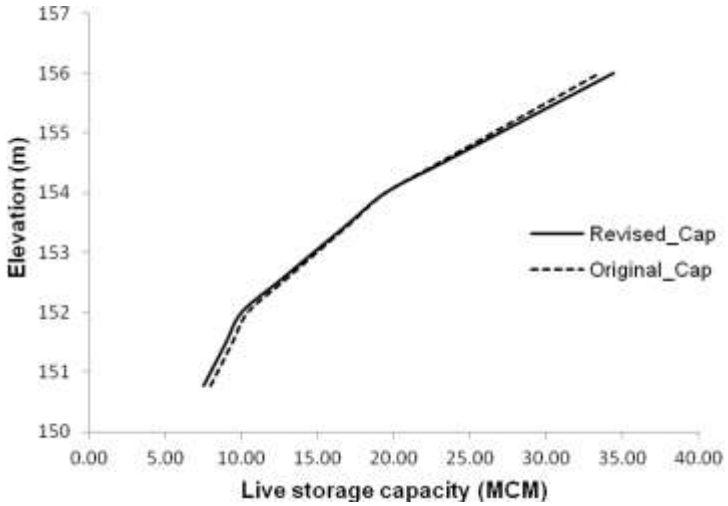


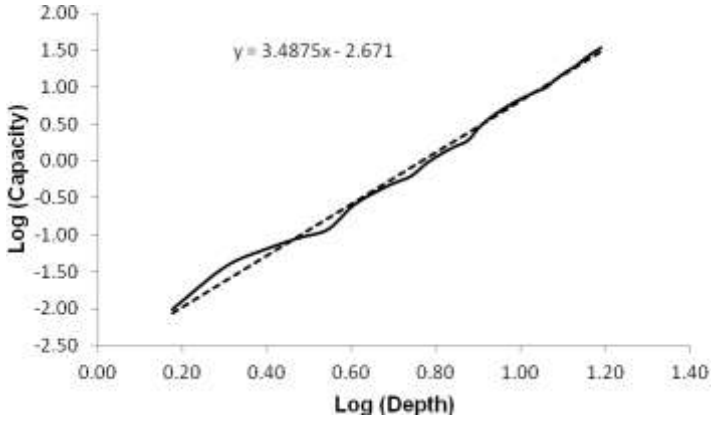


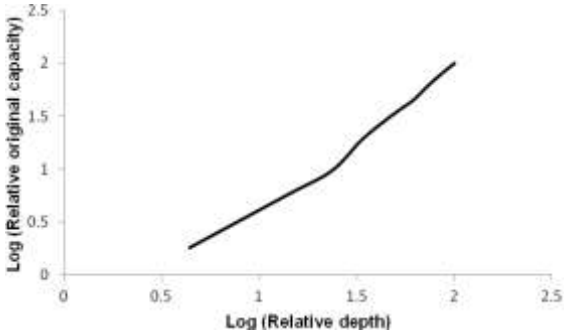


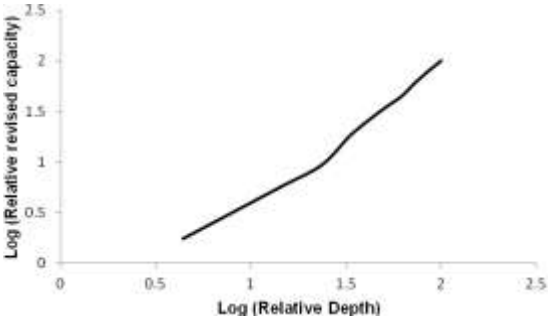
Mazam Project

State – ***Gujarat***				
River	***Mazam***		Catchment Area	***407***
MDDL (m)	***150.77***		Original capacity (MCM) at MDDL	***8.00***
FRL (m)	***157.10***		Original capacity (MCM) at FRL	***44.08***
Year of first impoundment	***1984***		Year of capacity survey	***1998***
Value of 'm'	***3.48***		Type of reservoir	***Type-II***



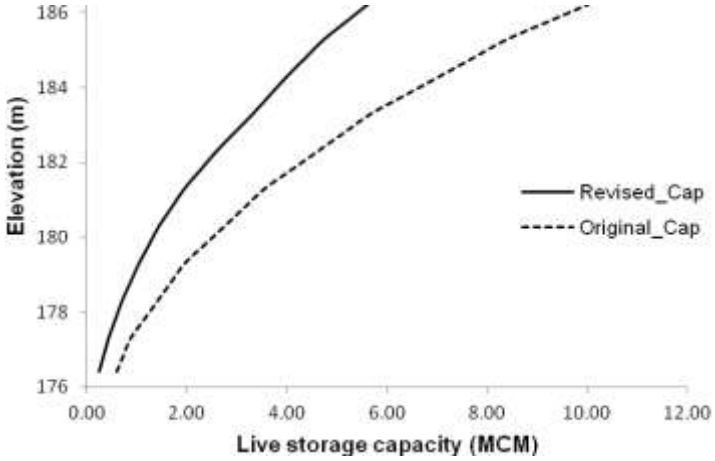


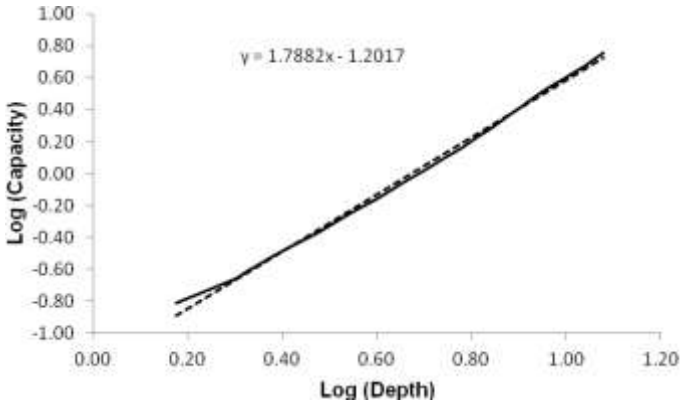


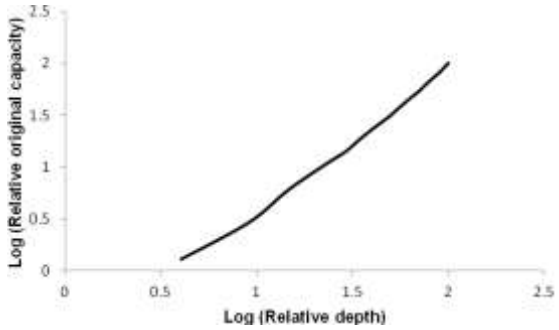


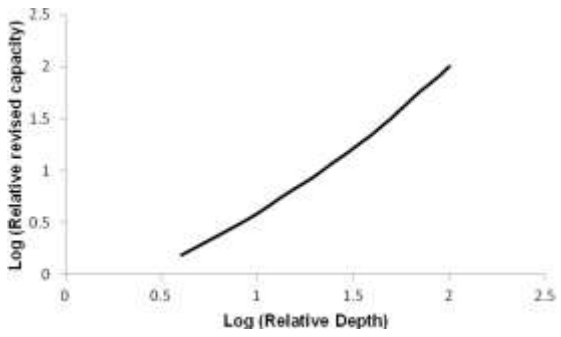
Chopadvav Project

State – ***Gujarat***				
River	***Doman***		Catchment Area	***27***
MDDL (m)	***176.40***		Original capacity (MCM) at MDDL	***0.601***
FRL (m)	***186.30***		Original capacity (MCM) at FRL	***10.15***
Year of first impoundment	***1985***		Year of capacity survey	***1998***
Value of 'm'	***1.79***		Type of reservoir	***Type-III***



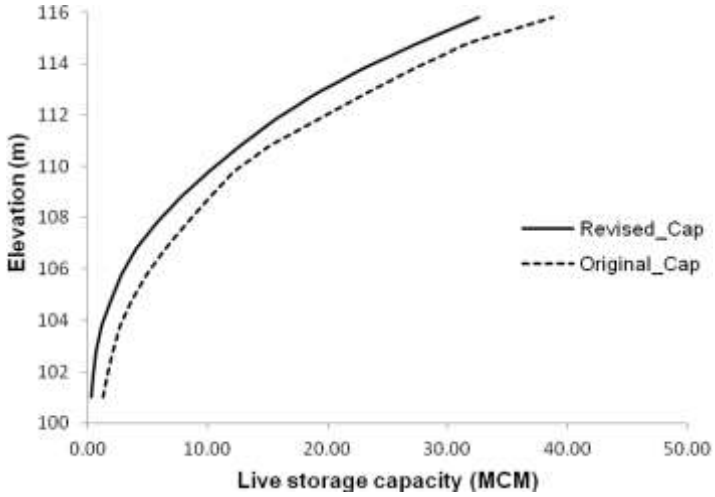


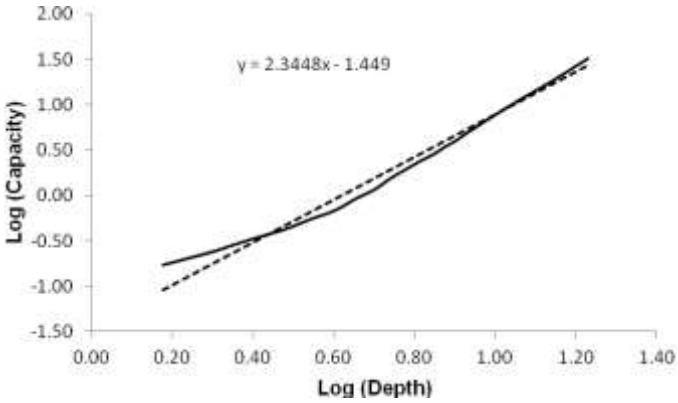


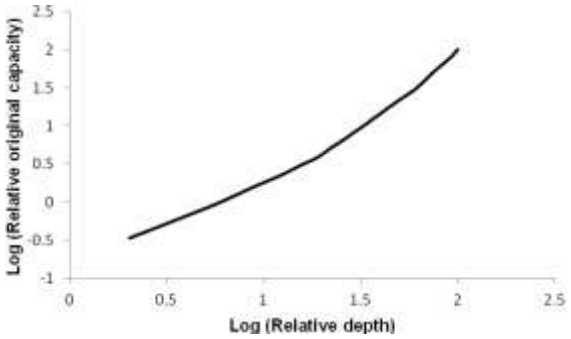


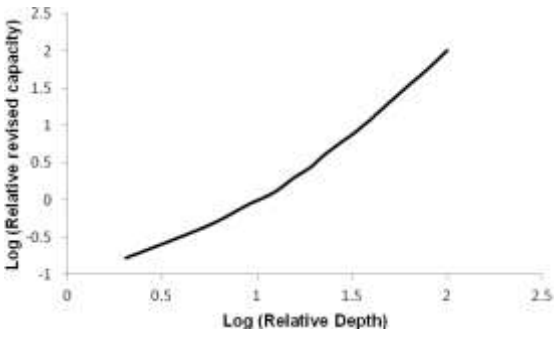
Ver-II Project

State – ***Gujarat***				
River	***Ver***		Catchment Area	***90***
MDDL (m)	***101***		Original capacity (MCM) at MDDL	***1.264***
FRL (m)	***115.80***		Original capacity (MCM) at FRL	***38.80***
Year of first impoundment	***1984***		Year of capacity survey	***1998***
Value of 'm'	***2.34***		Type of reservoir	***Type-III***



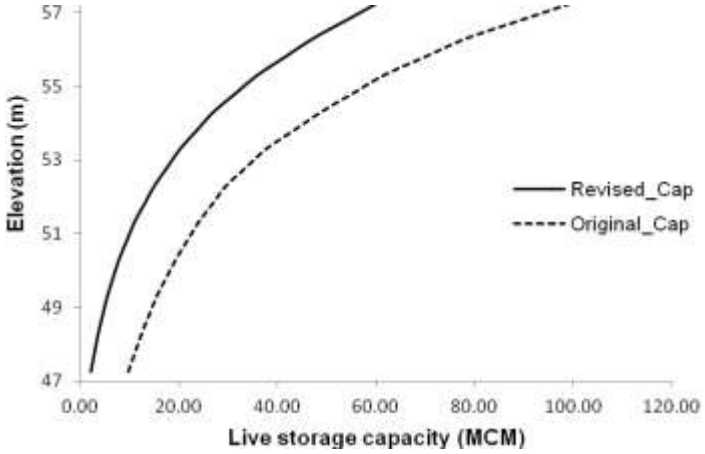


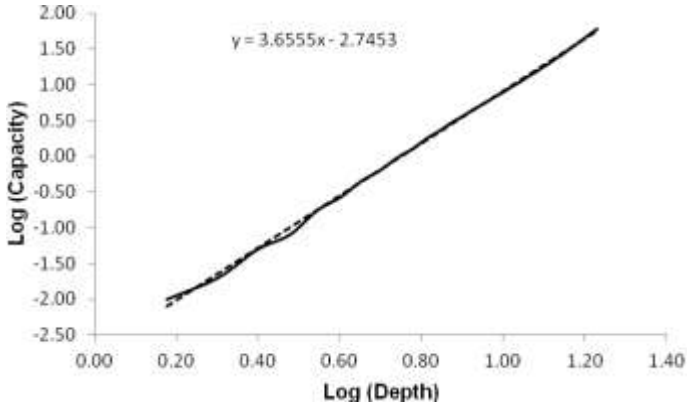


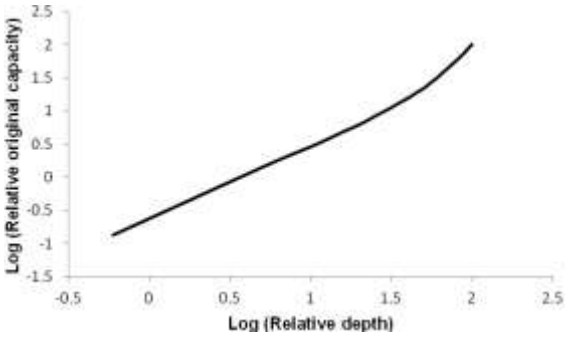


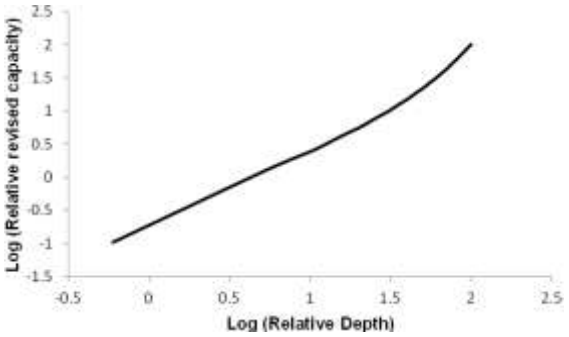
Machhu-II Project

State – Gujarat				
River	***Machhu***		Catchment Area	***1193***
MDDL (m)	***47.24***		Original capacity (MCM) at MDDL	***9.80***
FRL (m)	***57.30***		Original capacity (MCM) at FRL	***100.56***
Year of first impoundment	***1972***		Year of capacity survey	***1997***
Value of 'm'	***3.65***		Type of reservoir	***Type-I***



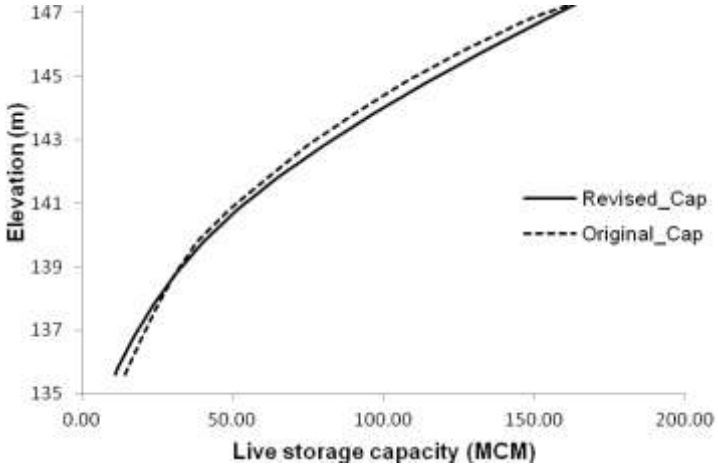


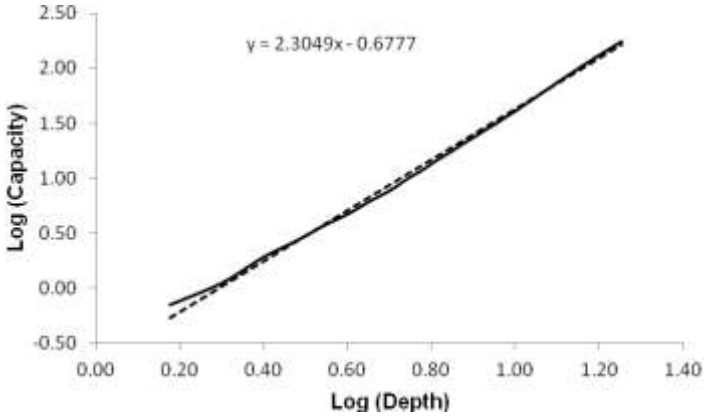


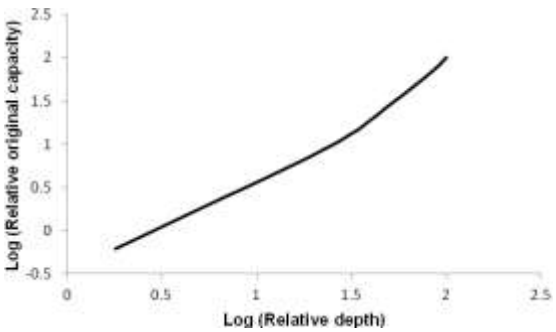


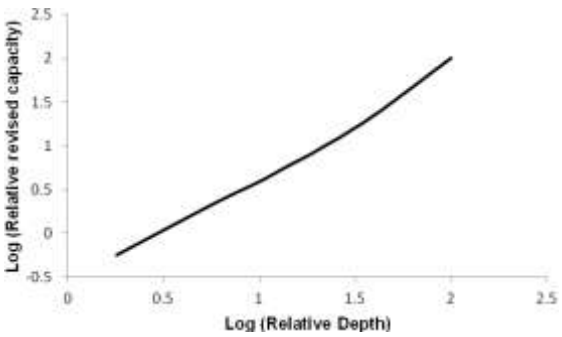
Sukhi Project

State – ***Gujarat***				
River	***Sukhi***		Catchment Area	***412***
MDDL (m)	***135.60***		Original capacity (MCM) at MDDL	***14.24***
FRL (m)	***147.82***		Original capacity (MCM) at FRL	***178.47***
Year of first impoundment	***1987***		Year of capacity survey	***1999***
Value of 'm'	***2.30***		Type of reservoir	***Type-III***



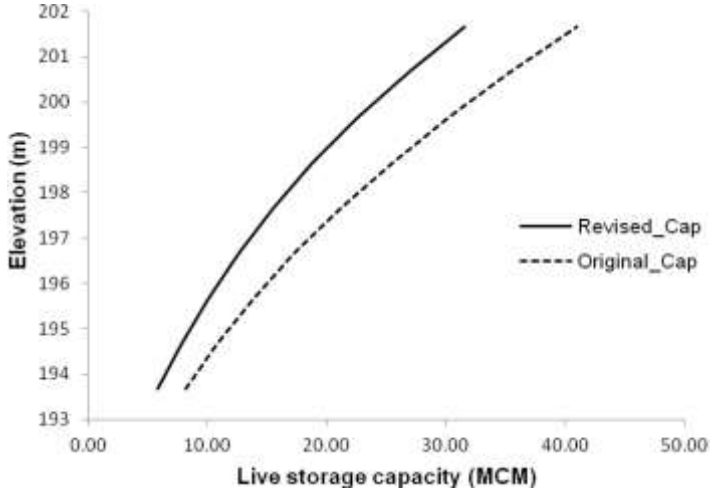


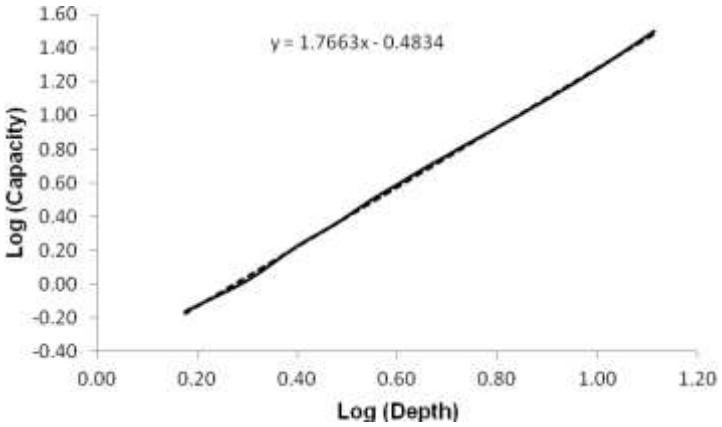


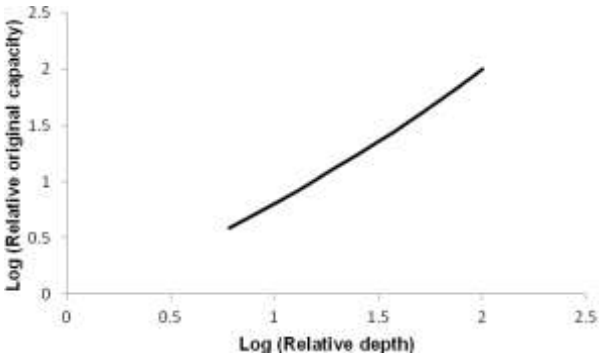


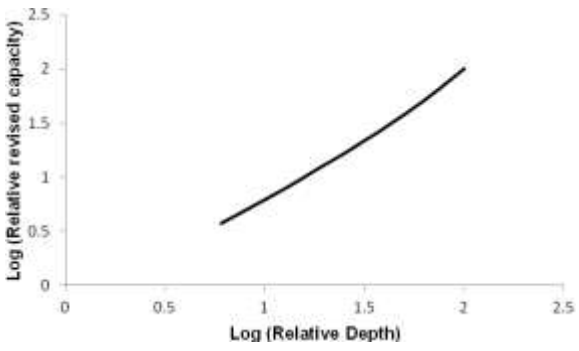
Mukteshwar Project

State – ***Gujarat***				
River	***Saraswati***		Catchment Area	***306***
MDDL (m)	***193.67***		Original capacity (MCM) at MDDL	***8.18***
FRL (m)	***201.65***		Original capacity (MCM) at FRL	***41***
Year of first impoundment	***1990***		Year of capacity survey	***1998***
Value of 'm'	***1.76***		Type of reservoir	***Type-III***



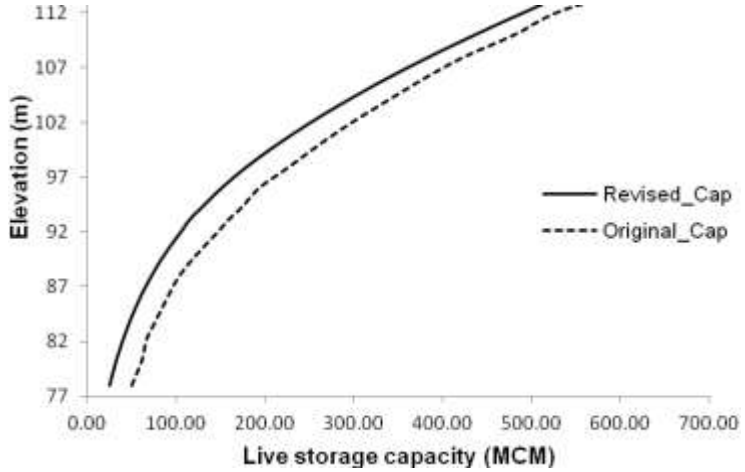


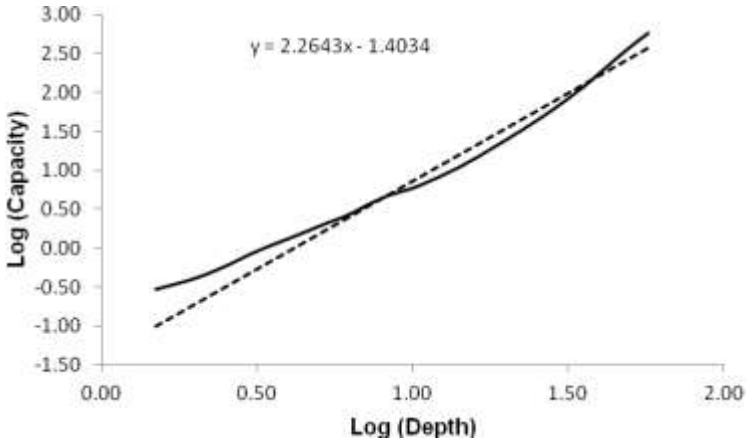


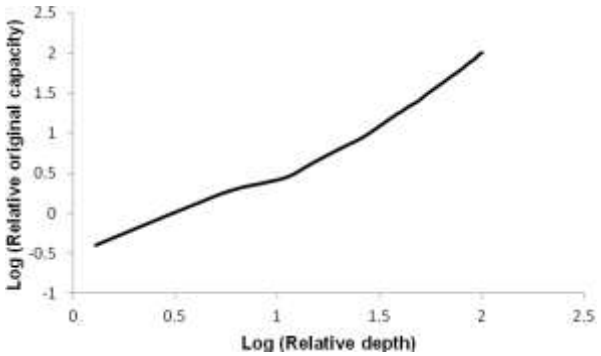


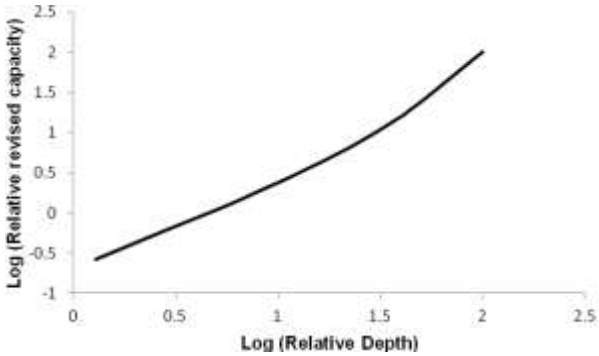
Karjan Project

State – ***Gujarat***				
River	***Karjan***		Catchment Area	***1404***
MDDL (m)	***78.00***		Original capacity (MCM) at MDDL	***50.41***
FRL (m)	***115.25***		Original capacity (MCM) at FRL	***630***
Year of first impoundment	***1984***		Year of capacity survey	***1998***
Value of 'm'	***2.26***		Type of reservoir	***Type-III***



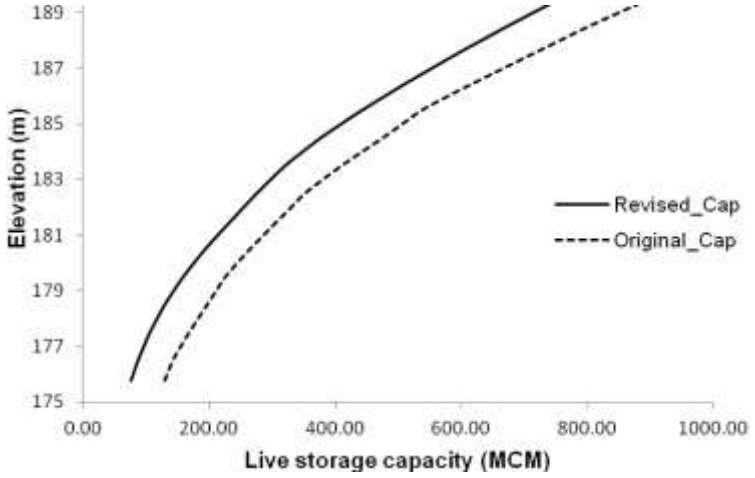


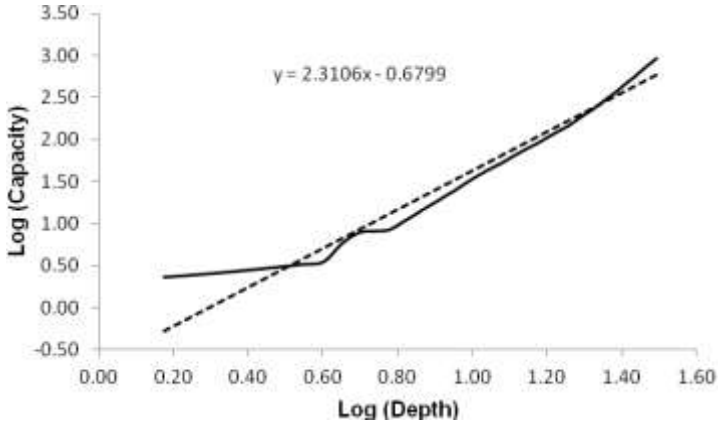


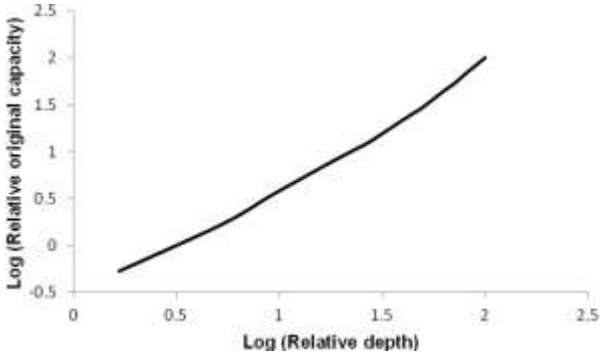


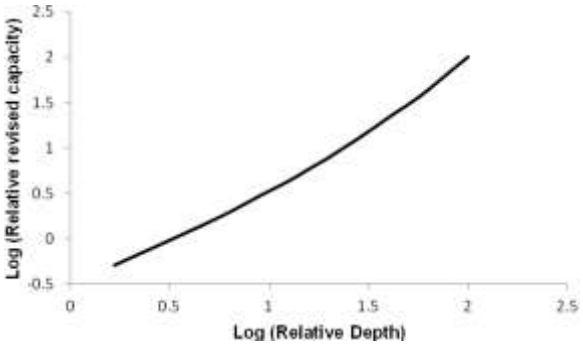
Dharoi Project

State – ***Gujarat***				
River	***Sabarmati***		Catchment Area	***5475***
MDDL (m)	***175.77***		Original capacity (MCM) at MDDL	***129.98***
FRL (m)	***189.59***		Original capacity (MCM) at FRL	***907.83***
Year of first impoundment	***1976***		Year of capacity survey	***2000***
Value of 'm'	***2.31***		Type of reservoir	***Type-III***



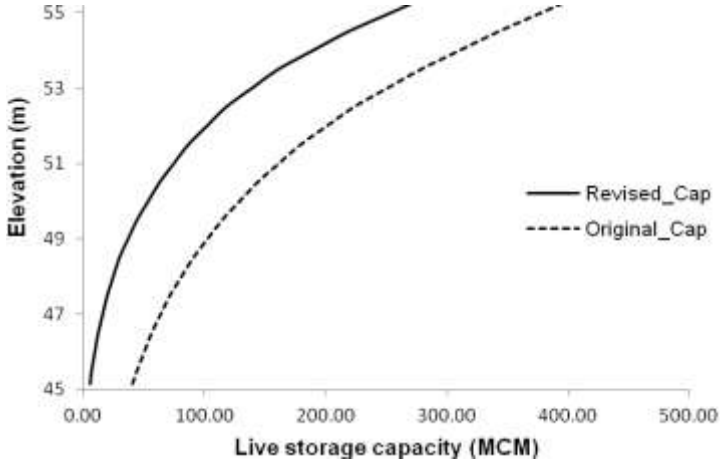


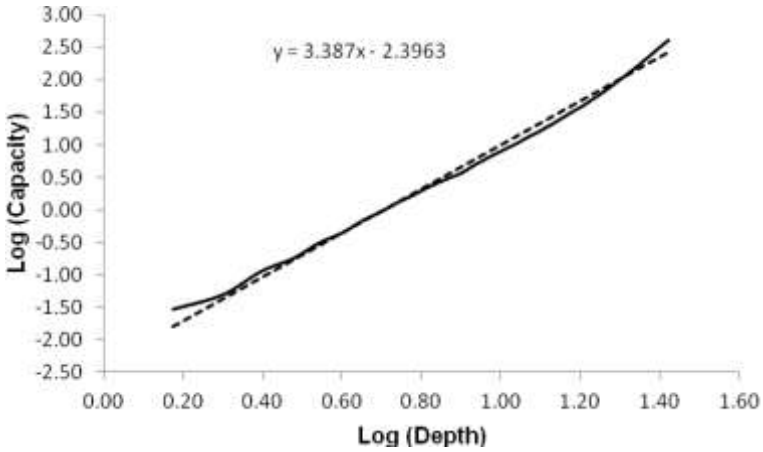


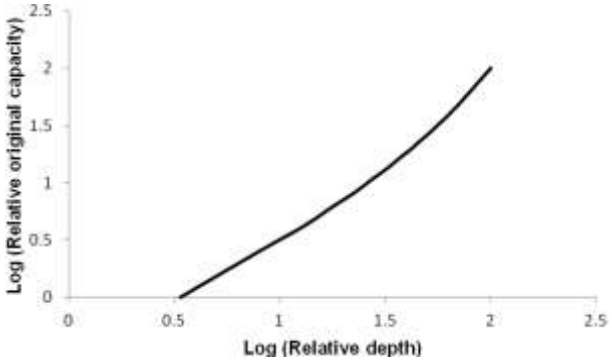


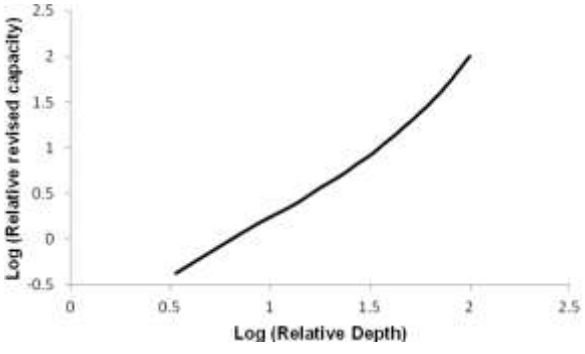
Shetrunji Project

State – ***Gujarat***				
River	***Shetrunji***		Catchment Area	***4317***
MDDL (m)	***45.15***		Original capacity (MCM) at MDDL	***40.58***
FRL (m)	***55.53***		Original capacity (MCM) at FRL	***415.41***
Year of first impoundment	***1959***		Year of capacity survey	***2000***
Value of 'm'	***3.38***		Type of reservoir	***Type-II***



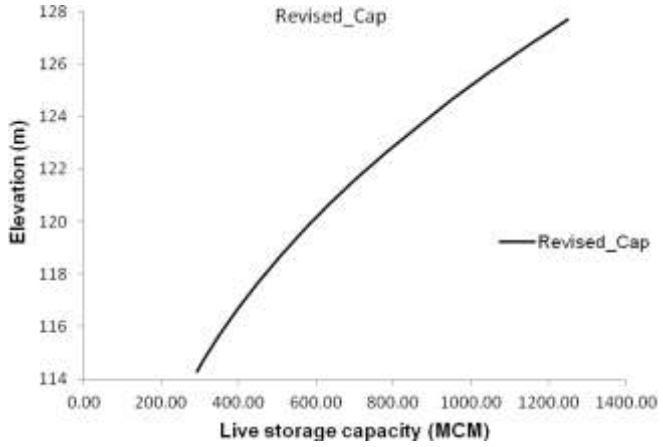


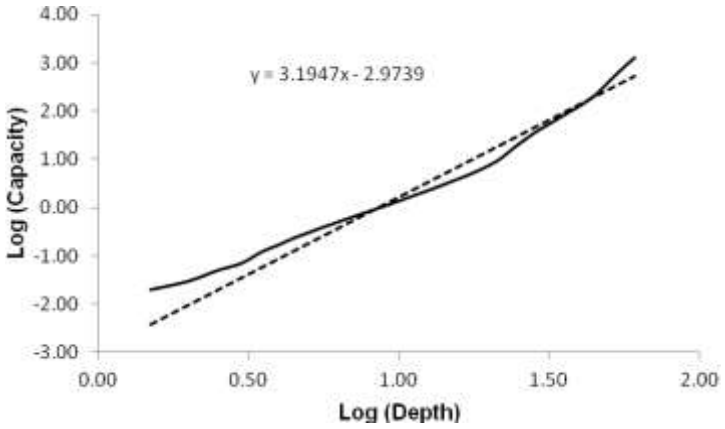


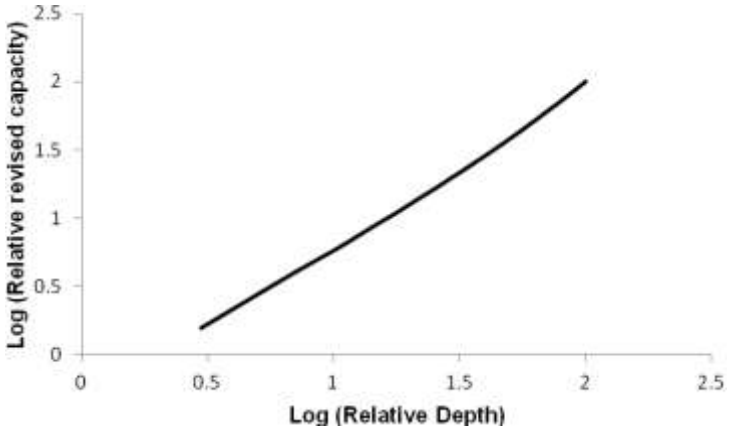


Kadana Project

State – ***Gujarat***				
River	***Mahi***		Catchment Area	***25486***
MDDL (m)	***114.30***		Original capacity (MCM) at MDDL	***291.26***
FRL (m)	***127.70***		Original capacity (MCM) at FRL	***1543***
Year of first impoundment	***1977***		Year of capacity survey	***2000***
Value of 'm'	***3.19***		Type of reservoir	***Type-II***

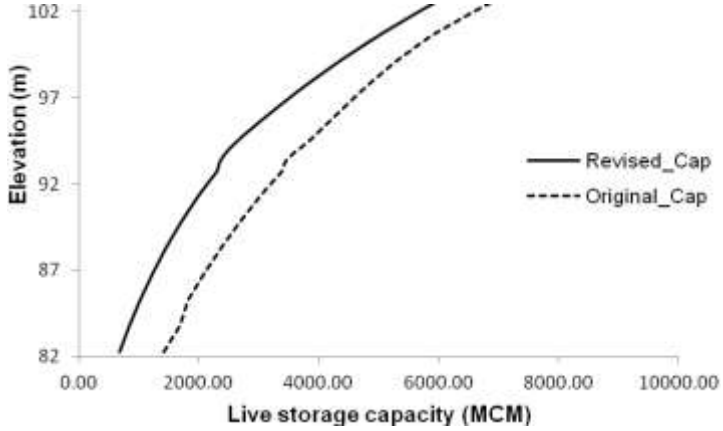


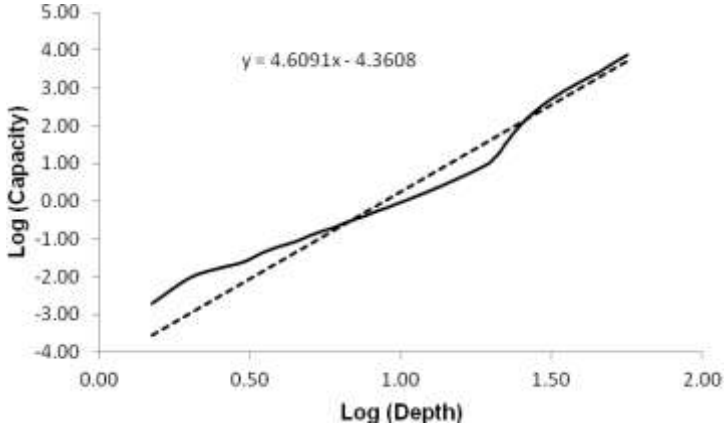


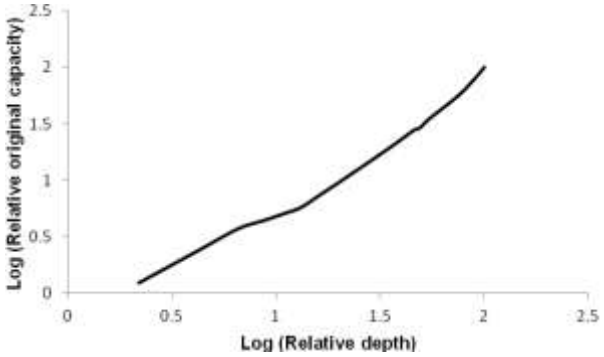


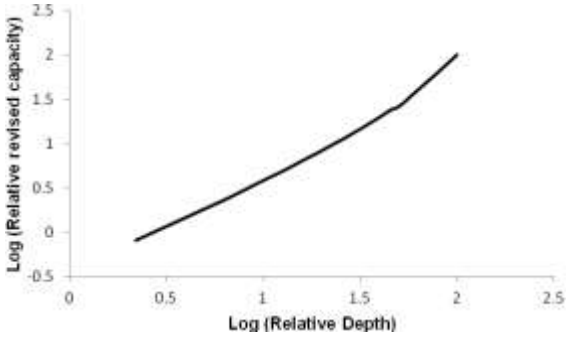
Ukai Project

State – ***Gujarat***				
River	***Tapi***		Catchment Area	***62750***
MDDL (m)	***82.30***		Original capacity (MCM) at MDDL	***1417.78***
FRL (m)	***105.15***		Original capacity (MCM) at FRL	***8510***
Year of first impoundment	***1972***		Year of capacity survey	***2003***
Value of 'm'	***4.6***		Type of reservoir	***Type-I***



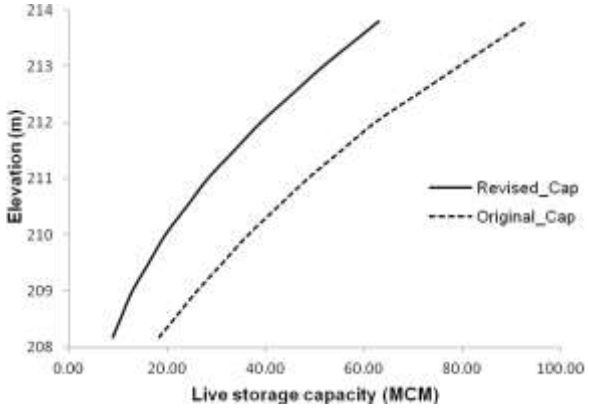


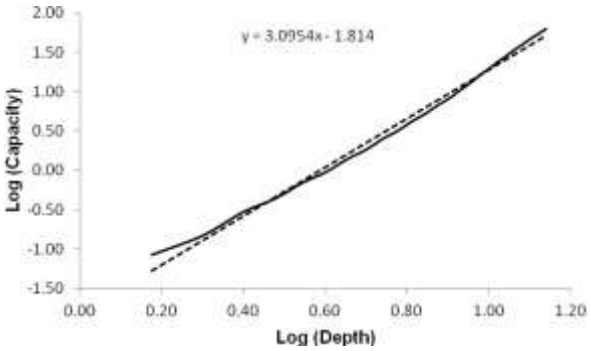


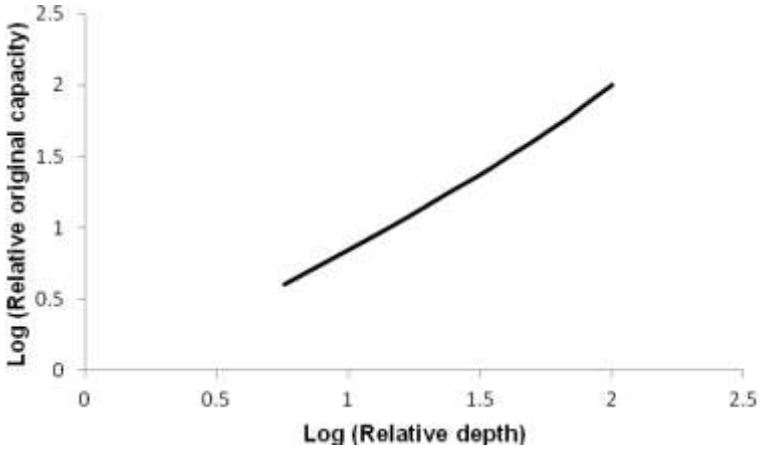


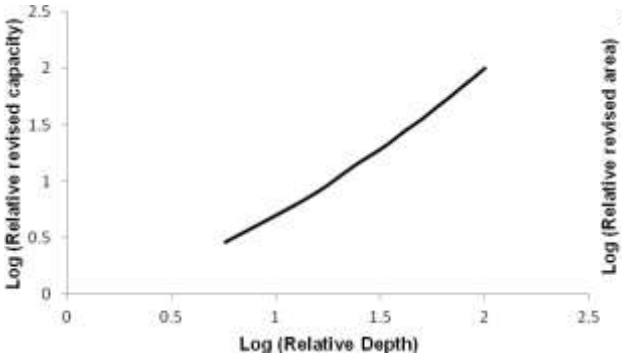
Asolamendha Project

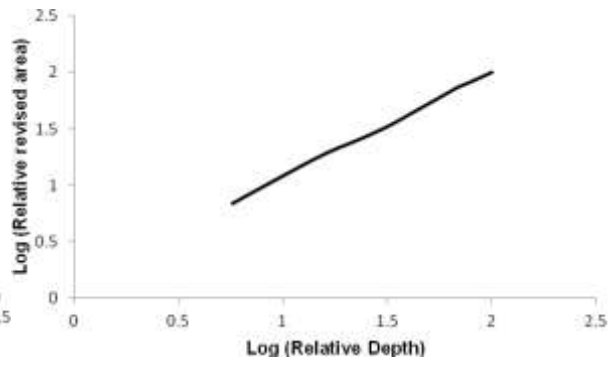
State – ***Maharashtra***				
River	***Pathari***		Catchment Area	***245.5***
MDDL (m)	***208.18***		Original capacity (MCM) at MDDL	***18.34***
FRL (m)	***213.80***		Original capacity (MCM) at FRL	***92.96***
Year of first impoundment	***1918***		Year of capacity survey	***1994***
Value of 'm'	***3.09***		Type of reservoir	***Type-II***





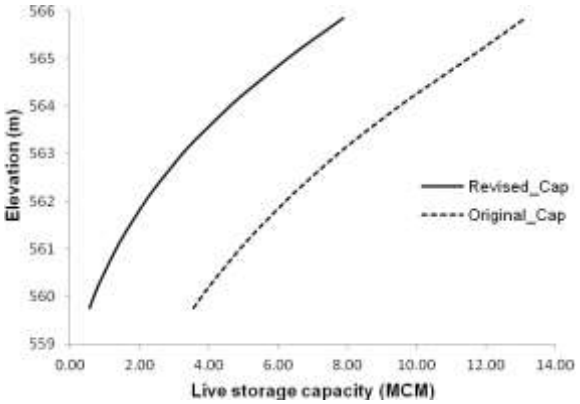


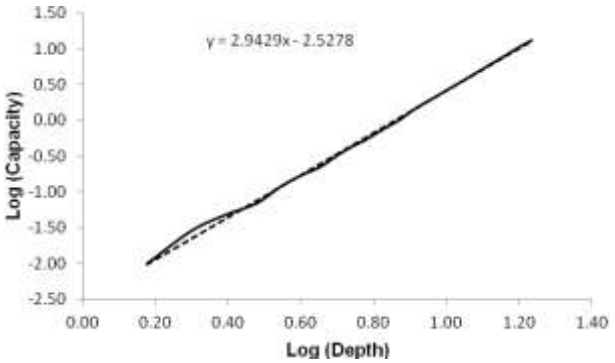


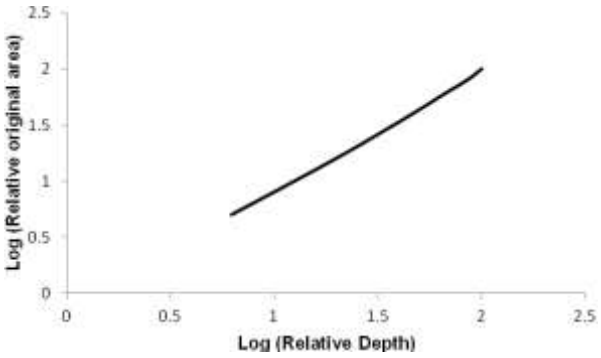


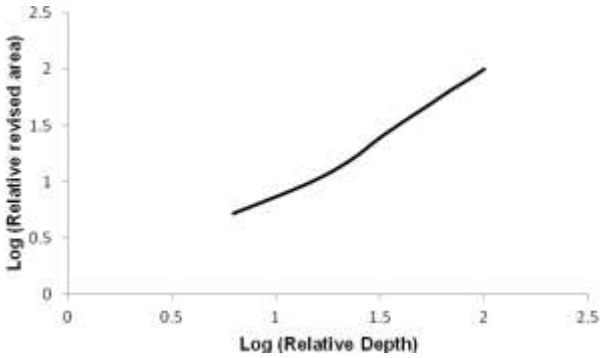
Bendsura Project

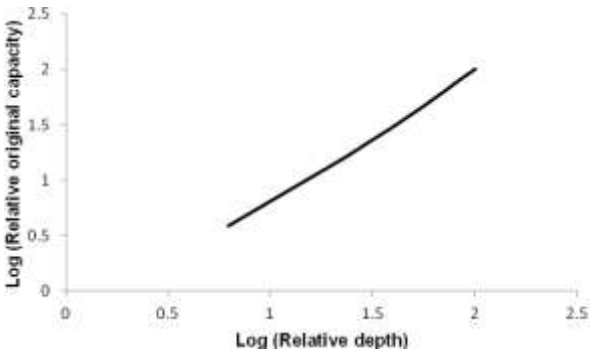
State – ***Maharashtra***				
River	***Bendsura***		Catchment Area	***NA***
MDDL (m)	***559.76***		Original capacity (MCM) at MDDL	***3.57***
FRL (m)	***565.85***		Original capacity (MCM) at FRL	***13.125***
Year of first impoundment	***1955***		Year of capacity survey	***1995***
Value of 'm'	***2.94***		Type of reservoir	***Type-II***

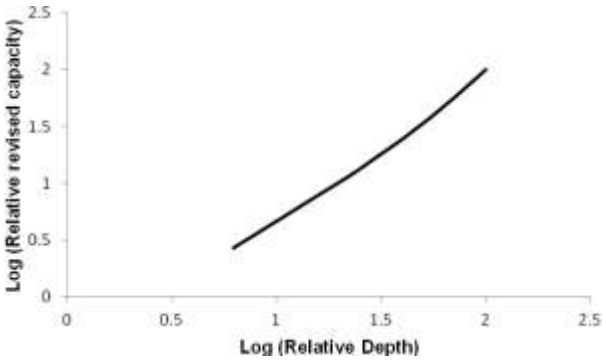






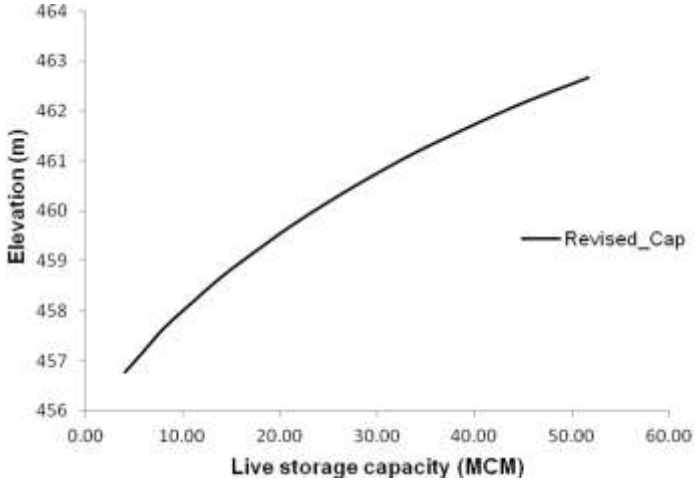


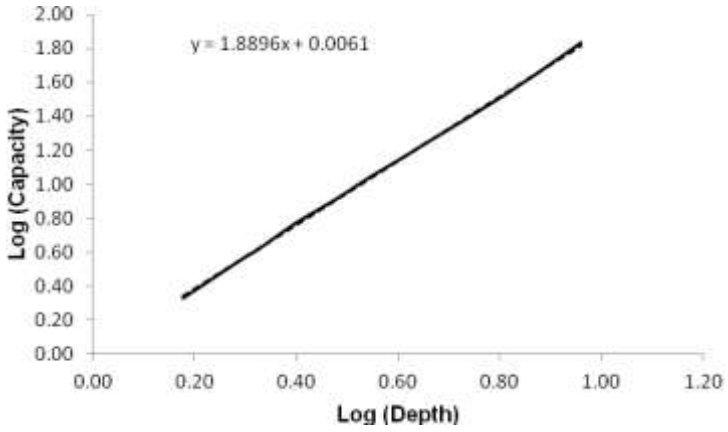


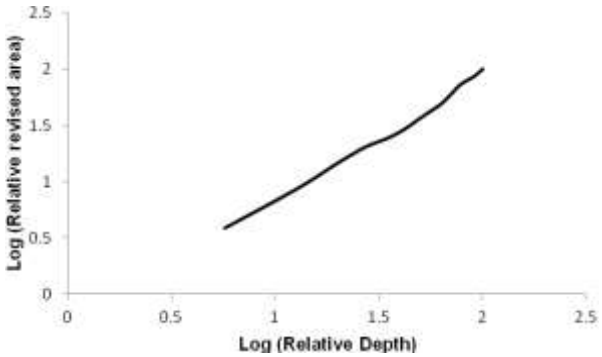


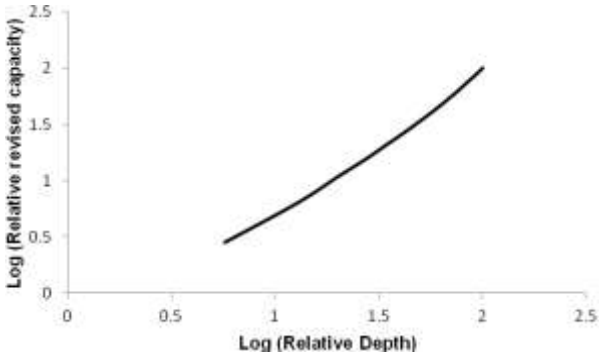
Ekrukh Project

State – ***Maharashtra***				
River	***Adela***		Catchment Area	***411.78***
MDDL (m)	***456.77***		Original capacity (MCM) at MDDL	***NA***
FRL (m)	***463.78***		Original capacity (MCM) at FRL	***67.86***
Year of first impoundment	***1871***		Year of capacity survey	***1991***
Value of 'm'	***1.89***		Type of reservoir	***Type-III***



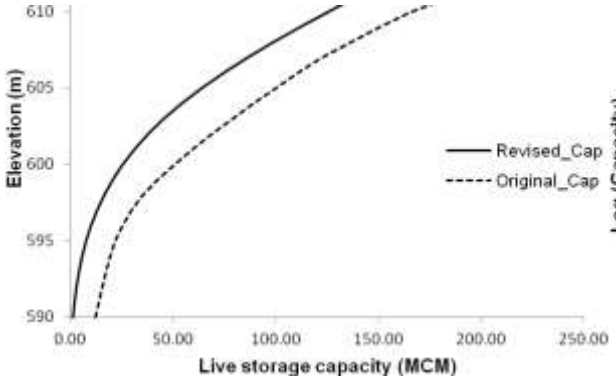


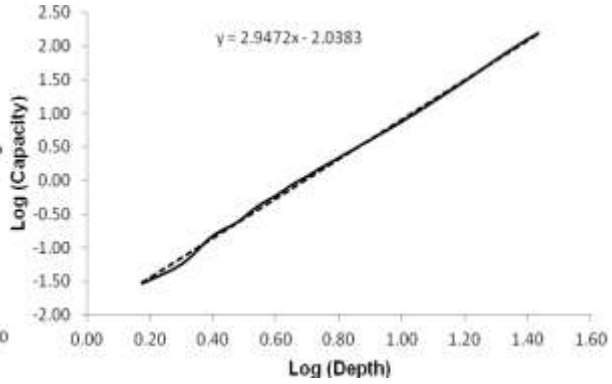


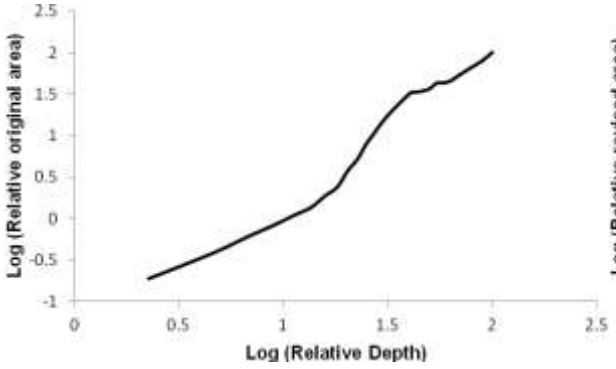


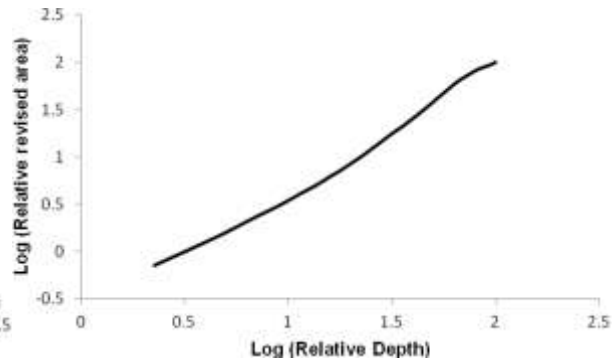
Gangapur Project

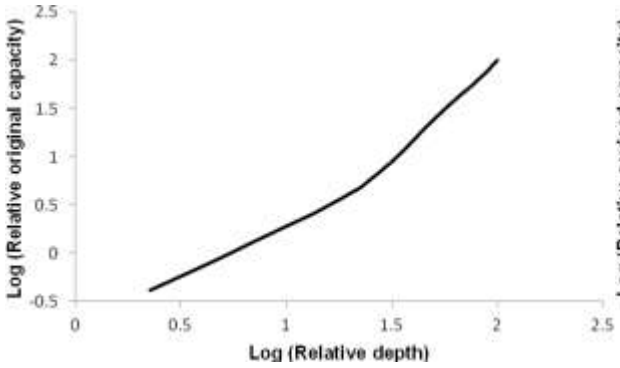
State – ***Maharashtra***				
River	***Godavari***		Catchment Area	***357.4***
MDDL (m)	***591.92***		Original capacity (MCM) at MDDL	***15.36***
FRL (m)	***612.50***		Original capacity (MCM) at FRL	***208.12***
Year of first impoundment	***1965***		Year of capacity survey	***2002***
Value of 'm'	***2.94***		Type of reservoir	***Type-II***

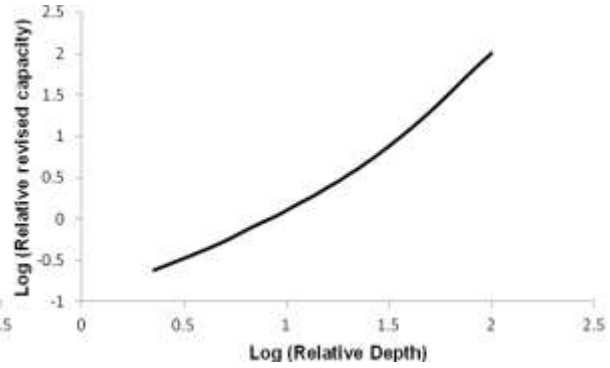






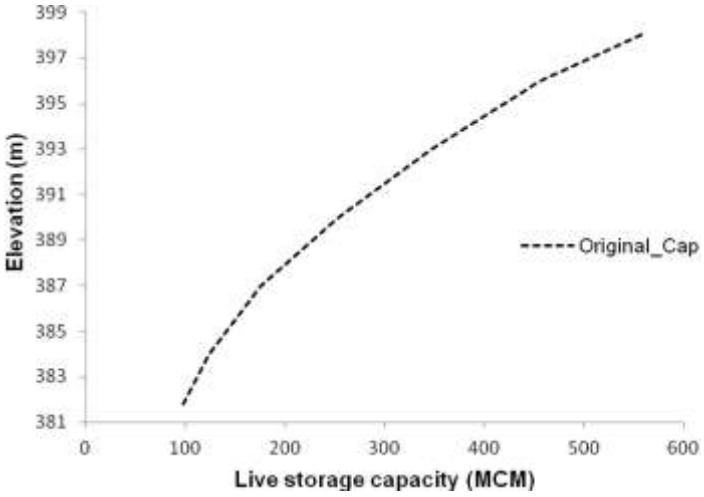


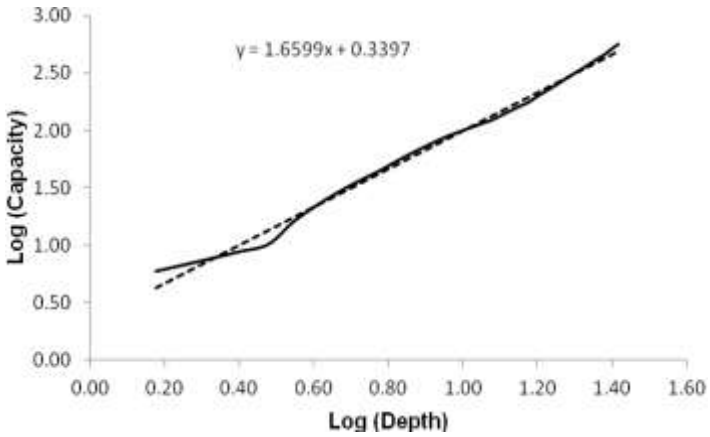


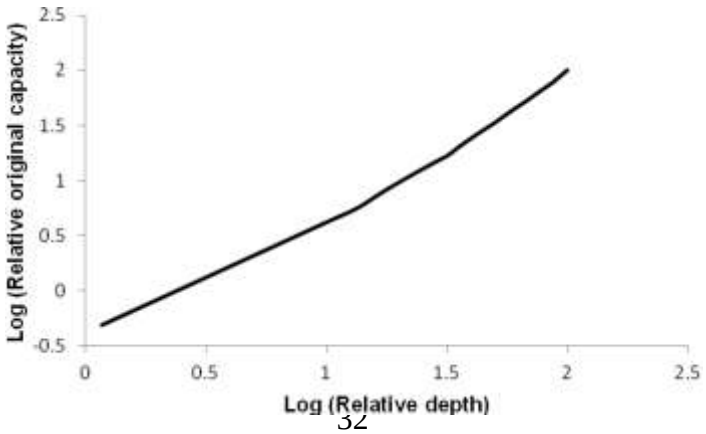


Girna Project

State – ***Maharashtra***				
River	***Girna***		Catchment Area	***4729.3***
MDDL (m)	***381.81***		Original capacity (MCM) at MDDL	***97.31***
FRL (m)	***398.07***		Original capacity (MCM) at FRL	***559.23***
Year of first impoundment	***1969***		Year of capacity survey	***NA***
Value of 'm'	***1.66***		Type of reservoir	***Type-III***

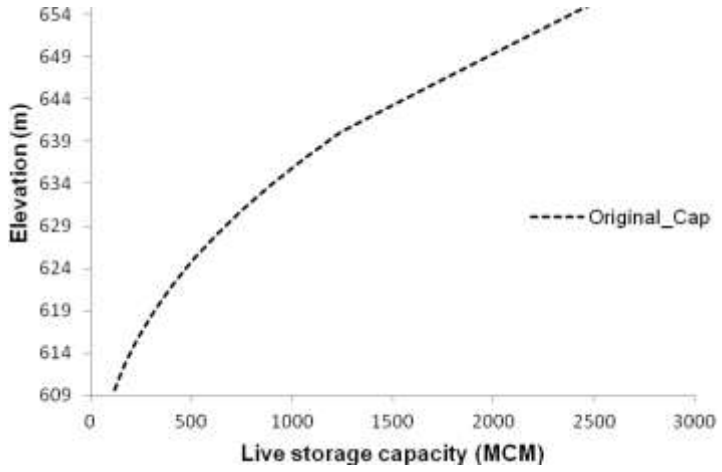


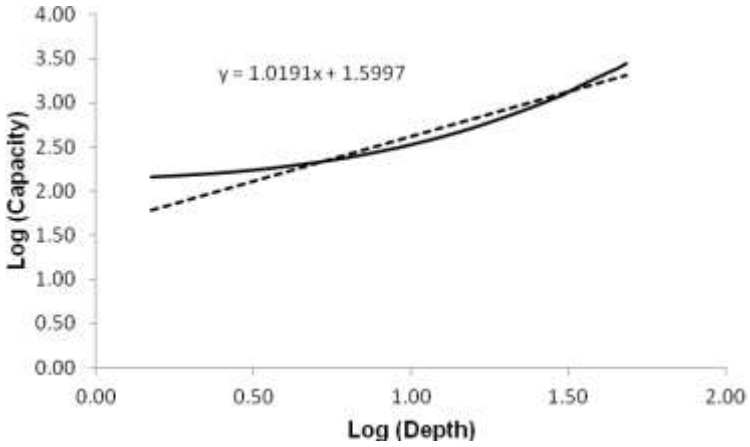


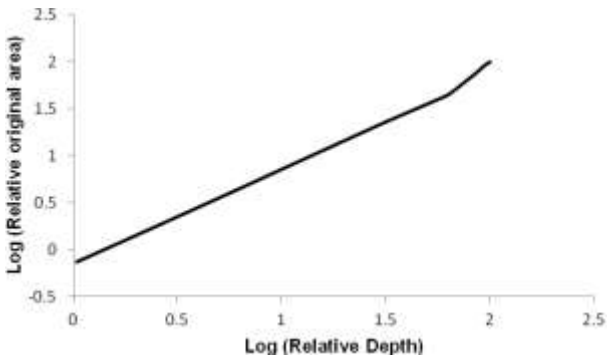


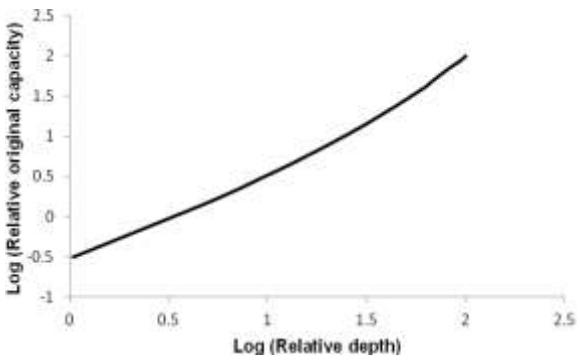
Koyna Project

State – ***Maharashtra***				
River	***Koyna***		Catchment Area	***891.78***
MDDL (m)	***609.60***		Original capacity (MCM) at MDDL	***119.79***
FRL (m)	***657.91***		Original capacity (MCM) at FRL	***2797.45***
Year of first impoundment	***1965***		Year of capacity survey	***2004***
Value of 'm'	***1.01***		Type of reservoir	***Type-IV***



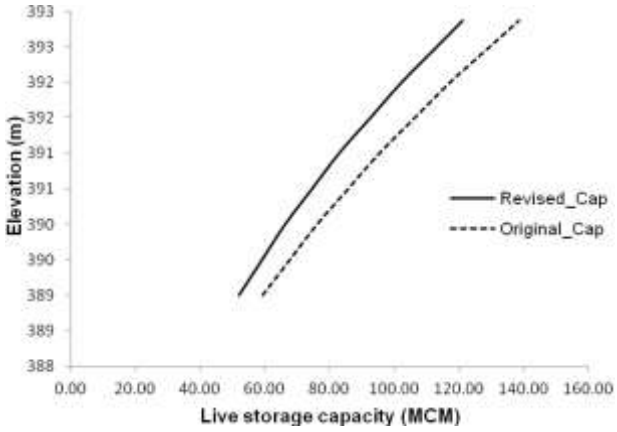


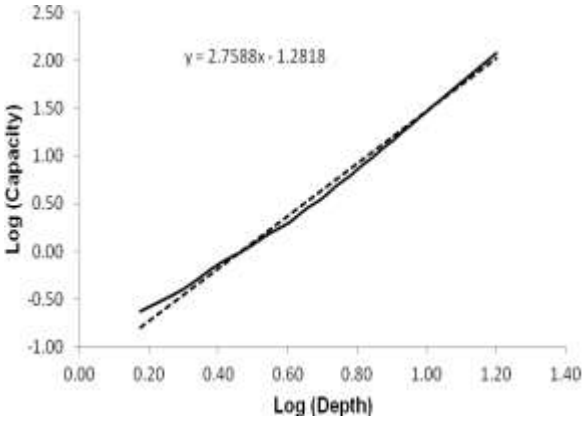


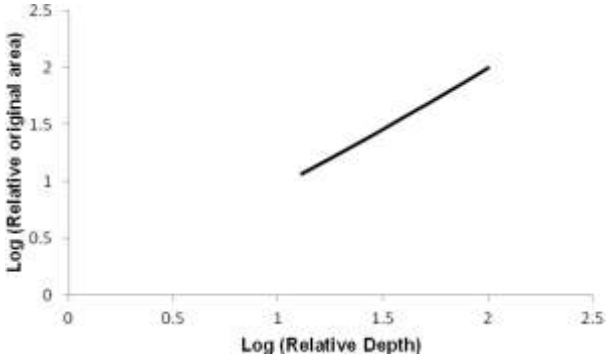


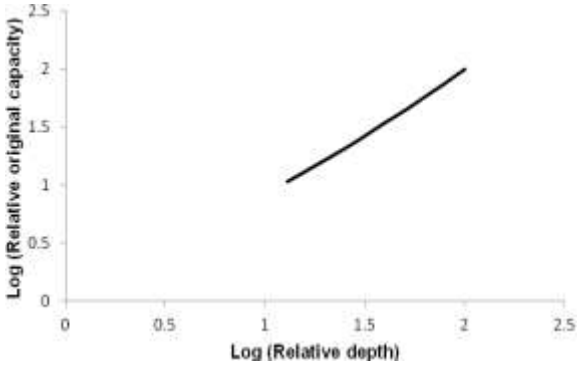
Manar Project

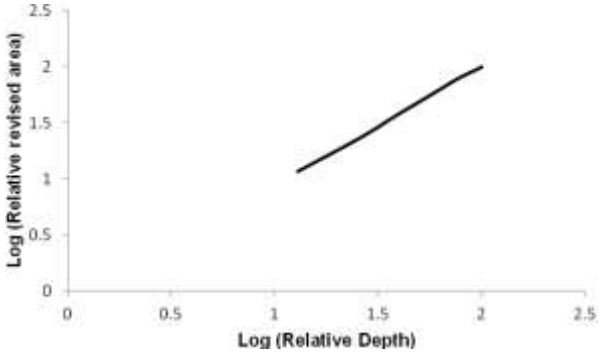
State – ***Maharashtra***				
River	***Manar***		Catchment Area	***1547***
MDDL (m)	***389.00***		Original capacity (MCM) at MDDL	***59.334***
FRL (m)	***392.87***		Original capacity (MCM) at FRL	***138.39***
Year of first impoundment	***1965***		Year of capacity survey	***1999***
Value of 'm'	***2.75***		Type of reservoir	***Type-II***

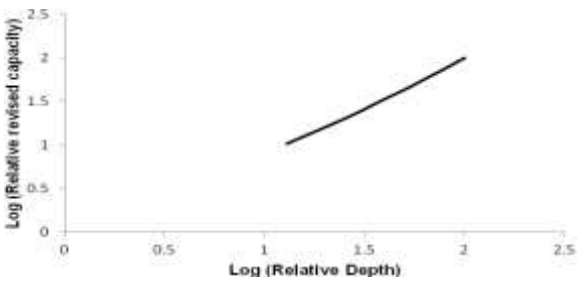






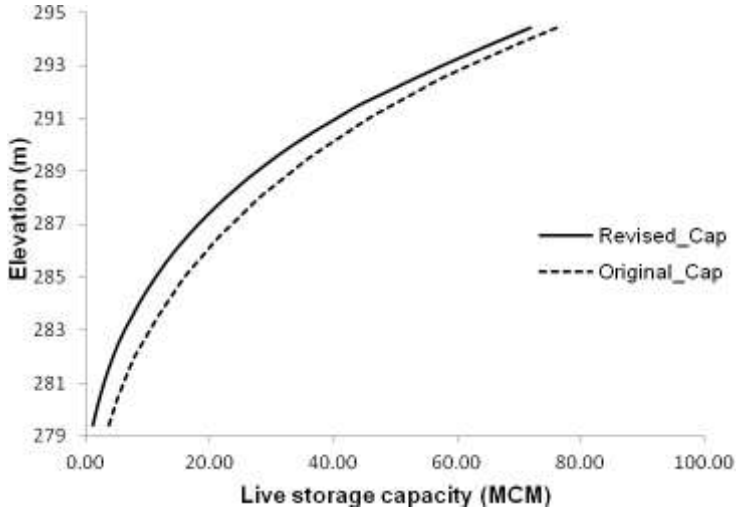


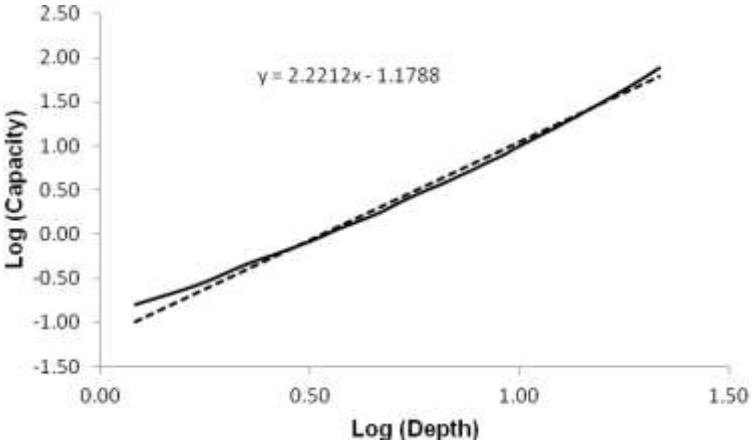


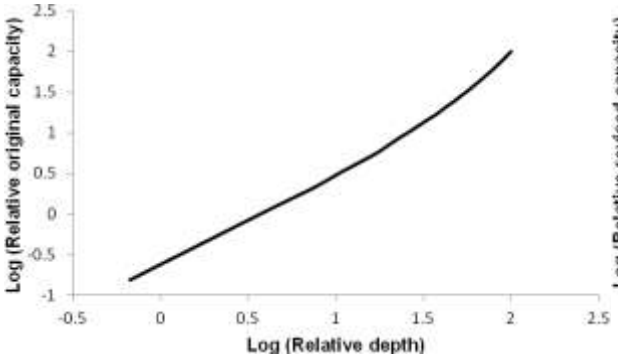


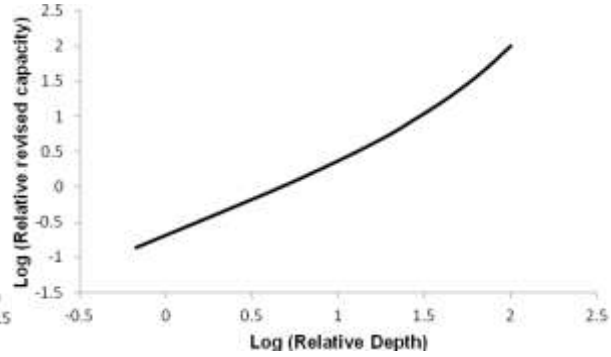
Nalganga Project

State – ***Maharashtra***				
River	***Nalganga***		Catchment Area	***316***
MDDL (m)	***279.40***		Original capacity (MCM) at MDDL	***3.81***
FRL (m)	***294.43***		Original capacity (MCM) at FRL	***76.201***
Year of first impoundment	***1962***		Year of capacity survey	***1985***
Value of 'm'	***2.22***		Type of reservoir	***Type-III***



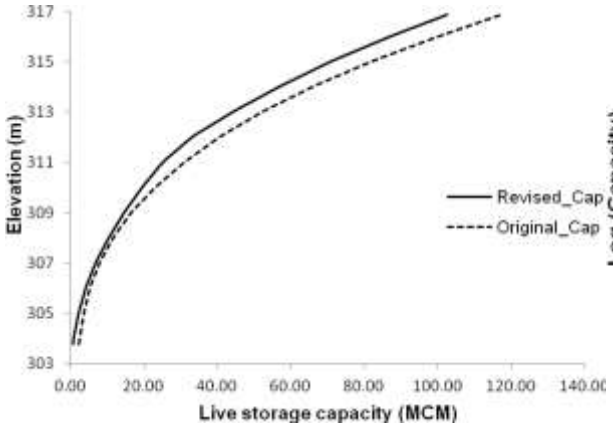


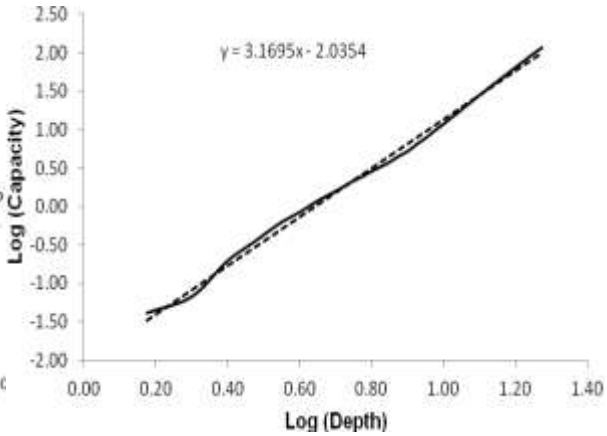


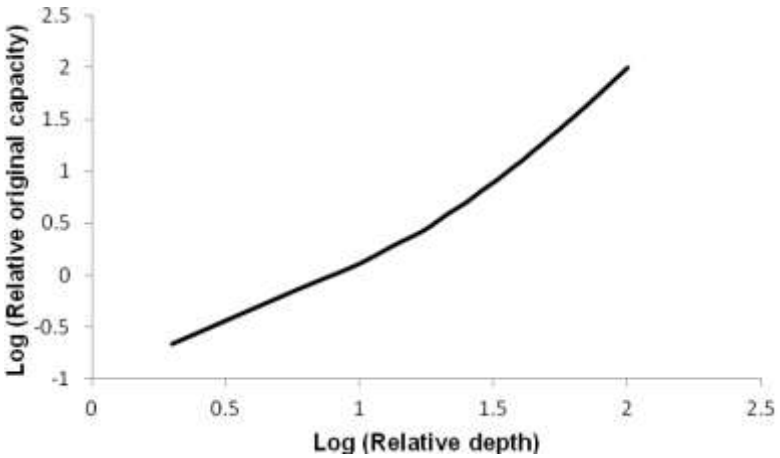


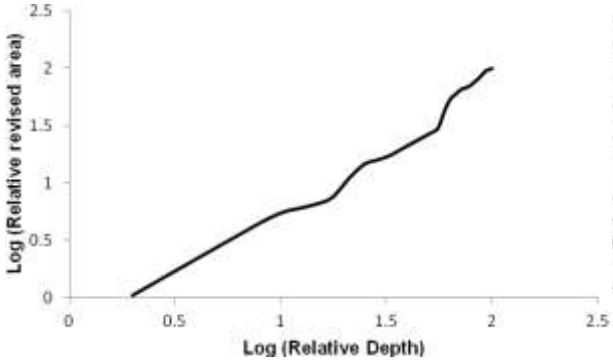
Ramtek Project

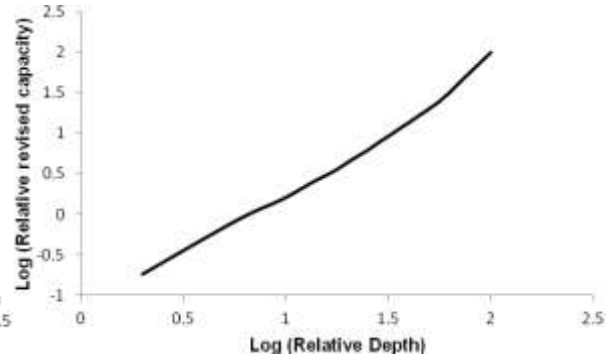
State – Maharashtra				
River	***Sur***		Catchment Area	***213***
MDDL (m)	***303.77***		Original capacity (MCM) at MDDL	***2.26***
FRL (m)	***316.87***		Original capacity (MCM) at FRL	***117.18***
Year of first impoundment	***1914***		Year of capacity survey	***1987***
Value of 'm'	***3.16***		Type of reservoir	***Type-II***





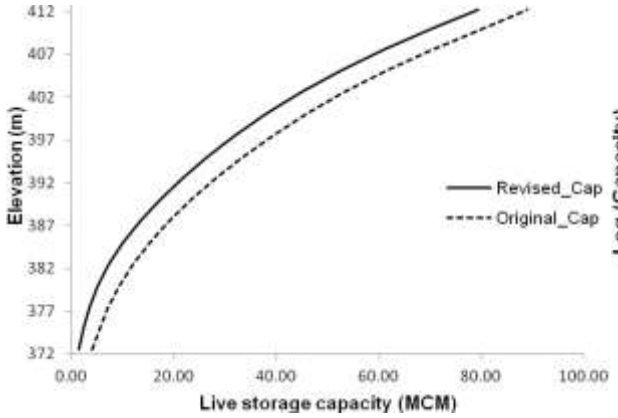


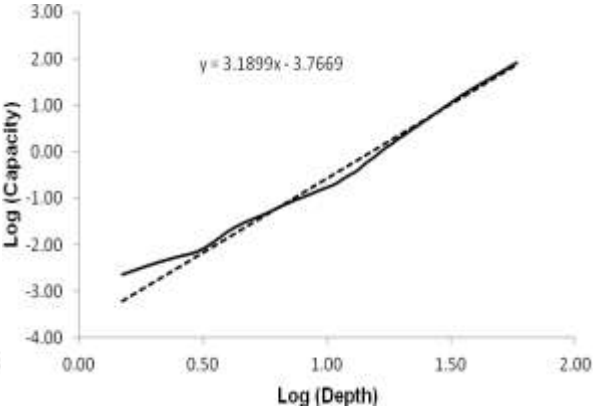


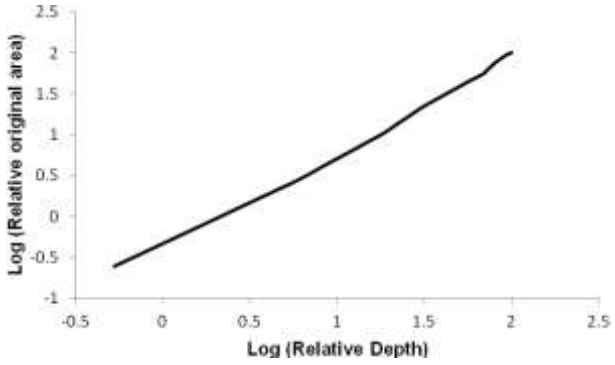


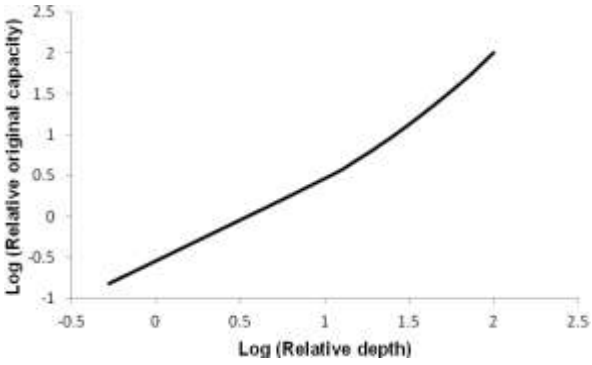
Wan – Akola Project

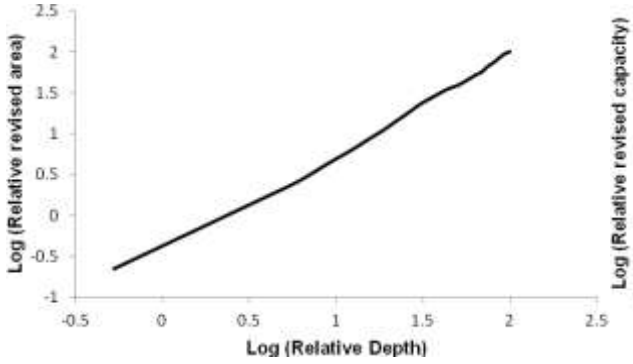
State – ***Maharashtra***				
River	***Wan***		Catchment Area	***278.9***
MDDL (m)	***372.5***		Original capacity (MCM) at MDDL	***4.077***
FRL (m)	***412.5***		Original capacity (MCM) at FRL	***90.15***
Year of first impoundment	***1988***		Year of capacity survey	***2001***
Value of 'm'	***3.19***		Type of reservoir	***Type-II***

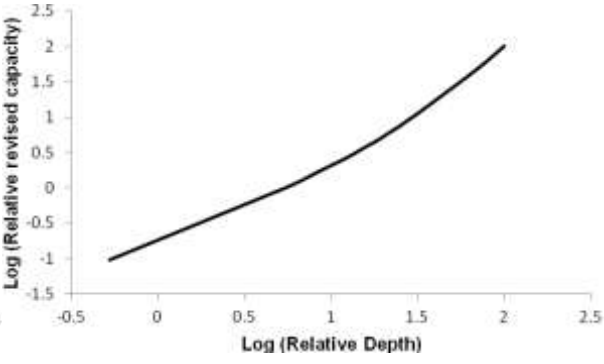






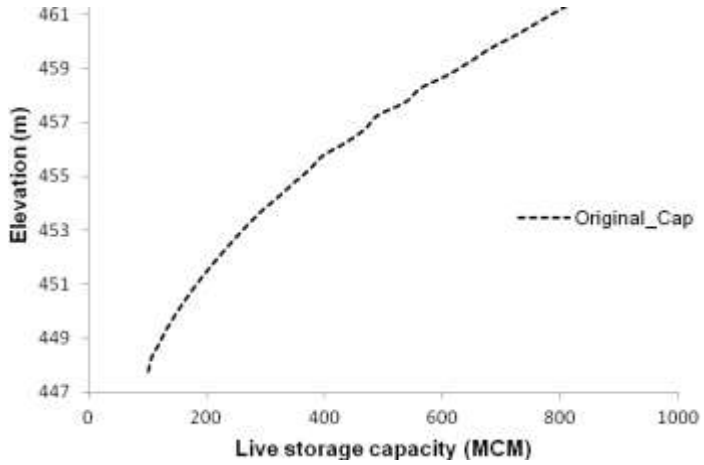


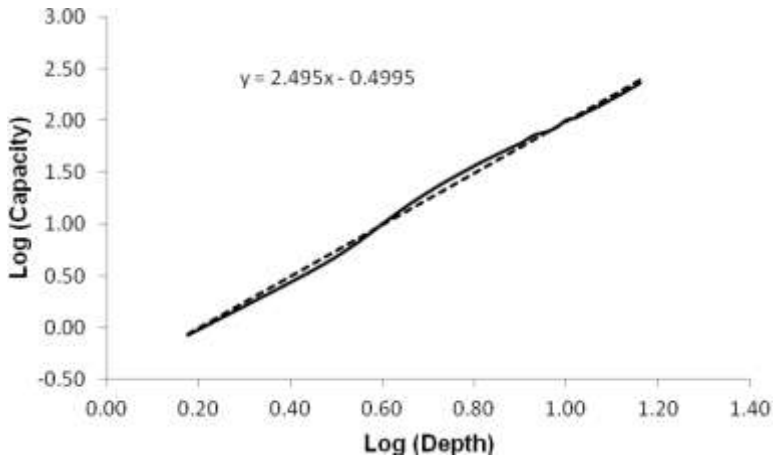


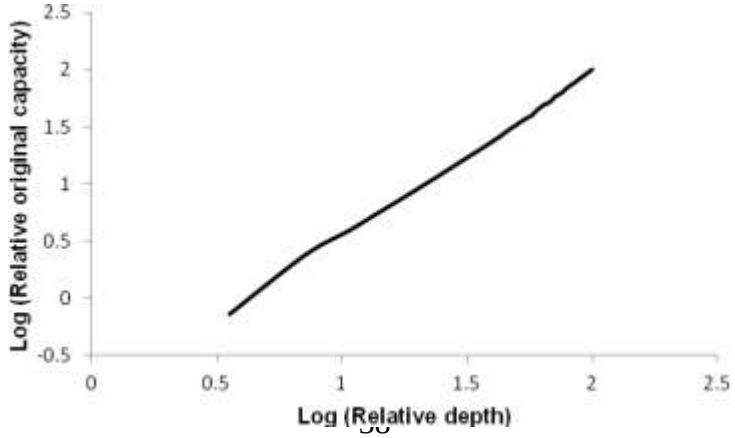


Yeldari Project

State – ***Maharashtra***				
River	***Purna***		Catchment Area	***7330***
MDDL (m)	***447.77***		Original capacity (MCM) at MDDL	***101.51***
FRL (m)	***461.77***		Original capacity (MCM) at FRL	***850.00***
Year of first impoundment	***1968***		Year of capacity survey	***1983***
Value of 'm'	***2.49***		Type of reservoir	***Type-III***

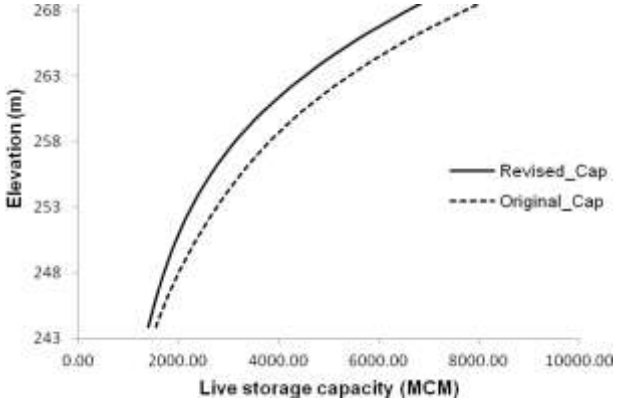


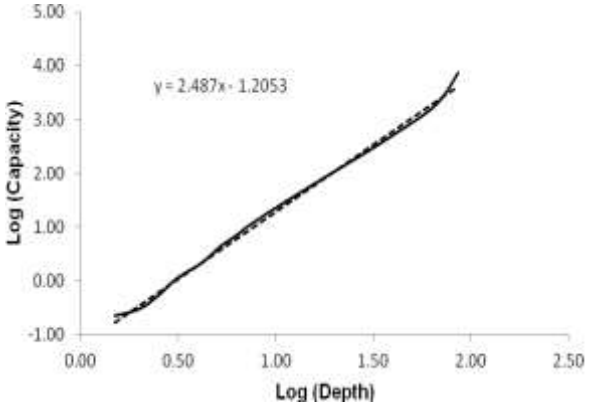


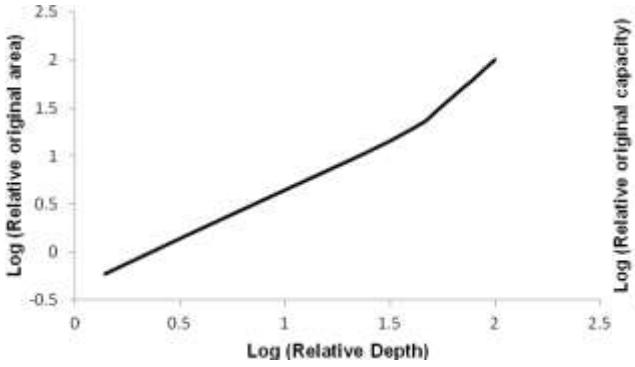


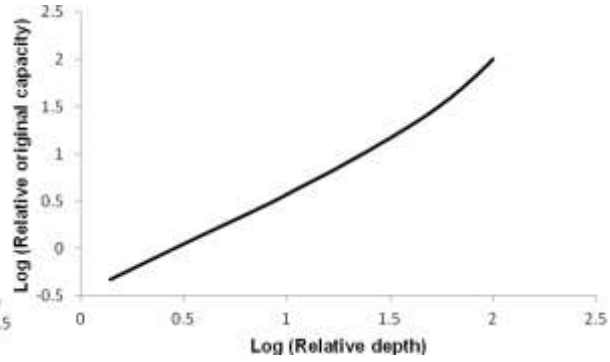
Srisailam Project

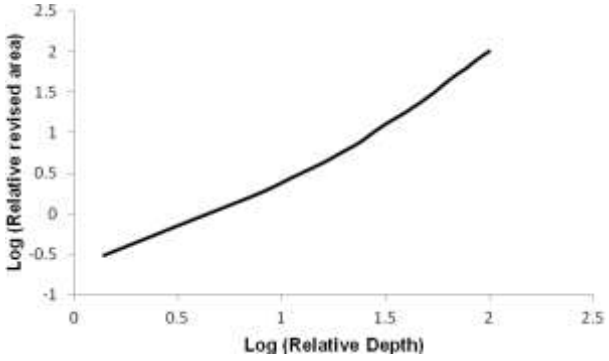
State – ***Andhra Pradesh***				
River	***Krishna***		Catchment area	***11790***
MDDL (m)	***243.84***		Original capacity (MCM) at MDDL	***1559.102***
FRL (m)	***269.75***		Original capacity (MCM) at FRL	***8724.88***
Year of first impoundment	***1976***		Year of capacity survey	***1997***
Value of 'm'	***2.48***		Type of reservoir	***Type-III***

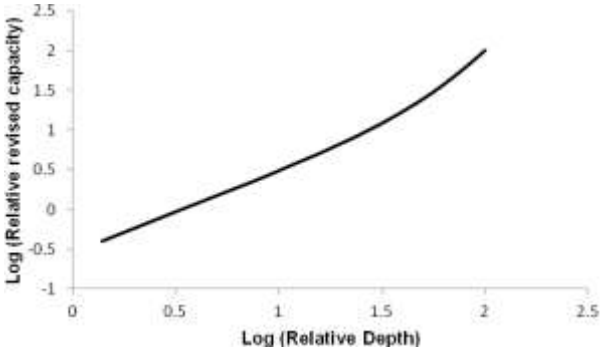






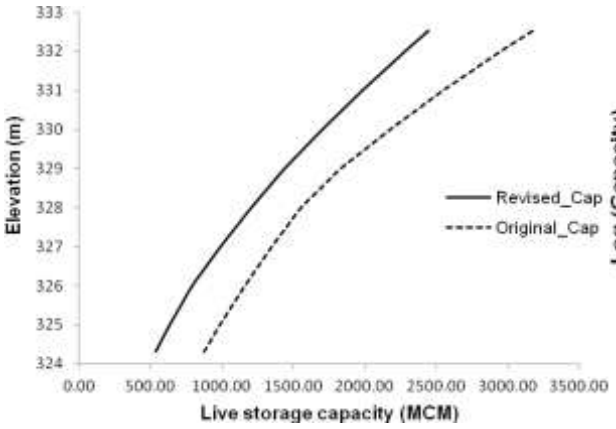


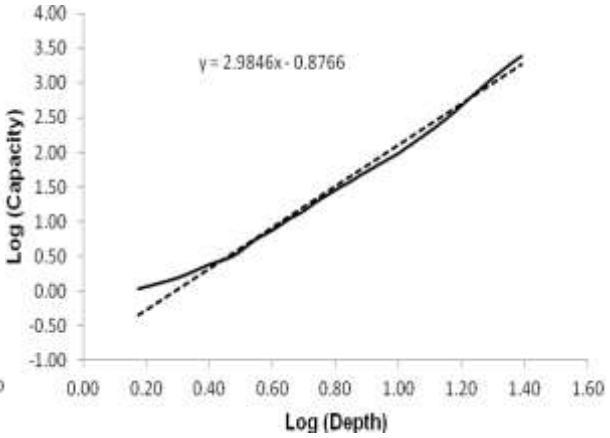


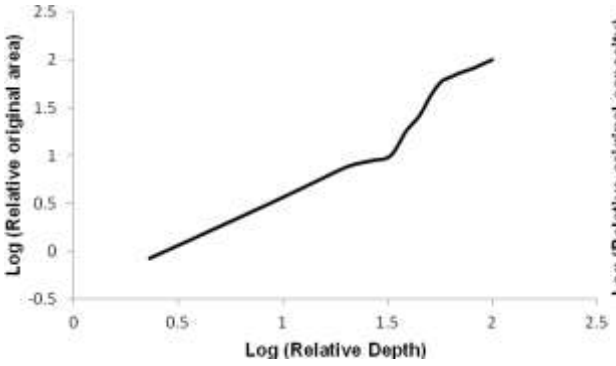


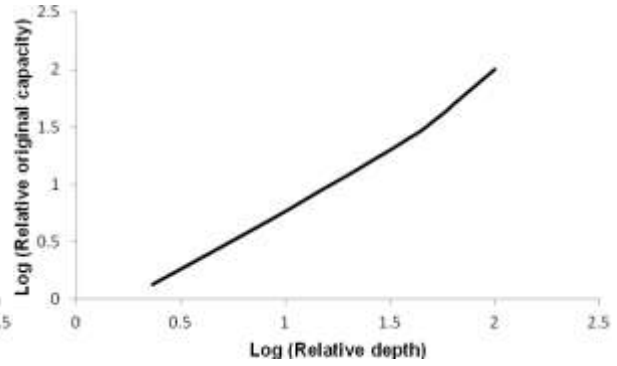
Sriramasagar Project

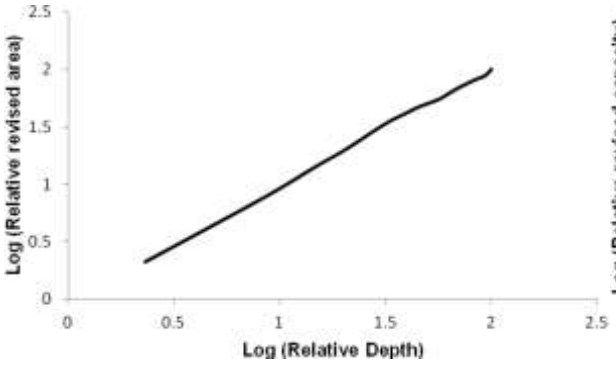
State – ***Andhra Pradesh***				
River	***Godavari***		Catchment area	***91750***
MDDL (m)	***324.31***		Original capacity (MCM) at MDDL	***874.82***
FRL (m)	***332.54***		Original capacity (MCM) at FRL	***3172***
Year of first impoundment	***1970***		Year of capacity survey	***1994***
Value of 'm'	***2.98***		Type of reservoir	***Type-II***

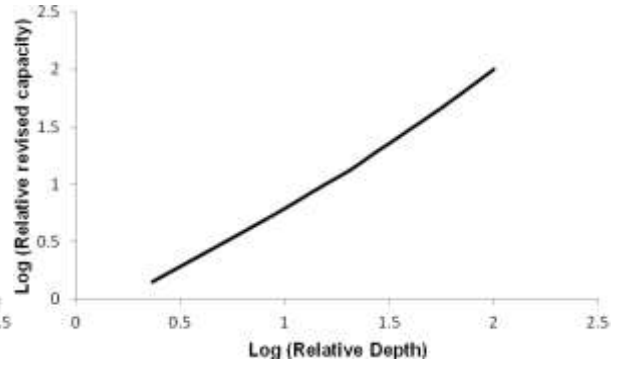






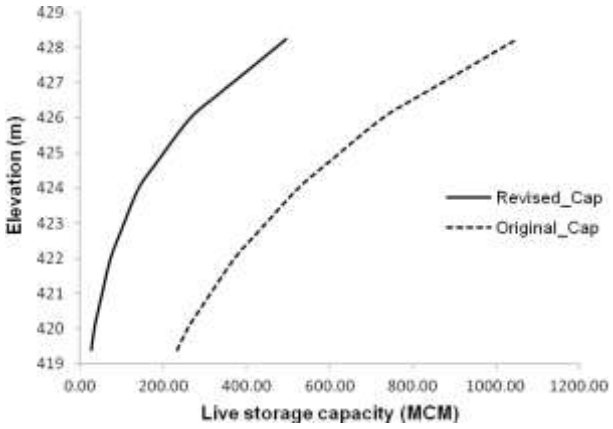


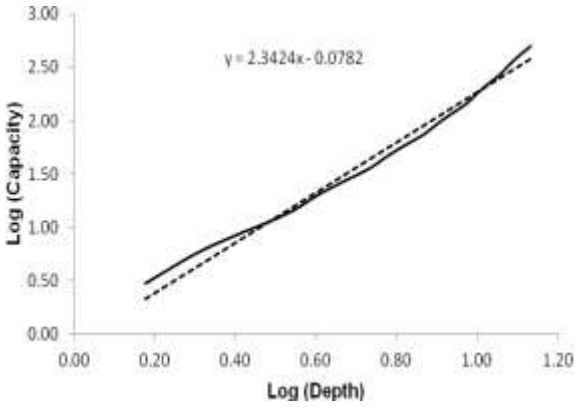


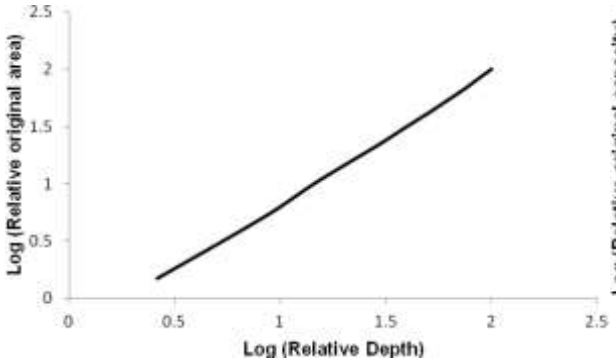


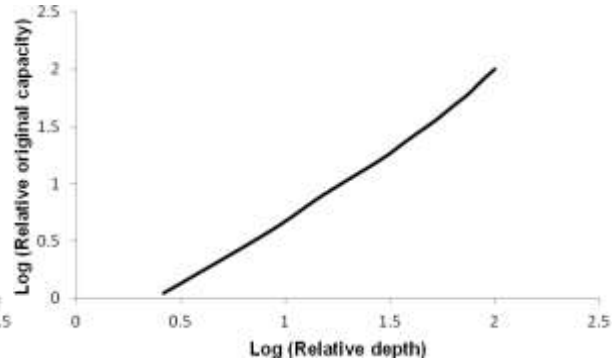
Nizamsagar Project

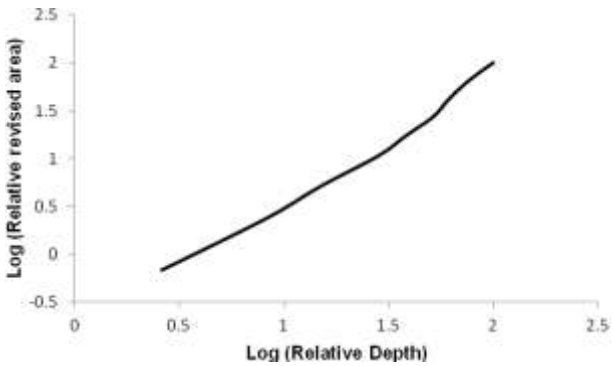
State – ***Andhra Pradesh***				
River	***Godavari***		Catchment area	***21693***
MDDL (m)	***419.4***		Original capacity (MCM) at MDDL	***232.93***
FRL (m)	***426.87***		Original capacity (MCM) at FRL	***841.18***
Year of first impoundment	***1930***		Year of capacity survey	***1992***
Value of 'm'	-		Type of reservoir	-

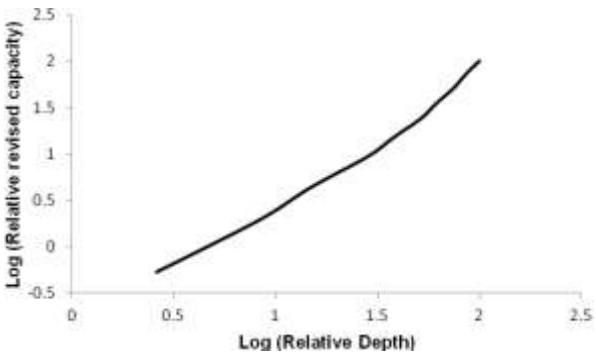






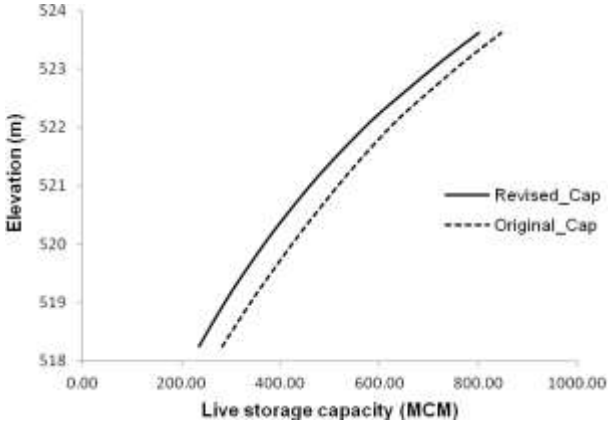


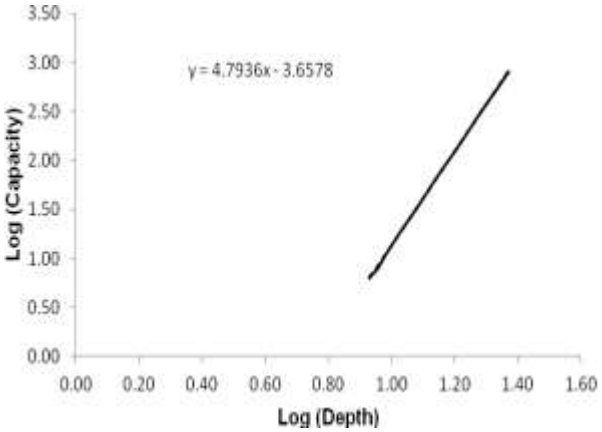


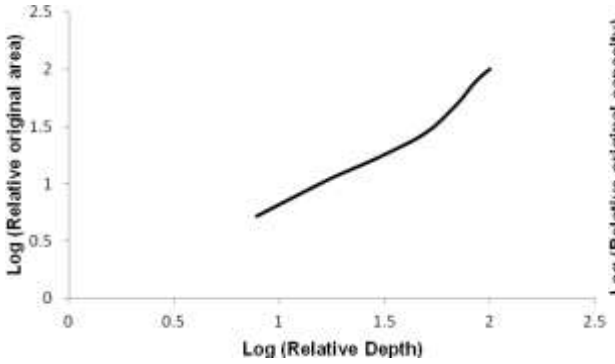


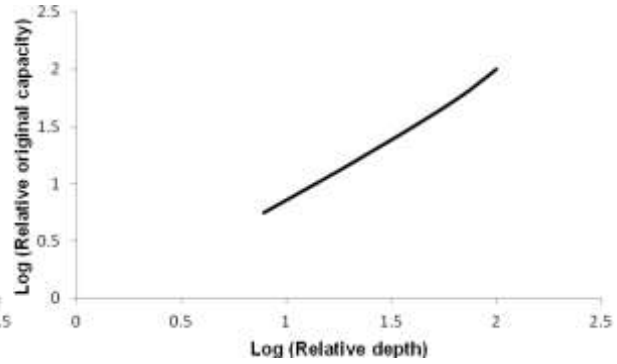
Singur Project

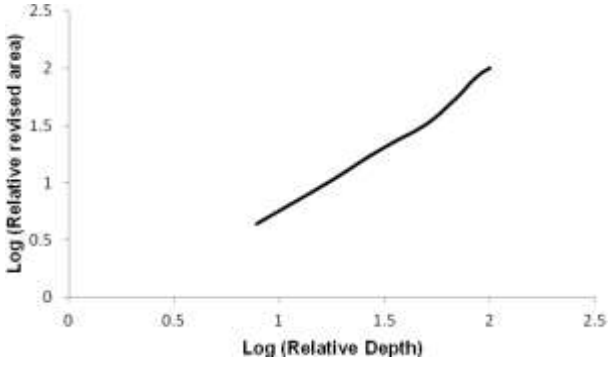
State – ***Andhra Pradesh***				
River	***Manjira***		Catchment area	***16096***
MDDL (m)	***518.25***		Original capacity (MCM) at MDDL	***282.78***
FRL (m)	***523.60***		Original capacity (MCM) at FRL	***847***
Year of first impoundment	***1989***		Year of capacity survey	***1997***
Value of 'm'	***4.79***		Type of reservoir	***Type-I***

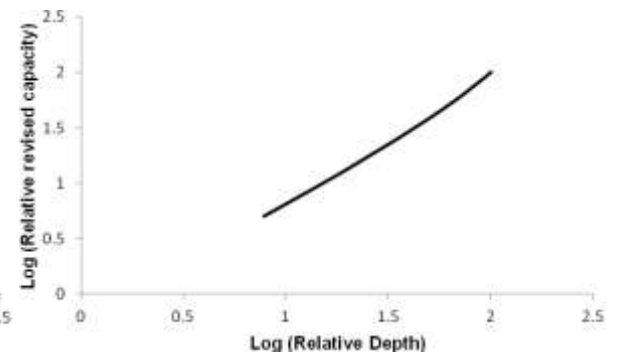






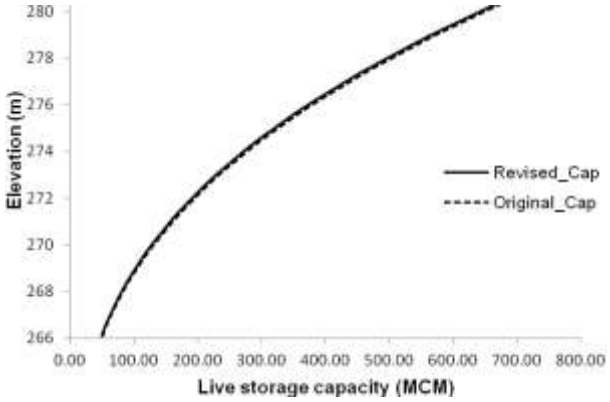


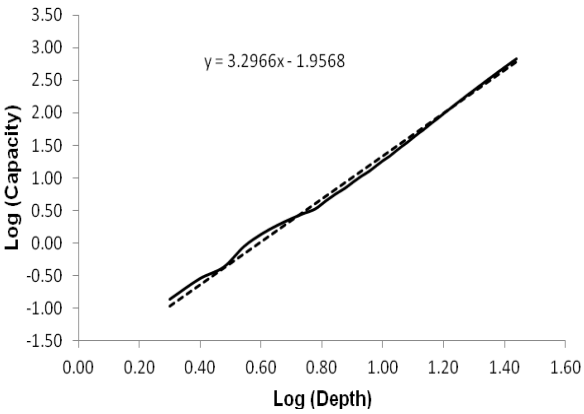


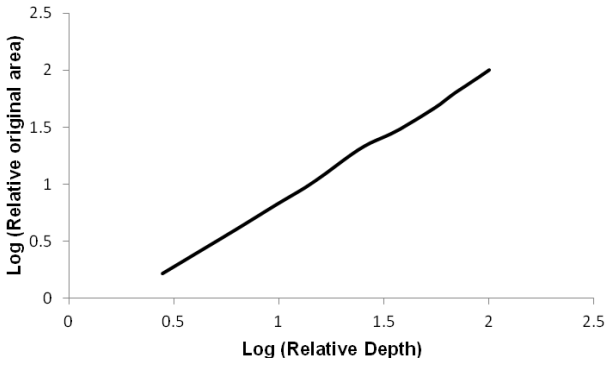


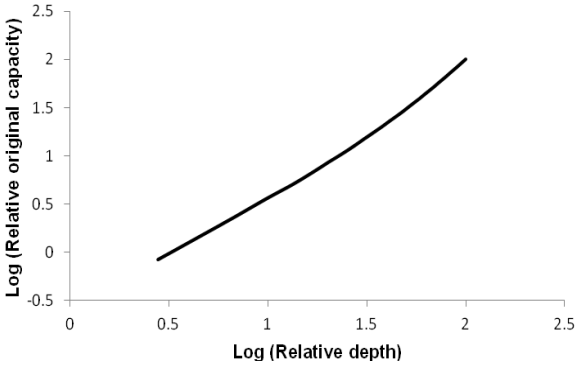
Lower Manair Project

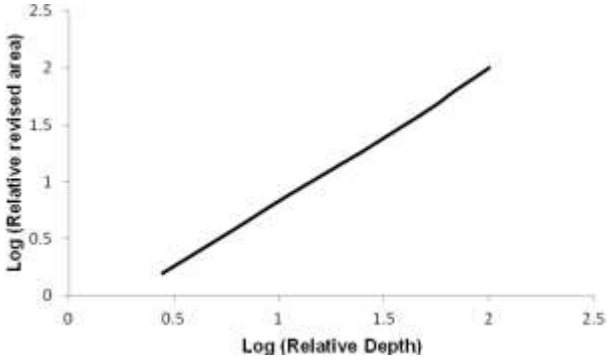
State – ***Andhra Pradesh***				
River	***Manair***		Catchment area	***6464***
MDDL (m)	***266.09***		Original capacity (MCM) at MDDL	***51.113***
FRL (m)	***280.416***		Original capacity (MCM) at FRL	***680.648***
Year of first impoundment	***1985***		Year of capacity survey	***1991***
Value of 'm'	***3.29***		Type of reservoir	***Type-II***

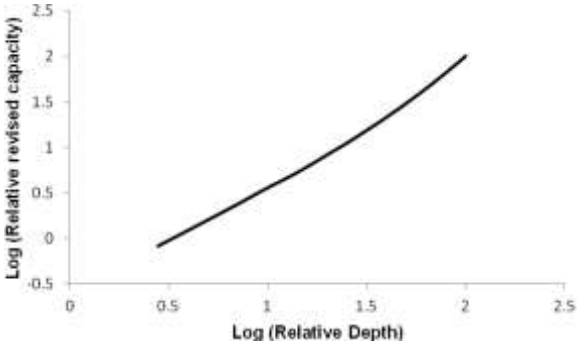






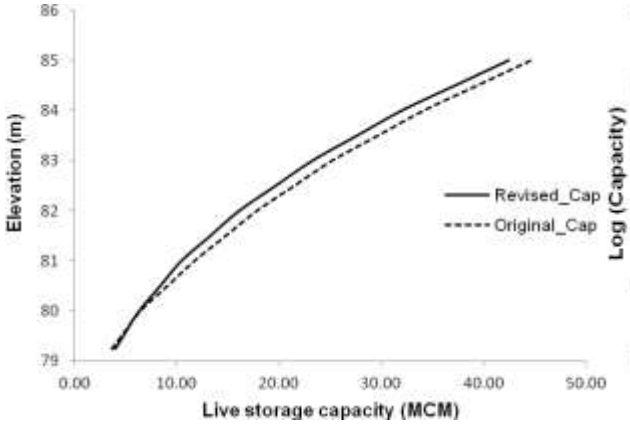


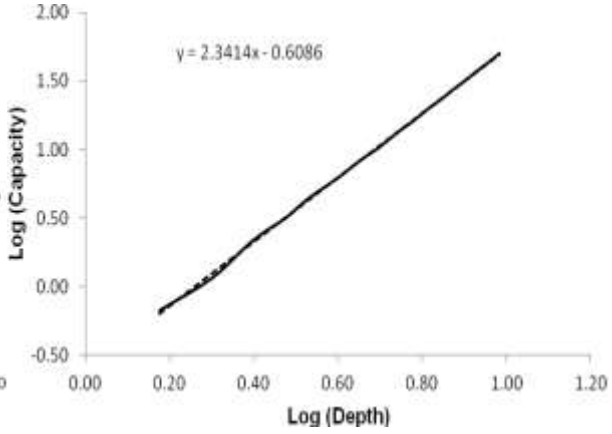


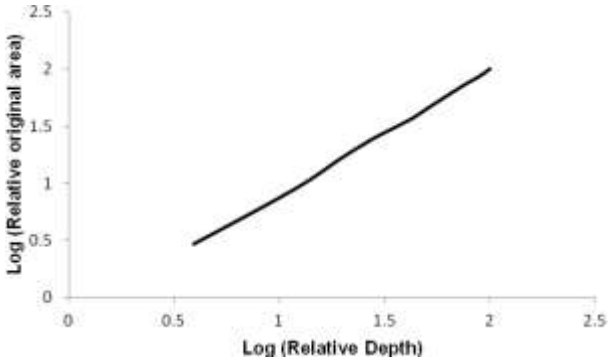


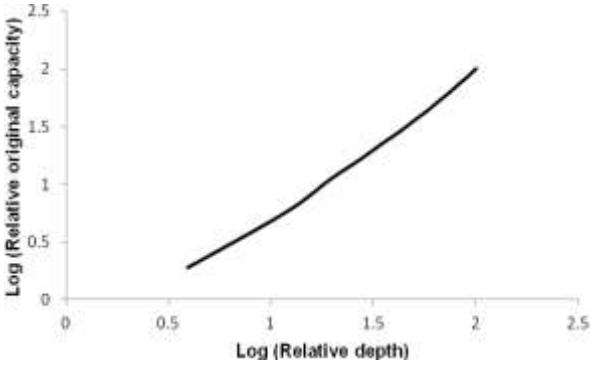
Araniar Project

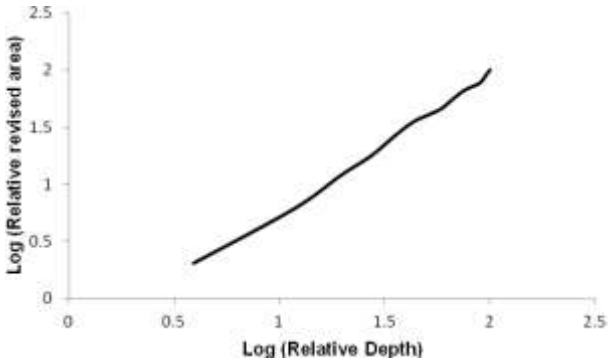
State – ***Andhra Pradesh***				
River	***Araniar***		Catchment area	***NA***
MDDL (m)	***79.25***		Original capacity (MCM) at MDDL	***3.65***
FRL (m)	***85.65***		Original capacity (MCM) at FRL	***52.47***
Year of first impoundment	***1958***		Year of capacity survey	***2001***
Value of 'm'	***2.34***		Type of reservoir	***Type-III***

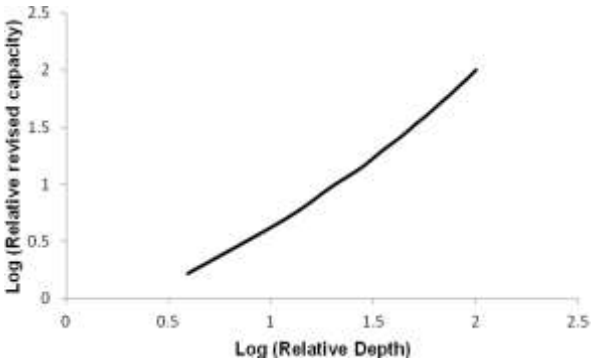






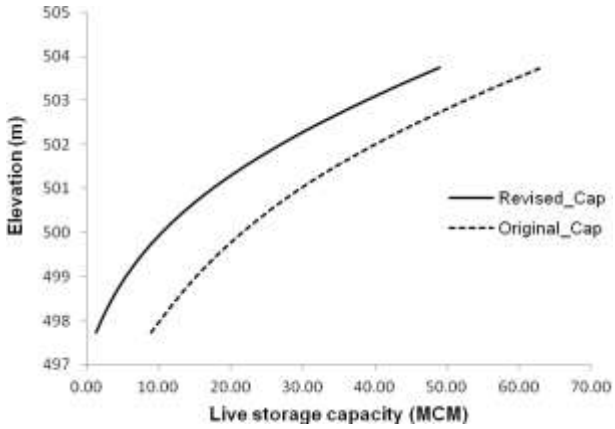


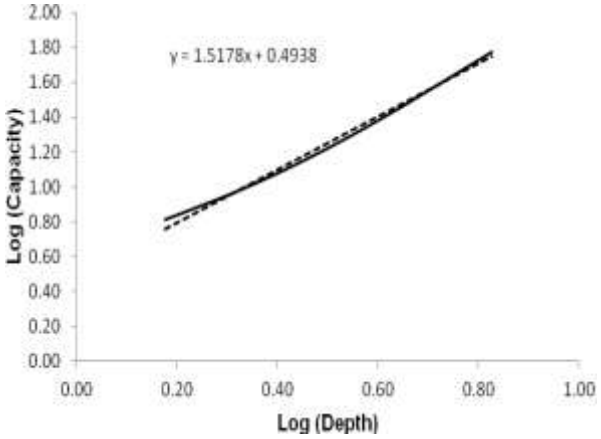


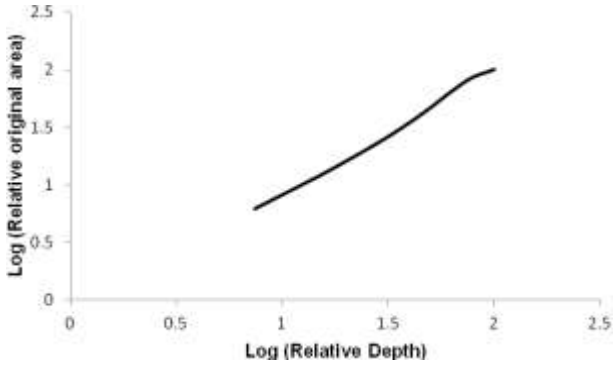


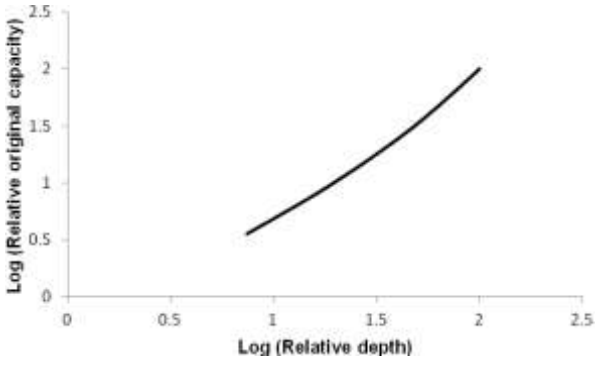
Bhairavani Thippa Project

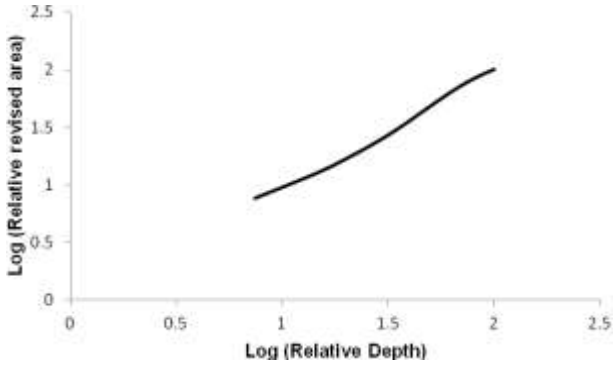
State – ***Andhra Pradesh***				
River	***Vedavathy***		Catchment area	***14386***
MDDL (m)	***497.74***		Original capacity (MCM) at MDDL	***8.96***
FRL (m)	***504.44***		Original capacity (MCM) at FRL	***74.23***
Year of first impoundment	***1961***		Year of capacity survey	***2000***
Value of 'm'	-		Type of reservoir	-

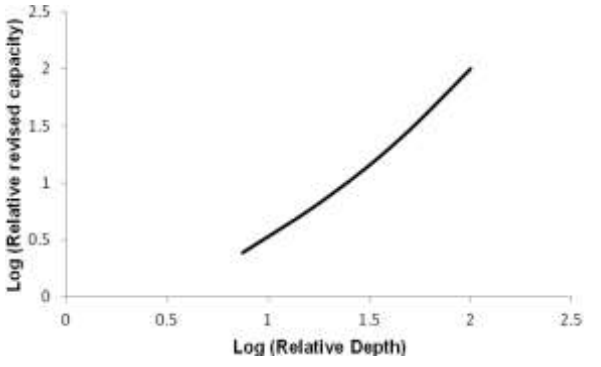






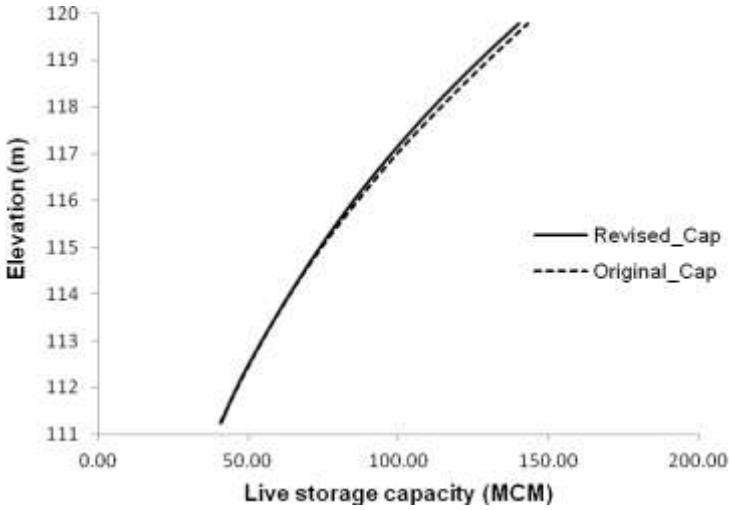


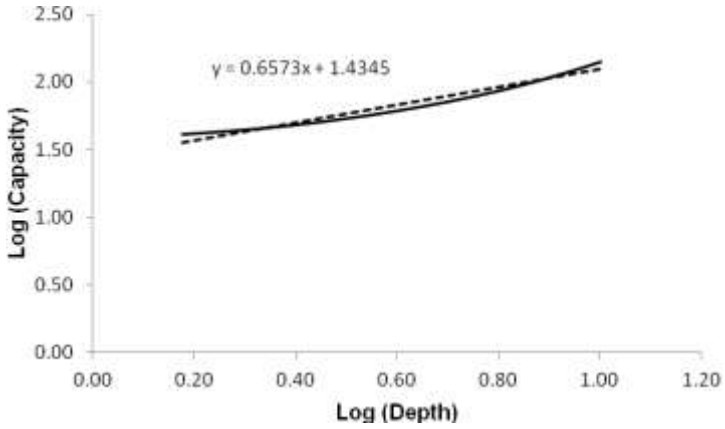


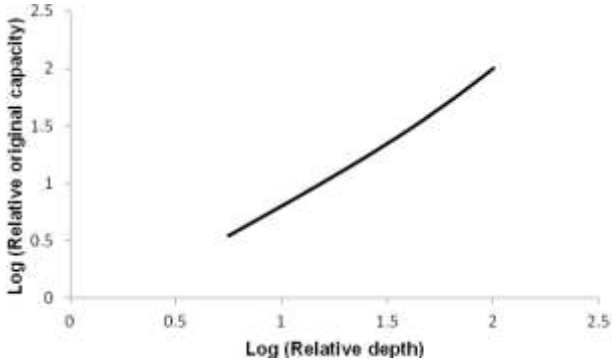


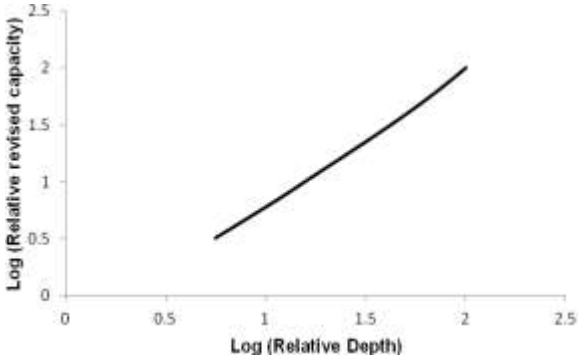
Kinnerasani Project

State – ***Andhra Pradesh***				
River	***Kinnersani***		Catchment area	***1333.3***
MDDL (m)	***111.25***		Original capacity (MCM) at MDDL	***40.58***
FRL (m)	***124.055***		Original capacity (MCM) at FRL	***237.87***
Year of first impoundment	***1970***		Year of capacity survey	***1985***
Value of 'm'	-		Type of reservoir	-



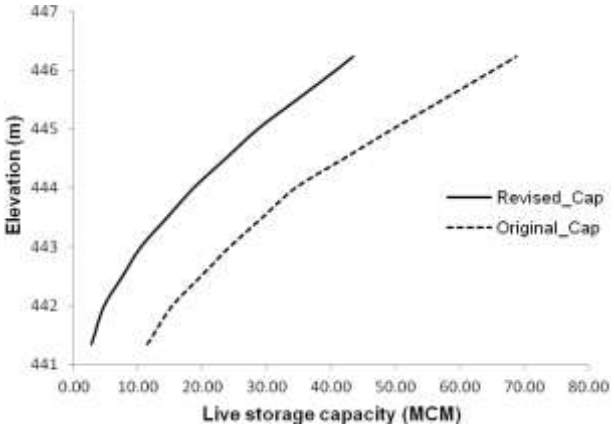


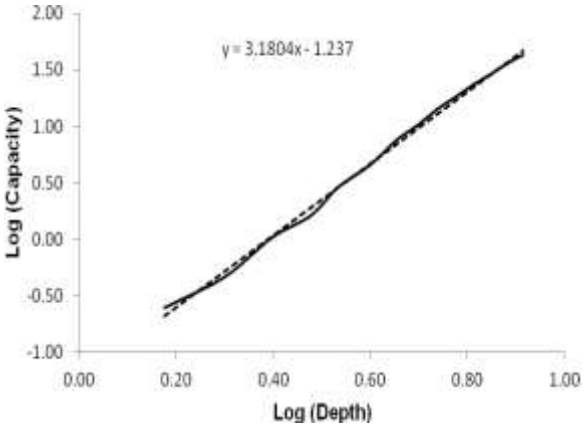


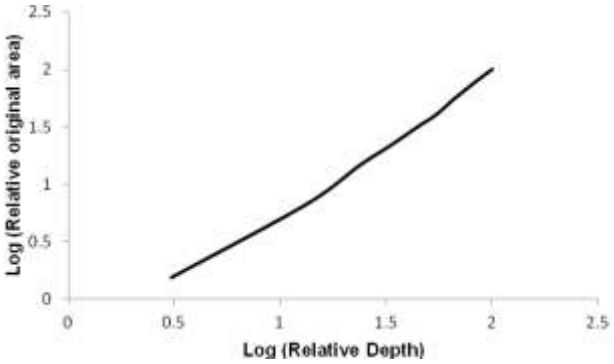


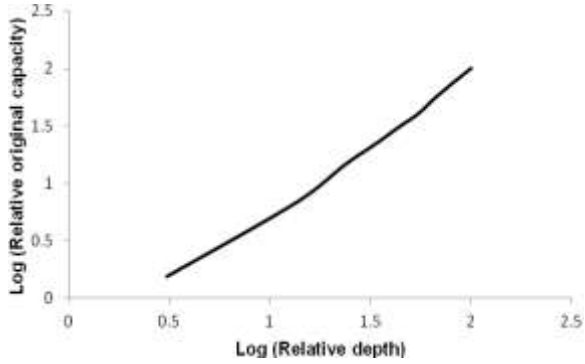
Pocharam Project

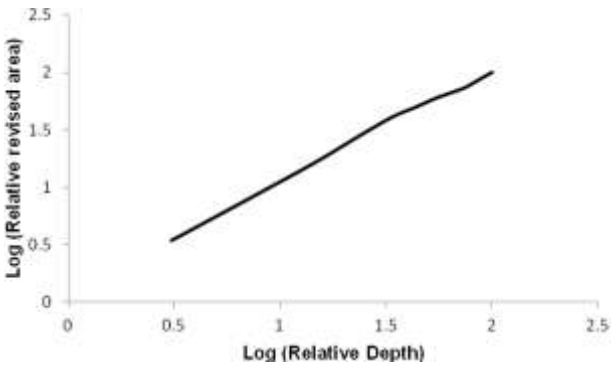
State – ***Andhra Pradesh***				
River	***Alair***		Catchment area	***673***
MDDL (m)	***441.35***		Original capacity (MCM) at MDDL	***11.46***
FRL (m)	***446.22***		Original capacity (MCM) at FRL	***68.64***
Year of first impoundment	***1922***		Year of capacity survey	***2000***
Value of 'm'	***3.18***		Type of reservoir	***Type-II***

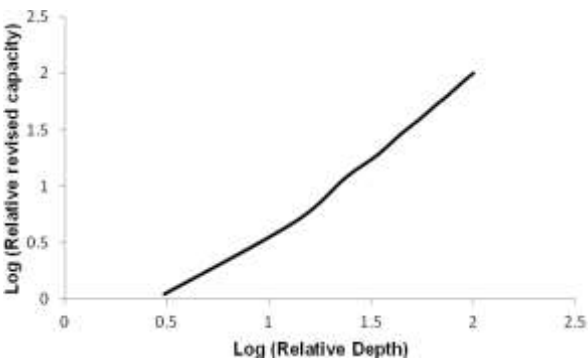






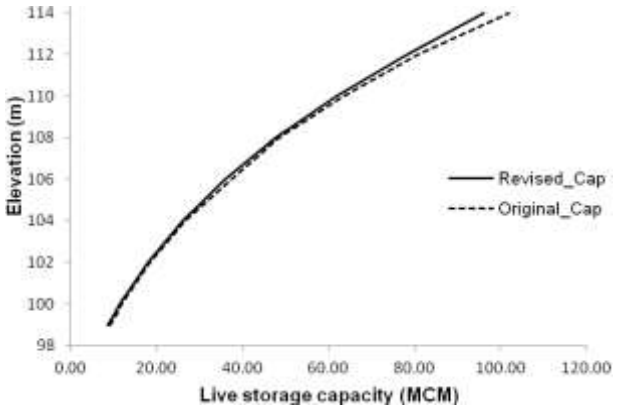


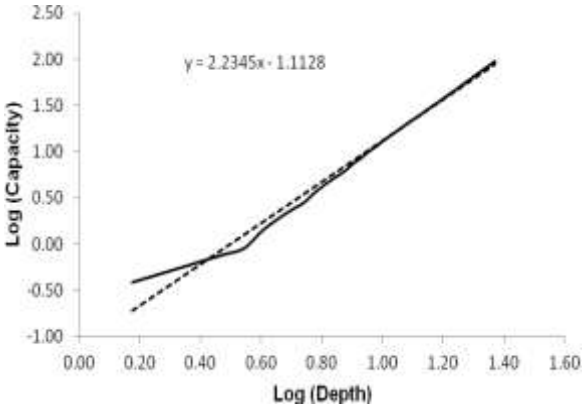


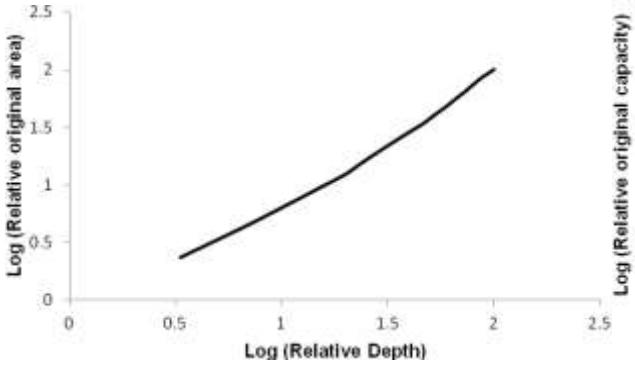


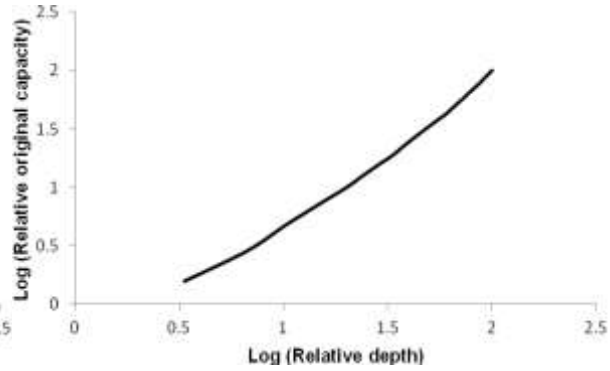
Raiwada Project

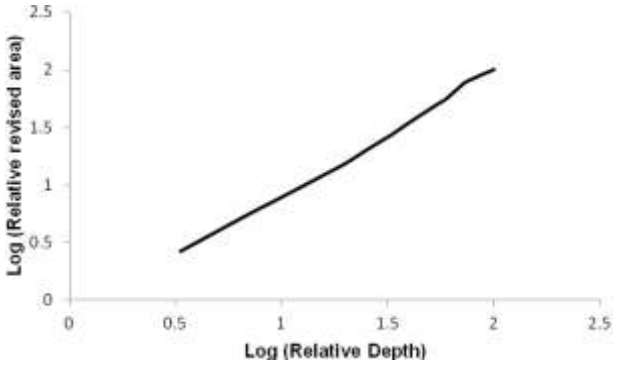
State – ***Andhra Pradesh***				
River	***Sarada***		Catchment area	***448***
MDDL (m)	***99.00***		Original capacity (MCM) at MDDL	***9.2***
FRL (m)	***114.00***		Original capacity (MCM) at FRL	***101.93***
Year of first impoundment	***1983***		Year of capacity survey	***1993***
Value of 'm'	***2.23***		Type of reservoir	***Type-III***

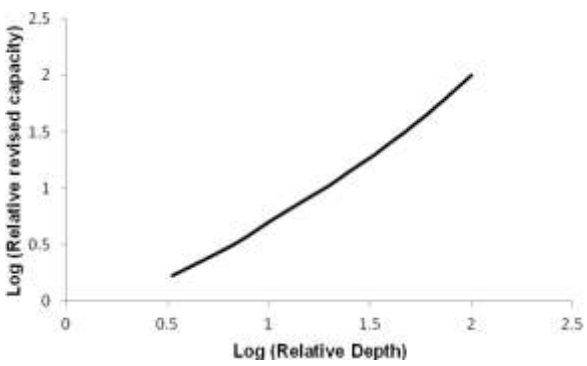






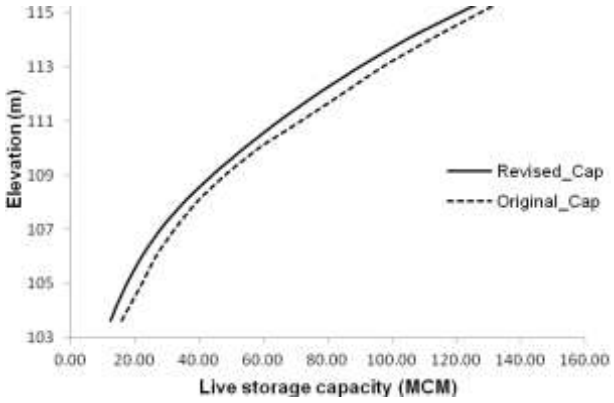


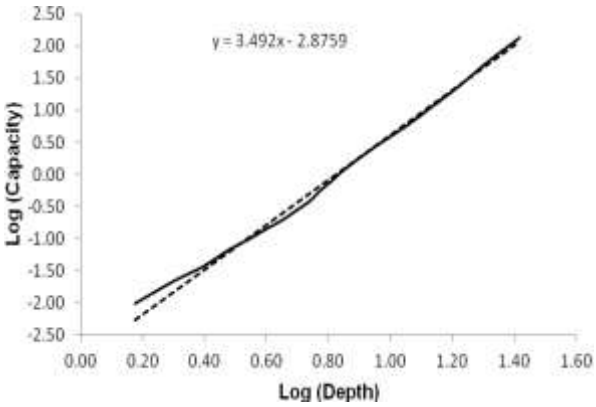


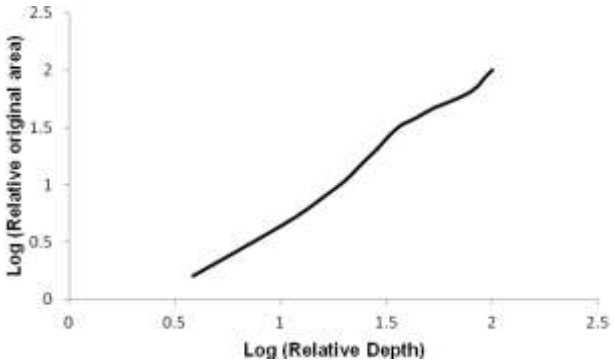


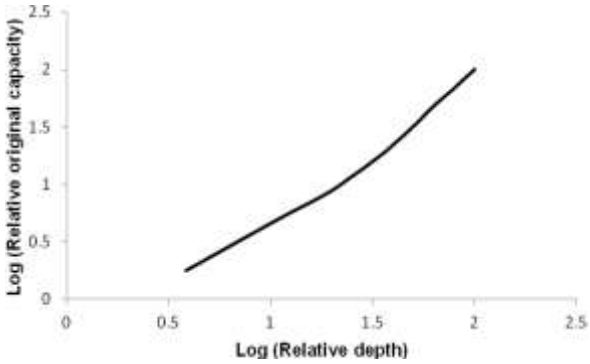
Thandava Project

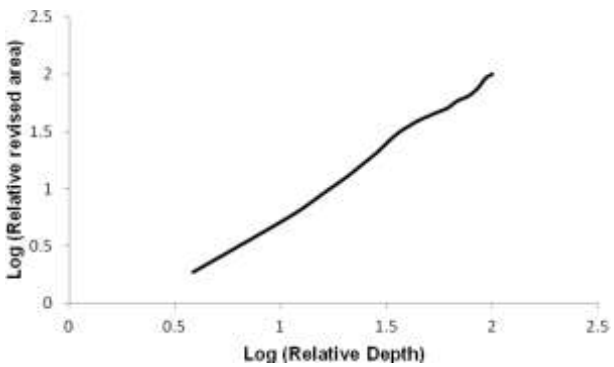
State – ***Andhra Pradesh***				
River	***Thandava***		Catchment area	***4480***
MDDL (m)	***103.63***		Original capacity (MCM) at MDDL	***15.85***
FRL (m)	***115.825***		Original capacity (MCM) at FRL	***140.43***
Year of first impoundment	***1974***		Year of capacity survey	***1991***
Value of 'm'	***3.49***		Type of reservoir	***Type-II***

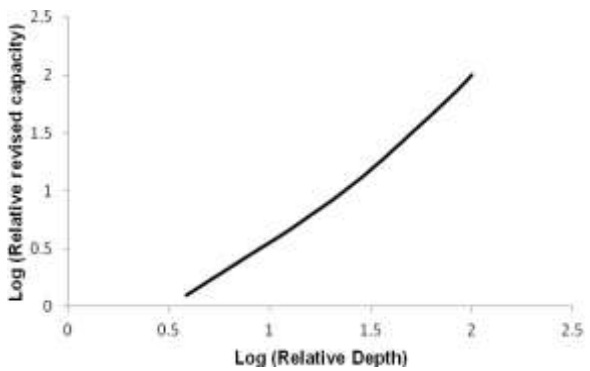






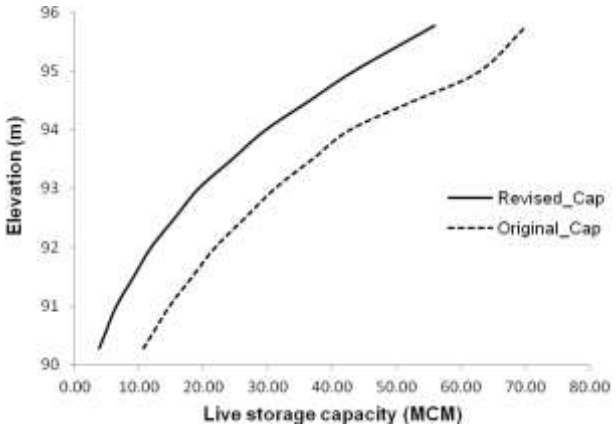


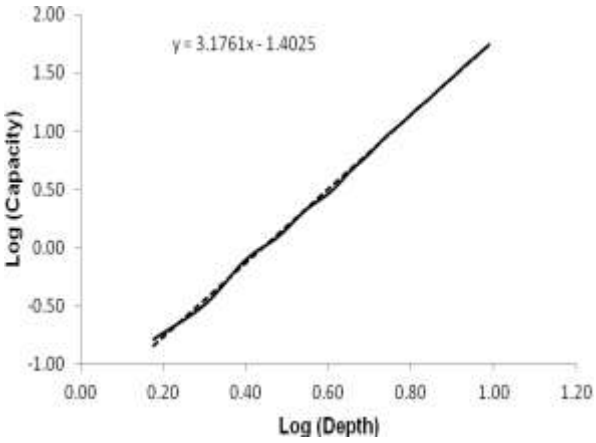


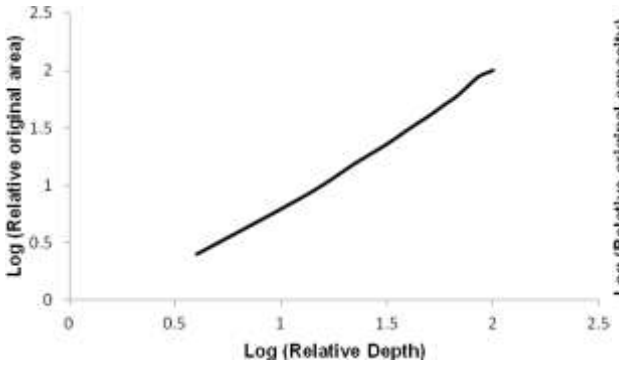


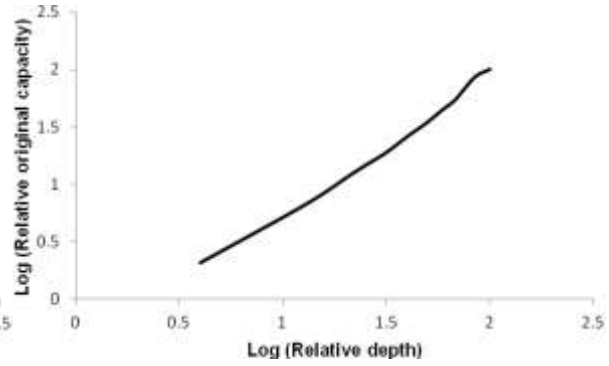
Wyra Project

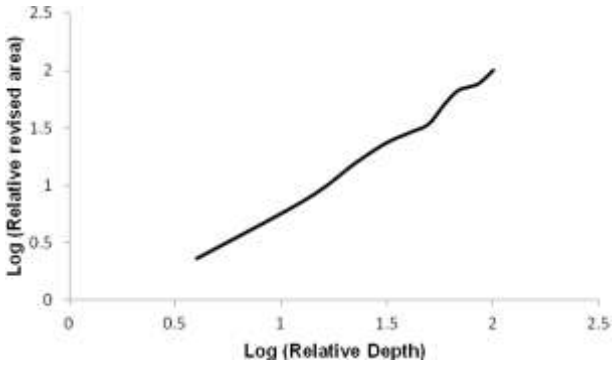
State – ***Andhra Pradesh***				
River	***Munneru***		Catchment area	***709.66***
MDDL (m)	***90.305***		Original capacity (MCM) at MDDL	***10.67***
FRL (m)	***95.77***		Original capacity (MCM) at FRL	***70.06***
Year of first impoundment	***1929***		Year of capacity survey	***2002***
Value of 'm'	***3.17***		Type of reservoir	***Type-II***

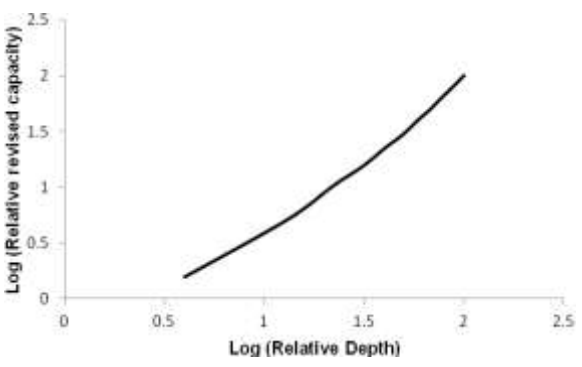






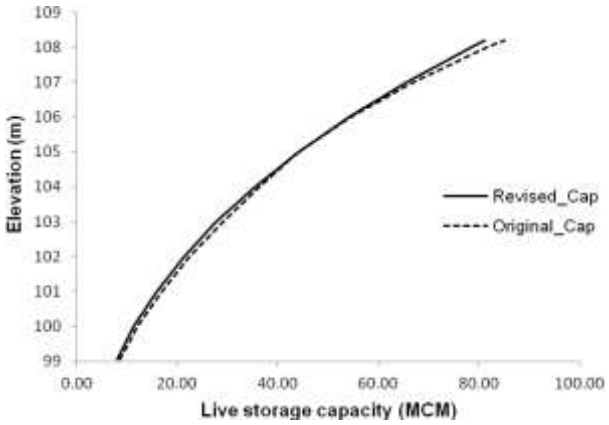


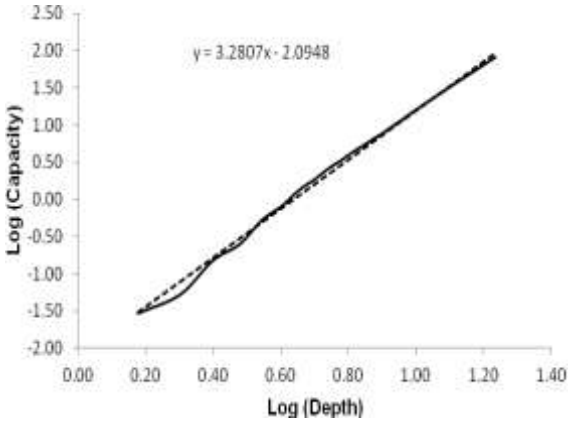


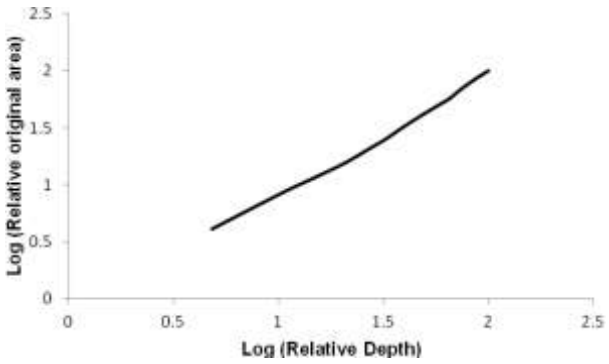


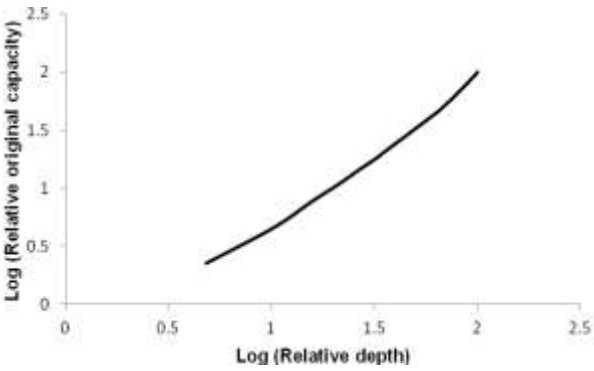
Thammileru Project

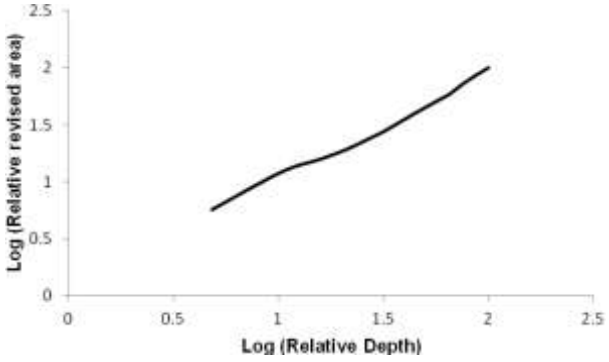
State – ***Andhra Pradesh***				
River	***Thammileru***		Catchment area	***576.6***
MDDL (m)	***98.603***		Original capacity (MCM) at MDDL	***8.49***
FRL (m)	***108.2***		Original capacity (MCM) at FRL	***84.95***
Year of first impoundment	***1977***		Year of capacity survey	***1987***
Value of 'm'	***3.28***		Type of reservoir	***Type-II***

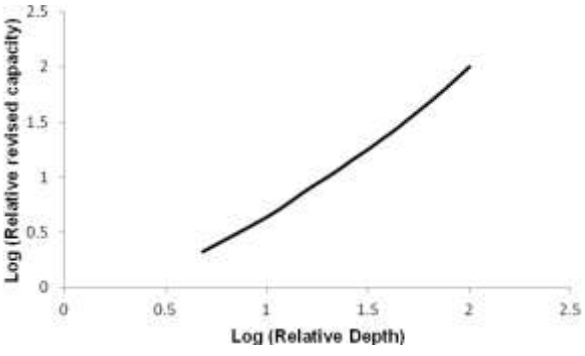












3.5 Analysis of Reservoirs from Studies carried out at NIH

A number of reservoir related studies have been carried out at NIH. Most of these studies have used the EAC tables of the reservoirs for analysis. From these studies, the available EAC table data of 16 reservoirs have been utilized in the present study. These reservoirs include Hirakud, Gandhi Sagar, Rihand, Bargi, Kabini, Tehri, Tawa, Ujjani (Bhima), Chaskaman, Khadakwasla, Panshet, Pawana, Mulshi, Yedgaon, Dimbhe, and Ghod. In most of the studies, original EAC tables were available, covering mostly the live storage zone of reservoirs. Therefore, type of reservoirs could not be determined for such reservoirs. Depending on the availability of data, plots of relative depth vs. relative area (and/or relative capacity) corresponding to original and revised conditions have been prepared.

3.6 Analysis of Reservoirs using data from Weekly Reservoir Bulletins of CWC

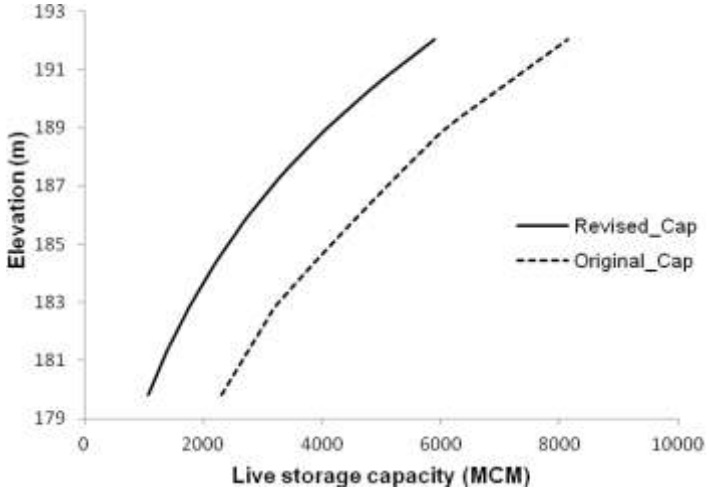
CWC publishes the weekly reports of 85 important reservoirs of India. These reports contain the information regarding the name of reservoir, FRL, current reservoir level, live capacity at FRL in billion cubic meter (BCM), current live storage in BCM, storage as % of live capacity at FRL and benefits from the reservoir for irrigation and hydropower. In the present study, information pertaining to current reservoir level and live capacity at current level has been utilized. For different reservoirs, these details for the past two years have been computerized and Elevation – Capacity tables have been prepared.

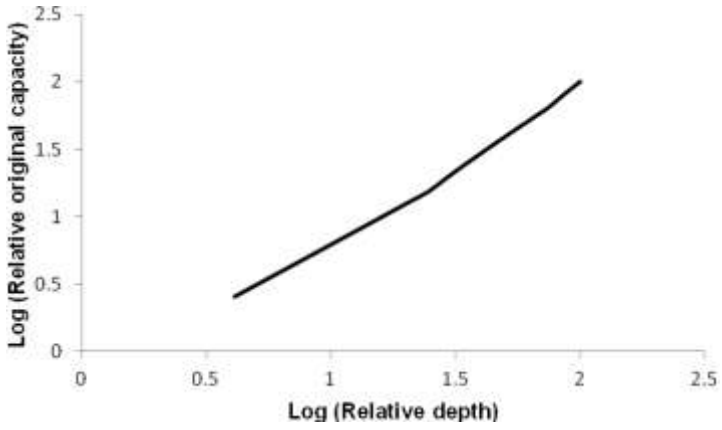
Those reservoirs have been included in the present analysis for which appreciable range of live storage zone is covered. From the weekly bulletin, data of 20 reservoirs has been included in the present study. These reservoirs include Sholayar, Harangi, Hemavathy, Lingnamakki, Bhadra, Ghataprabha, Tungabhadra, Krishna Raja Sagar, Somasila, Indira Sagar, Ranganga, Matatila, Mula, Jayakwadi, Upper Indravathy, Rengali, Salandi, Pong, Thein, and Balimela.

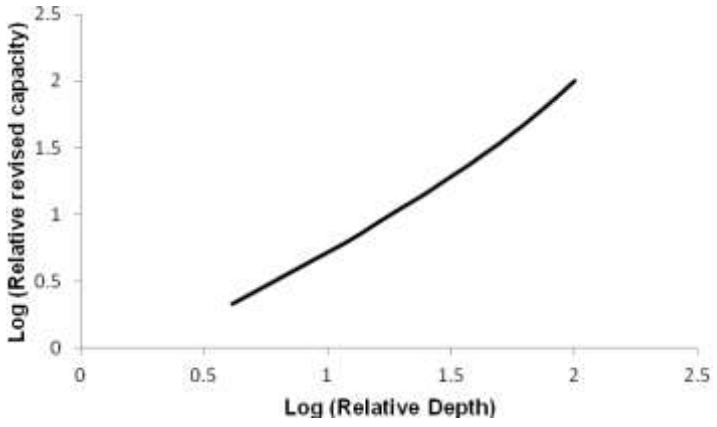
From the available data, only the Elevation - Capacity tables in the live storage zone of the reservoir could be prepared. Because of this reason, type of reservoirs could not be determined. Depending on the availability of data, plots of relative depth vs. relative capacity corresponding to revised conditions have been prepared. The general details for the reservoirs have been obtained from India WRIS web site.

Hirakud Project

State – ***Orissa***				
River	***Mahanadi***		Catchment area	***83400***
MDDL (m)	***179.83***		Original capacity (MCM) at MDDL	***2318.3***
FRL (m)	***192.024***		Original capacity (MCM) at FRL	***8144.15***
Year of first impoundment	***1957***		Year of capacity survey	***2000***
Value of 'm'	-		Type of reservoir	-

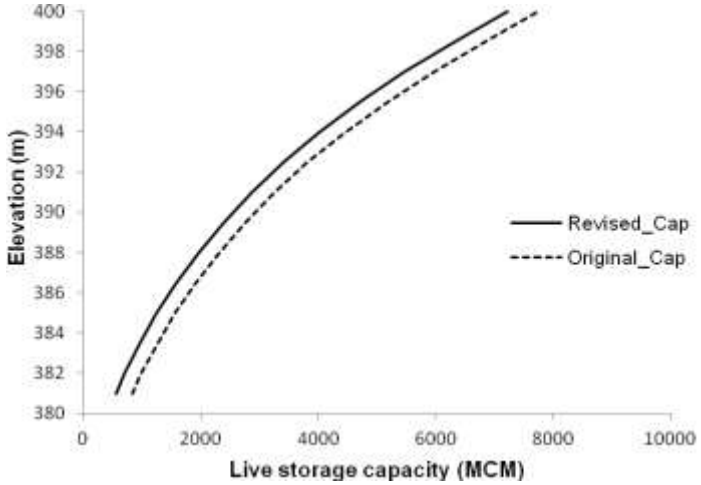


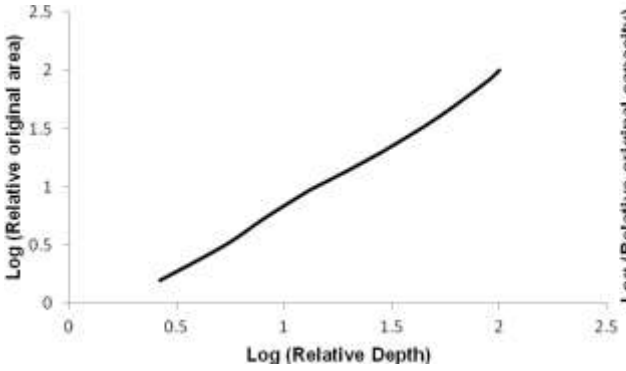


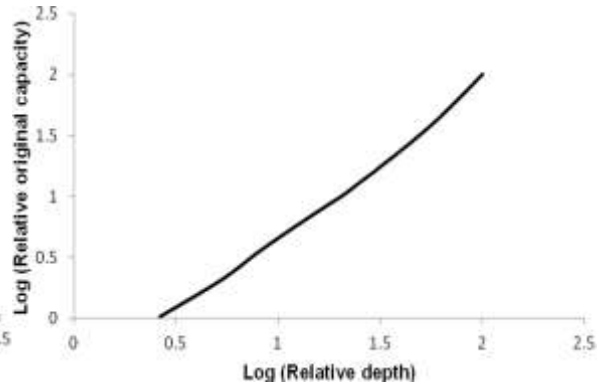


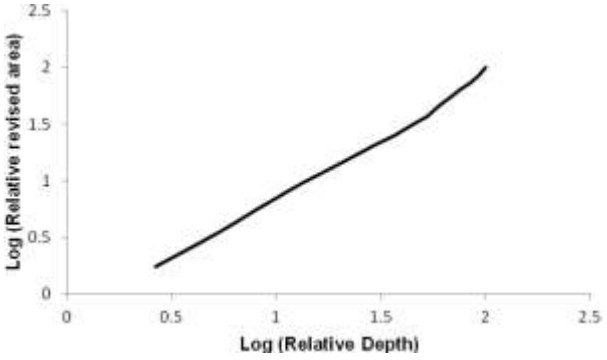
Gandhi Sagar Project

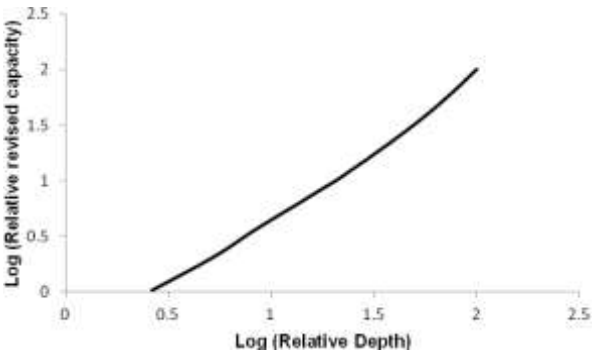
State – ***M.P.***				
River	***Chambal***		Catchment area	***23025***
MDDL (m)	***381***		Original capacity (MCM) at MDDL	***836***
FRL (m)	***399.9***		Original capacity (MCM) at FRL	***7746***
Year of first impoundment	***1960***		Year of capacity survey	***2001***
Value of 'm'	-		Type of reservoir	-





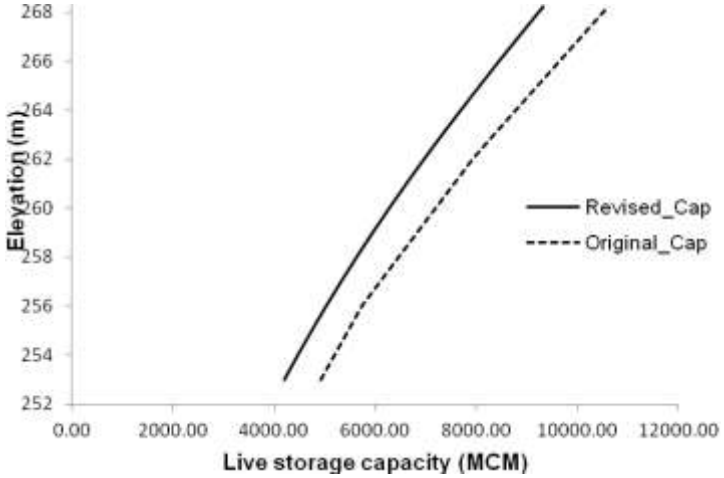


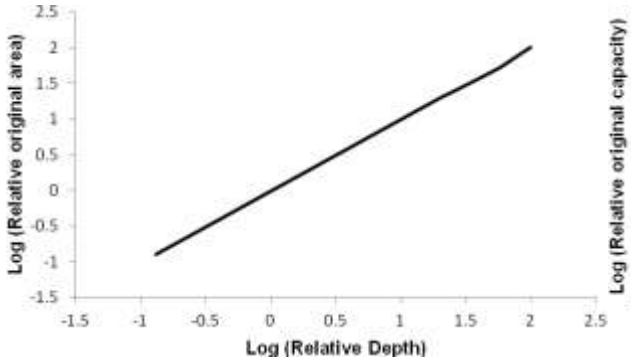


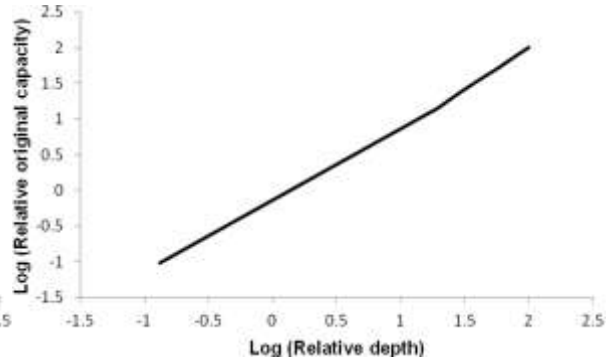


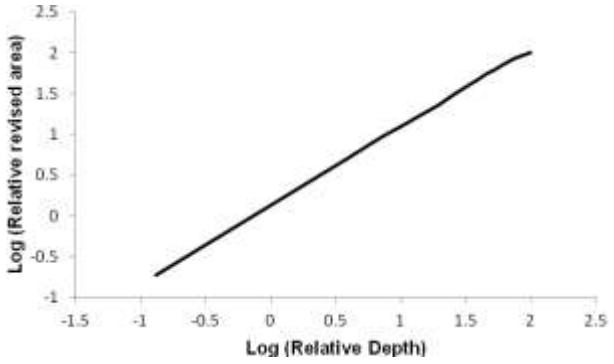
Rihand Project

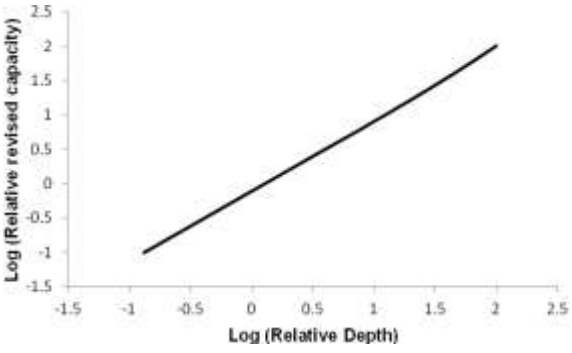
State – ***M.P.***				
River	***Rihand***		Catchment area	***13263***
MDDL (m)	***252.98***		Original capacity (MCM) at MDDL	***4918.91***
FRL (m)	***268.22***		Original capacity (MCM) at FRL	***10600.32***
Year of first impoundment	***1962***		Year of capacity survey	***1995***
Value of 'm'	-		Type of reservoir	-





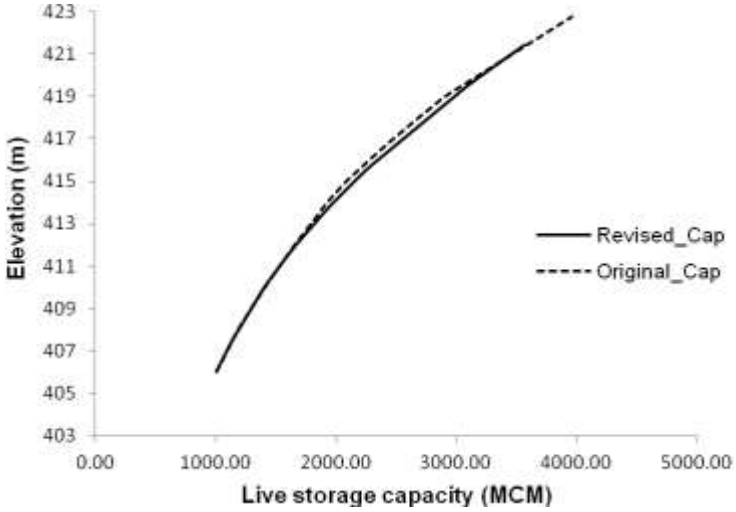


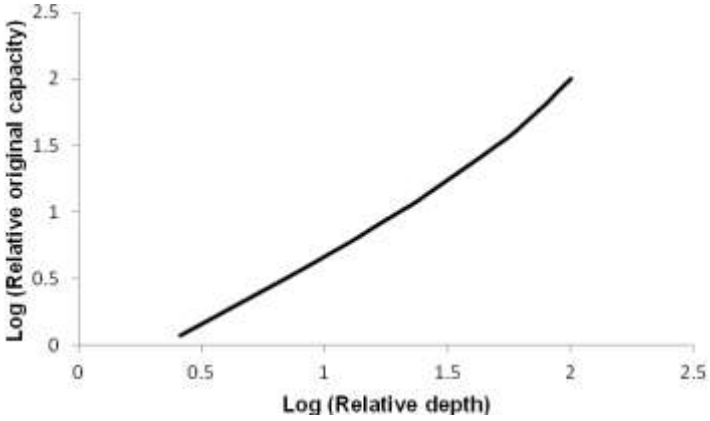


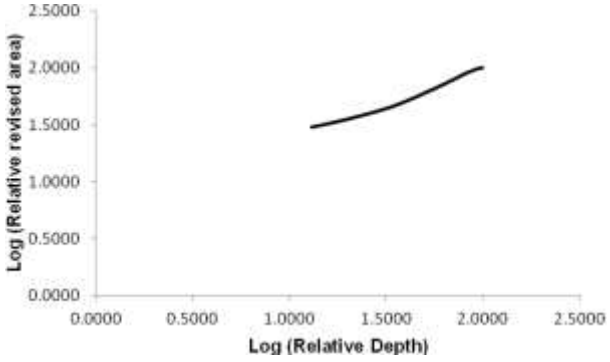


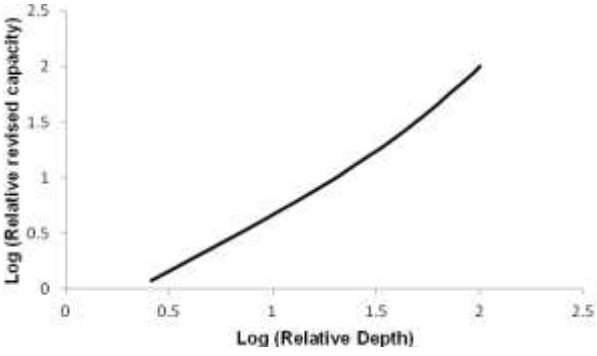
Bargi Project

State – ***M.P.***				
River	***Bargi***		Catchment area	***14556***
MDDL (m)	***403.55***		Original capacity (MCM) at MDDL	***817.5***
FRL (m)	***422.76***		Original capacity (MCM) at FRL	***3962.8***
Year of first impoundment	***1988***		Year of capacity survey	***1997***
Value of 'm'	-		Type of reservoir	***Type-II***



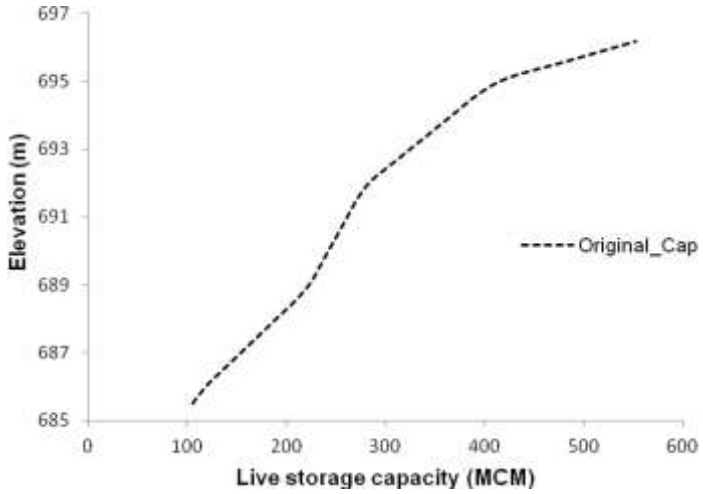


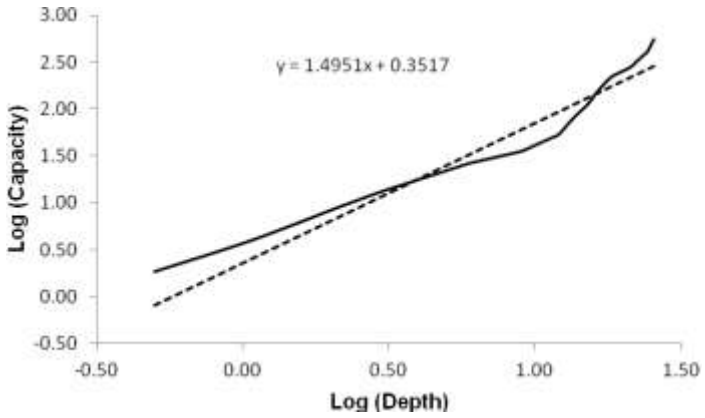


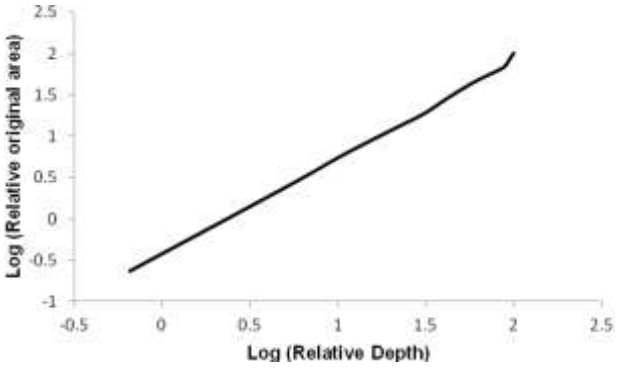


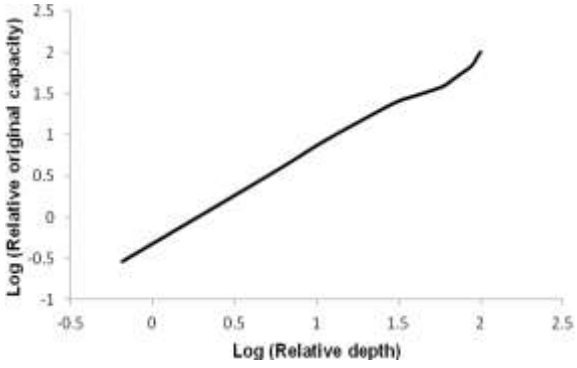
Kabini Project

State – ***Karnataka***				
River	***Kabini***		Catchment area	***2142***
MDDL (m)	***685.5***		Original capacity (MCM) at MDDL	***105.63***
FRL (m)	***696.16***		Original capacity (MCM) at FRL	***552.69***
Year of first impoundment	***1974***		Year of capacity survey	-
Value of 'm'	***1.49***		Type of reservoir	***Type-IV***



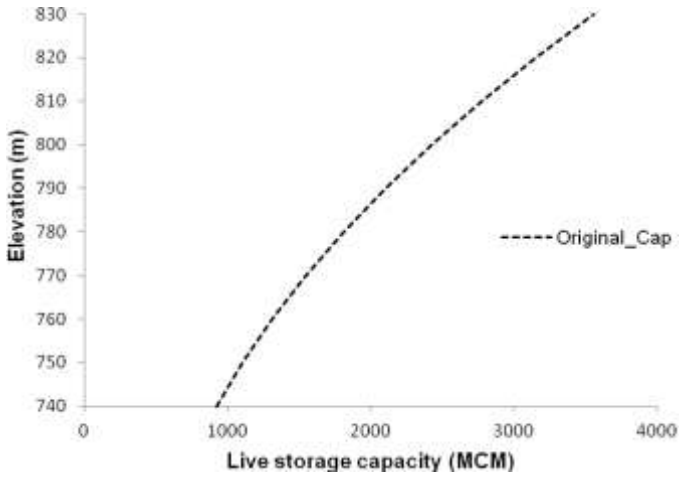


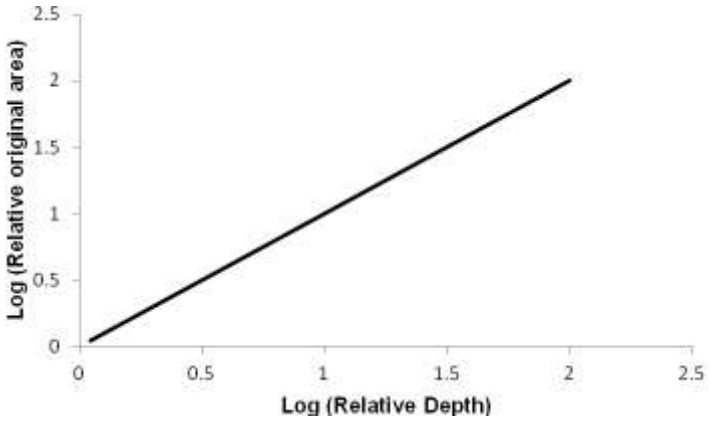


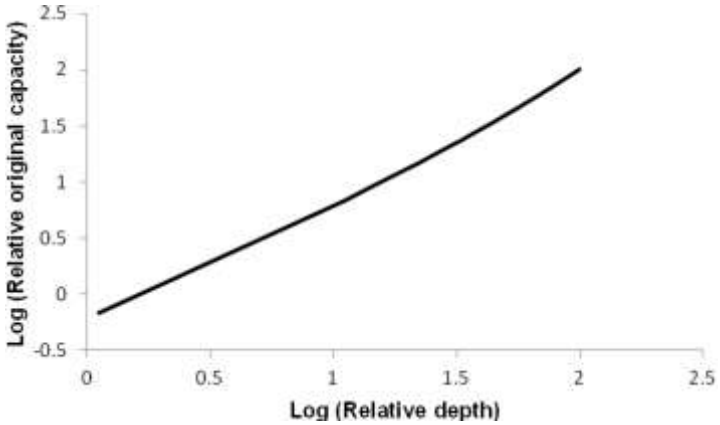


Tehri Project

State – ***Uttarakhand***				
River	***Bhagirathi***		Catchment area	***7255***
MDDL (m)	***740***		Original capacity (MCM) at MDDL	***925***
FRL (m)	***830***		Original capacity (MCM) at FRL	***3560.89***
Year of first impoundment	***2006***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

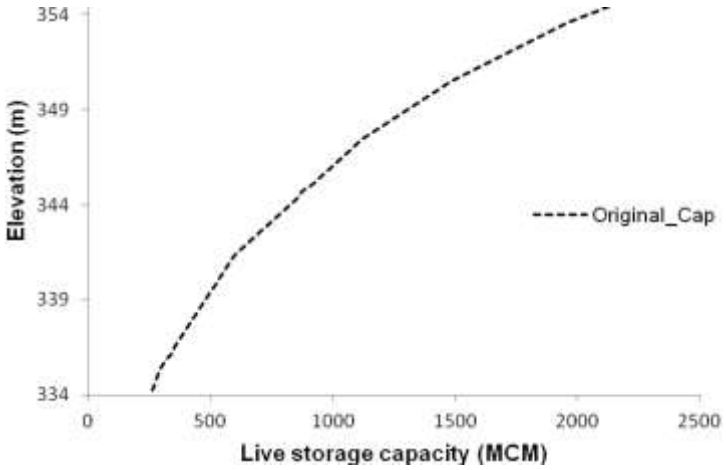


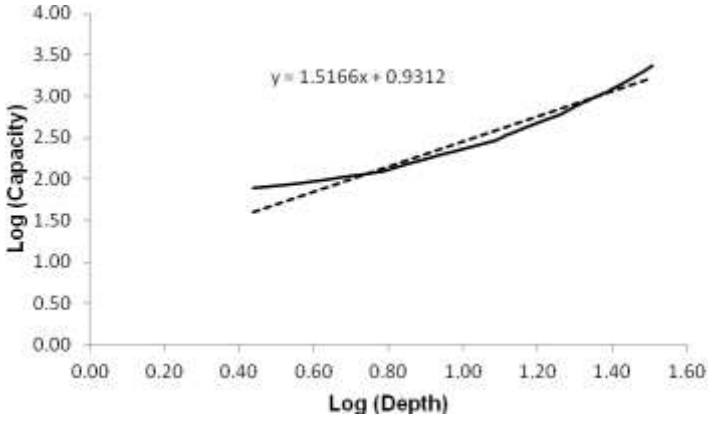


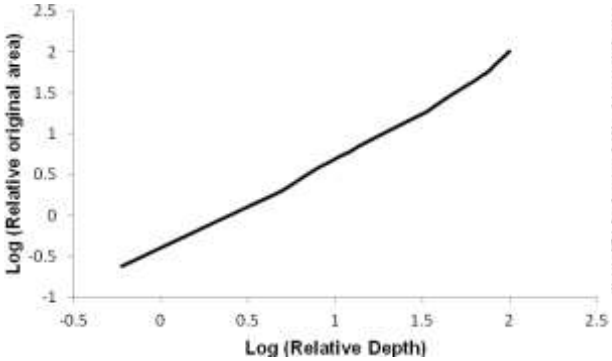


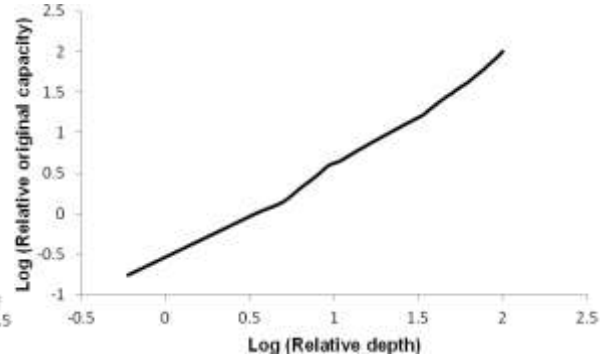
Tawa Project

State – ***M.P.***				
River	***Tawa***		Catchment area	***5982.9***
MDDL (m)	***334.24***		Original capacity (MCM) at MDDL	***262.86***
FRL (m)	***355.397***		Original capacity (MCM) at FRL	***2312***
Year of first impoundment	***1978***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-



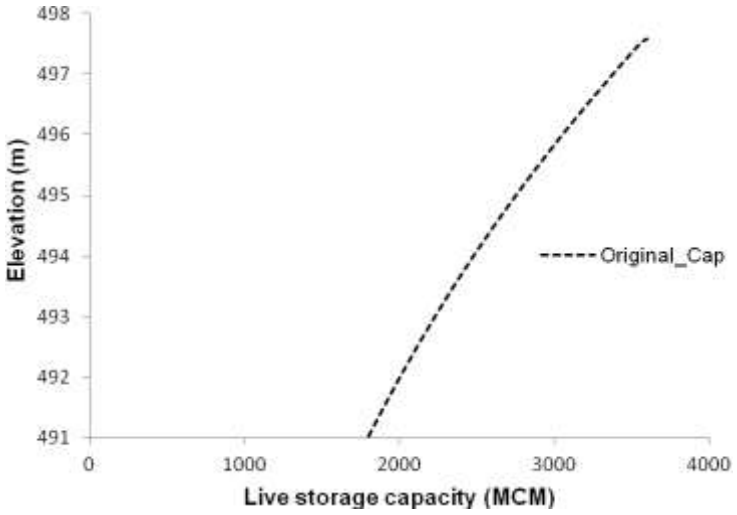


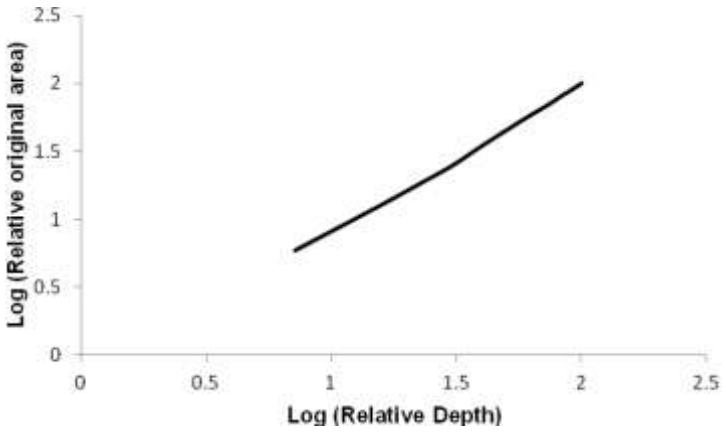


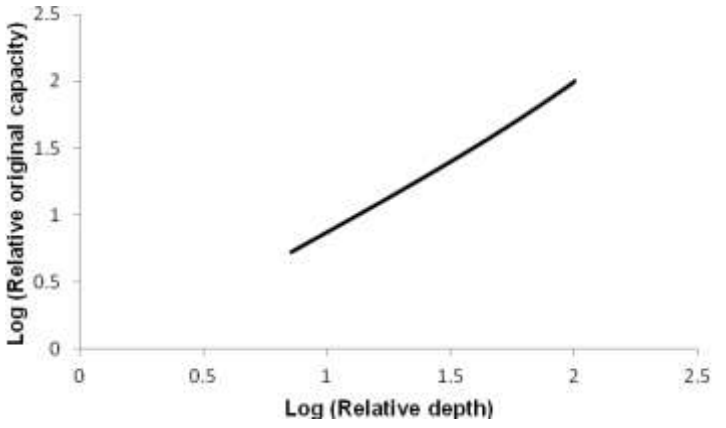


Ujjaini (Bhima) Project

State – ***Maharashtra***				
River	***Bhima***		Catchment area	***14850***
MDDL (m)	***491.03***		Original capacity (MCM) at MDDL	***1802.09***
FRL (m)	***496.83***		Original capacity (MCM) at FRL	***3320.01***
Year of first impoundment	***1980***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

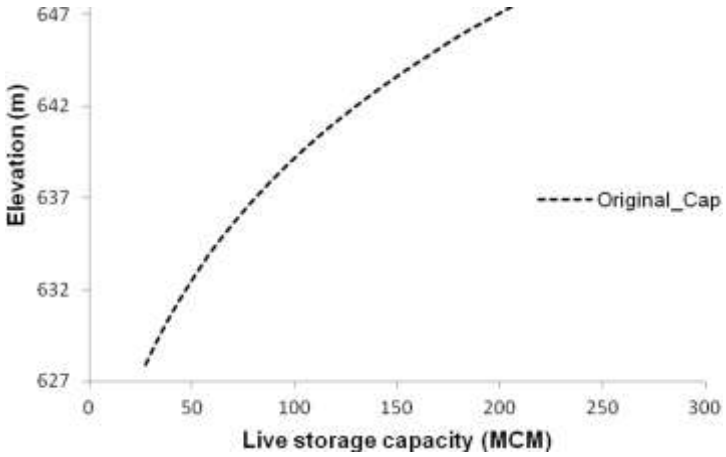


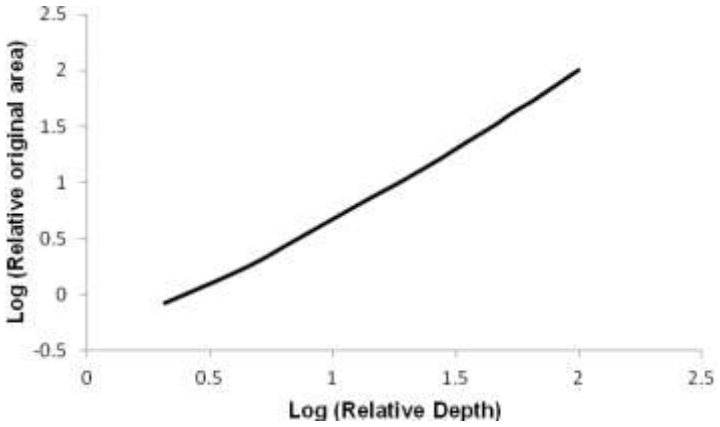


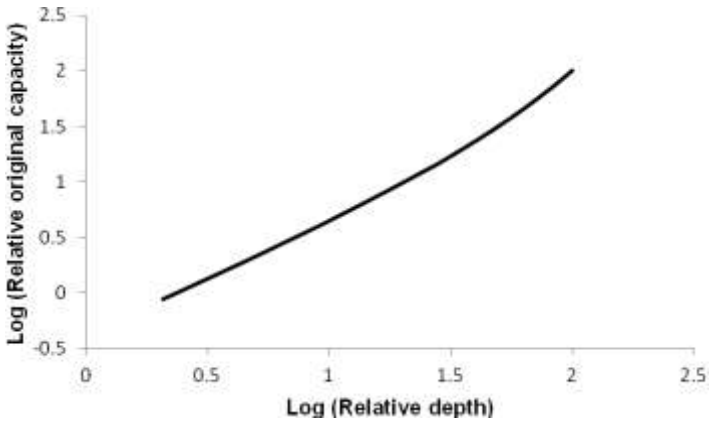


Chaskaman Project

State – ***Maharashtra***				
River	***Bhima***		Catchment area	***305.56***
MDDL (m)	***627.89***		Original capacity (MCM) at MDDL	***27.194***
FRL (m)	***649.53***		Original capacity (MCM) at FRL	***241.69***
Year of first impoundment	***1999***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

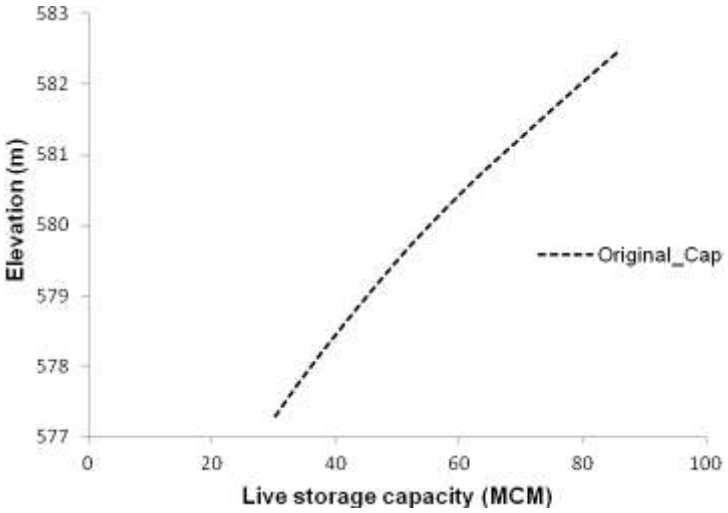


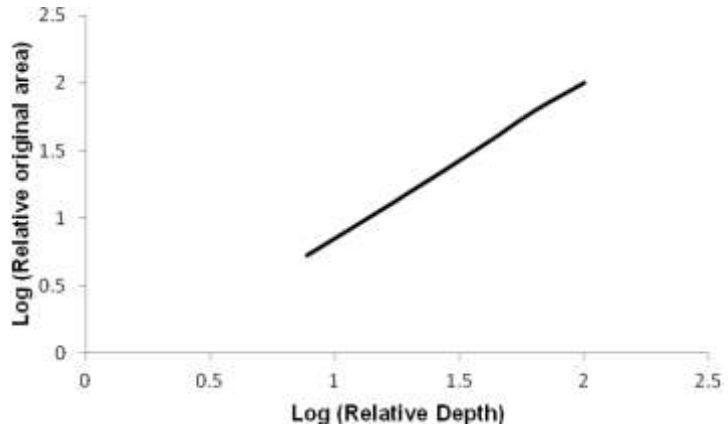


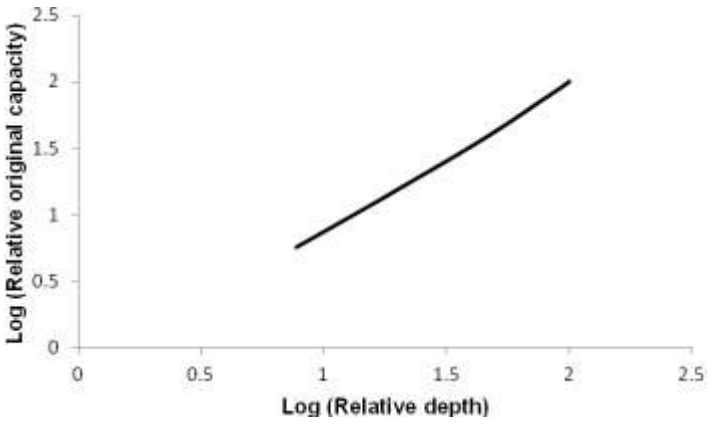


Khadakwasla Project

State – ***Maharashtra***				
River	***Mutha***		Catchment area	***501.8***
MDDL (m)	***577.29***		Original capacity (MCM) at MDDL	***30.23***
FRL (m)	***582.68***		Original capacity (MCM) at FRL	***89.55***
Year of first impoundment	***1880***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

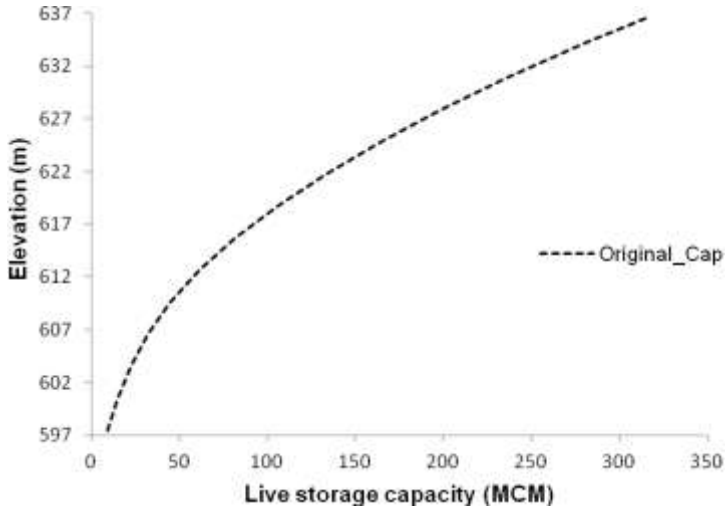


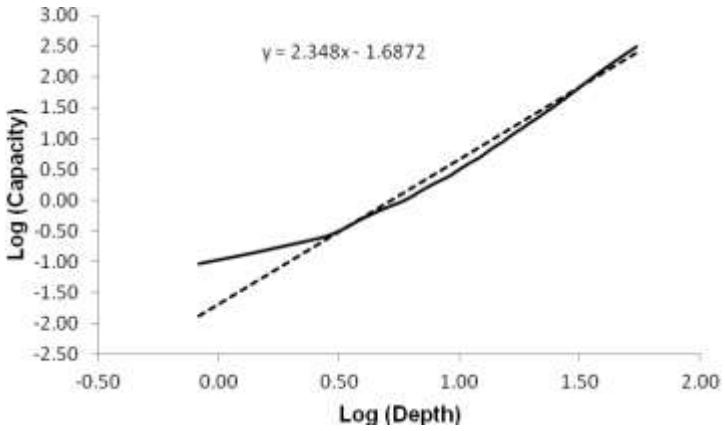


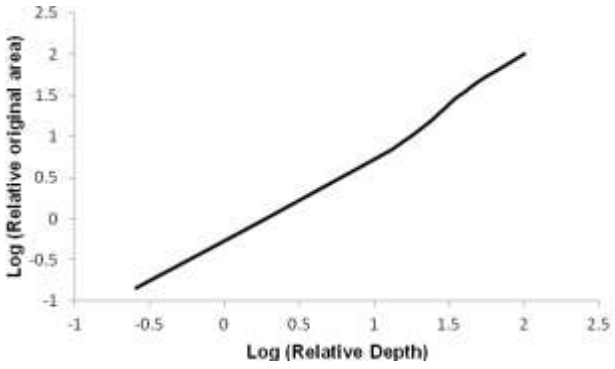


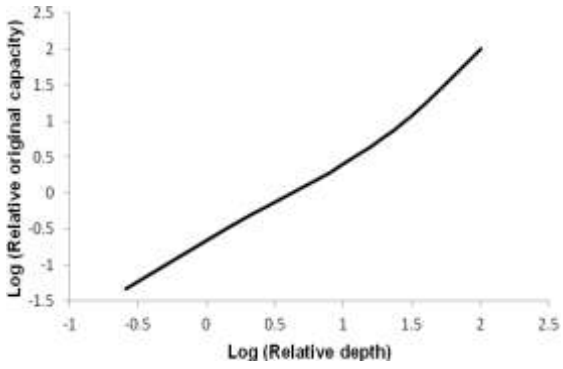
Panshet Project

State – ***Maharashtra***				
River	***Ambi***		Catchment area	***NA***
MDDL (m)	***597.40***		Original capacity (MCM) at MDDL	***9.03***
FRL (m)	***636.72***		Original capacity (MCM) at FRL	***317.154***
Year of first impoundment	***1972***		Year of capacity survey	***-***
Value of 'm'	***2.38***		Type of reservoir	***Type-III***



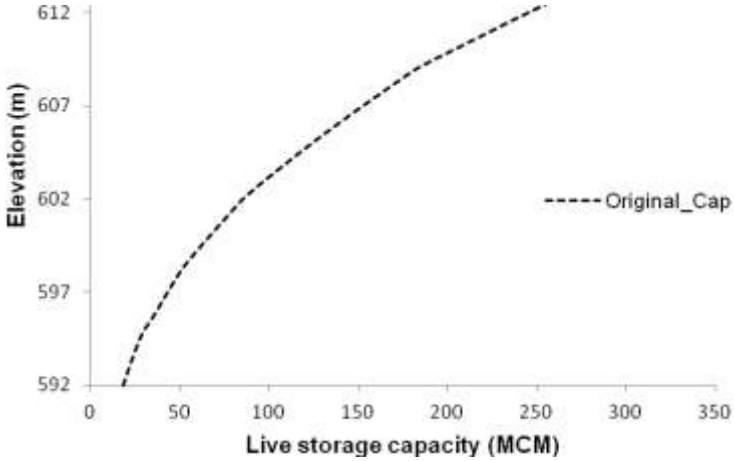


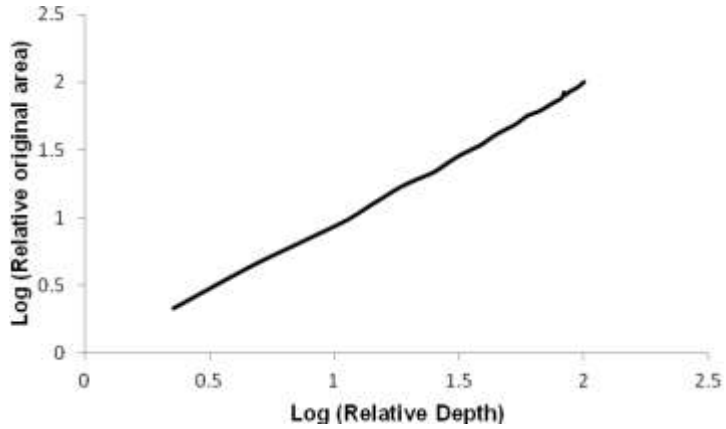


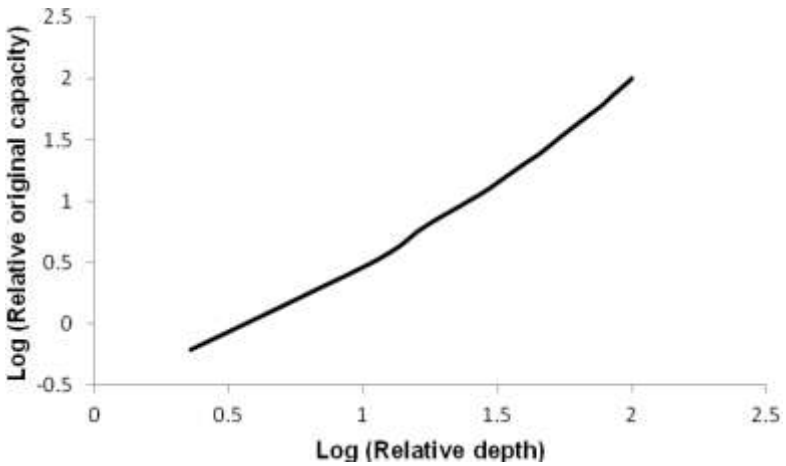


Pawana Project

State – ***Maharashtra***				
River	***Pawana***		Catchment area	***119.96***
MDDL (m)	***592.00***		Original capacity (MCM) at MDDL	***18.55***
FRL (m)	***614.00***		Original capacity (MCM) at FRL	***291.87***
Year of first impoundment	***1972***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

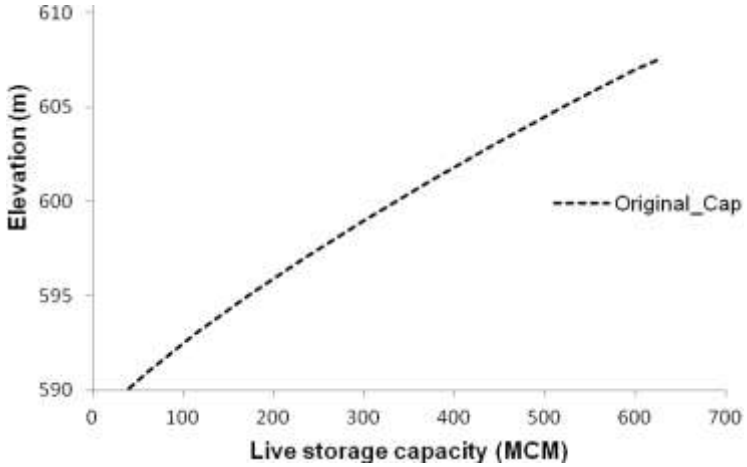


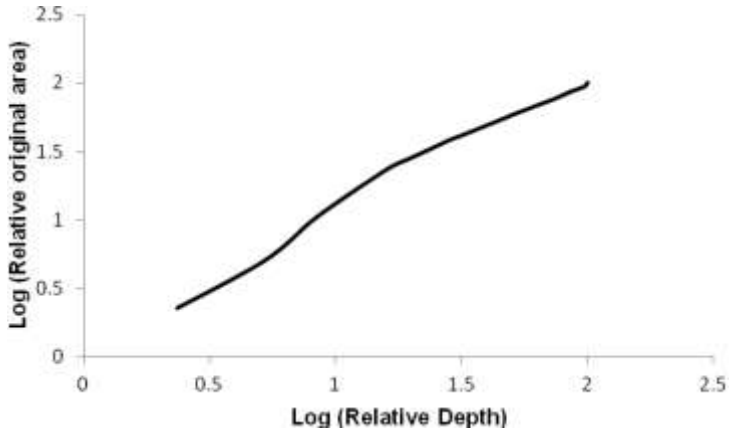


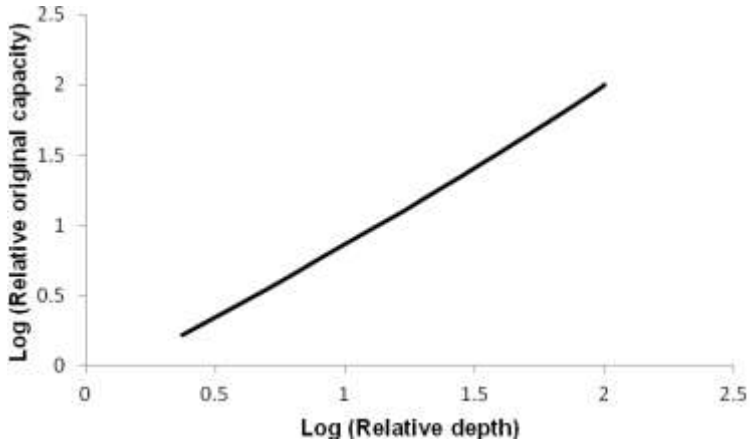


Mulshi Project

State – ***Maharashtra***				
River	***Mulshi***		Catchment area	***NA***
MDDL (m)	***590.09***		Original capacity (MCM) at MDDL	***40.428***
FRL (m)	***607.25***		Original capacity (MCM) at FRL	***604.05***
Year of first impoundment	***1927***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

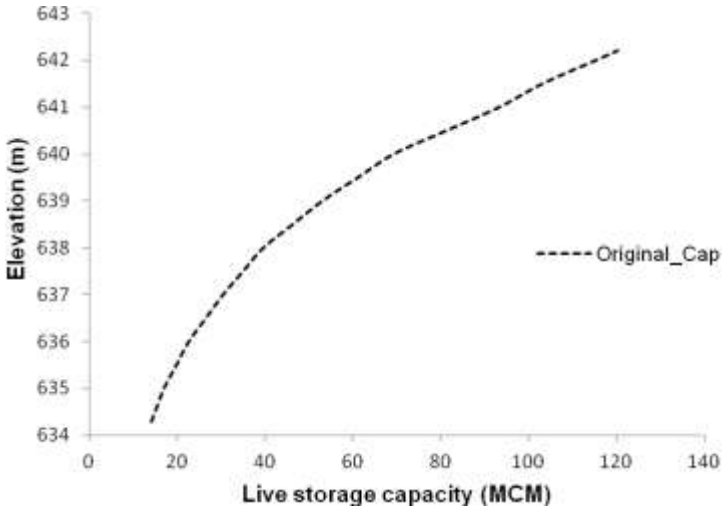


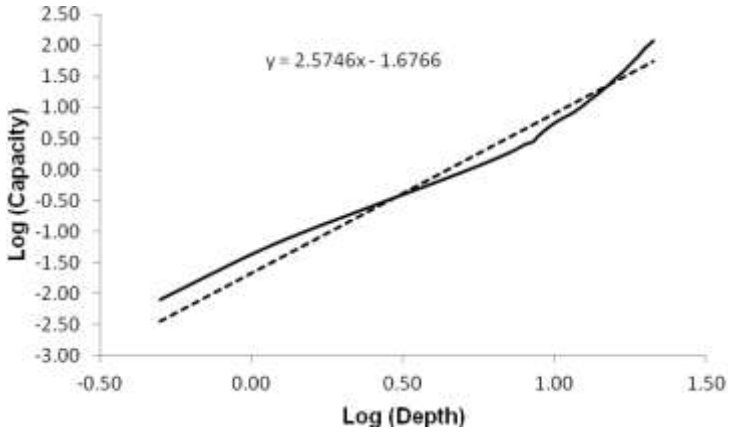


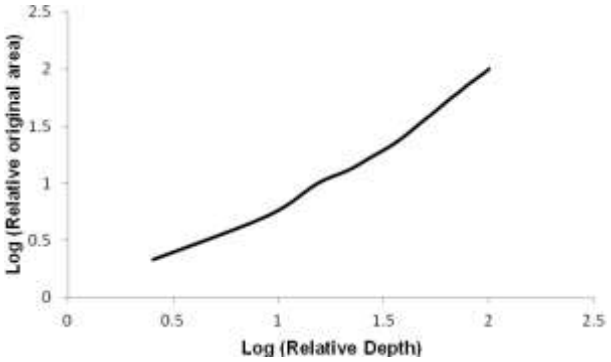


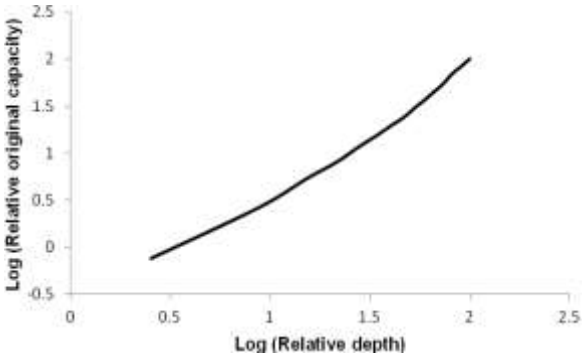
Yedgaon Project

State – ***Maharashtra***				
River	***Kukadi***		Catchment area	***461***
MDDL (m)	***634.30***		Original capacity (MCM) at MDDL	***14.156***
FRL (m)	***642.15***		Original capacity (MCM) at FRL	***120.32***
Year of first impoundment	***1977***		Year of capacity survey	**-**
Value of 'm'	***2.57***		Type of reservoir	***Type-II***



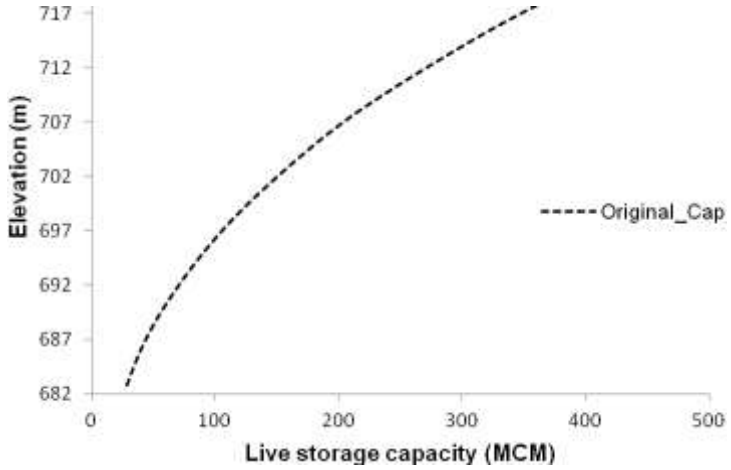


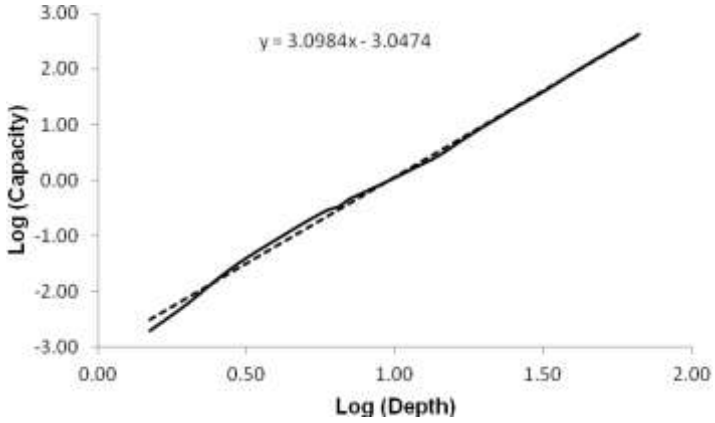


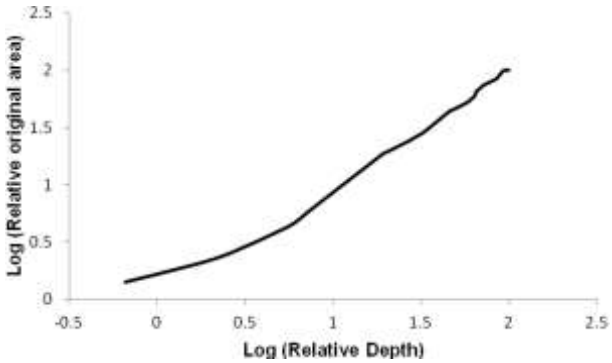


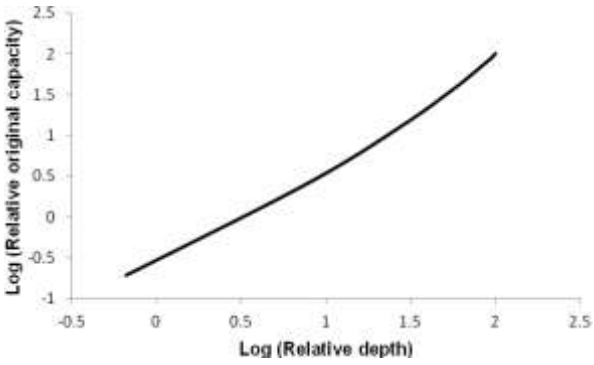
Dimbhe Project

State – ***Maharashtra***				
River	***Ghod***		Catchment area	***412***
MDDL (m)	***682.75***		Original capacity (MCM) at MDDL	***28.335***
FRL (m)	***719.645***		Original capacity (MCM) at FRL	***383.117***
Year of first impoundment	***2000***		Year of capacity survey	-
Value of 'm'	***3.09***		Type of reservoir	***Type-II***



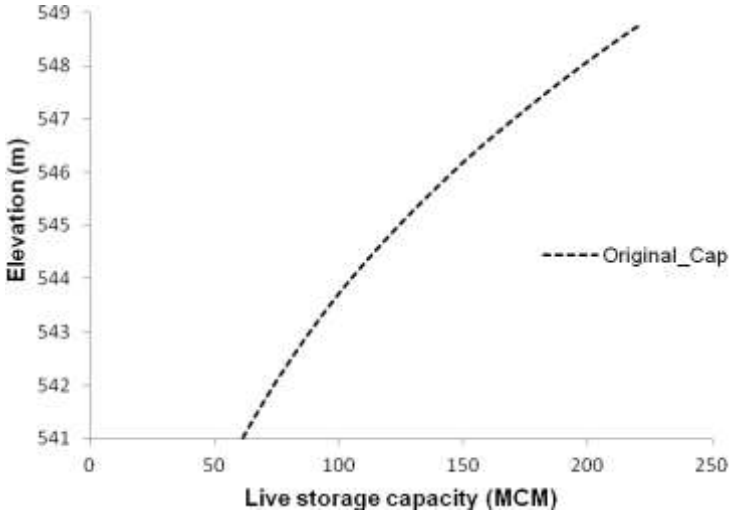


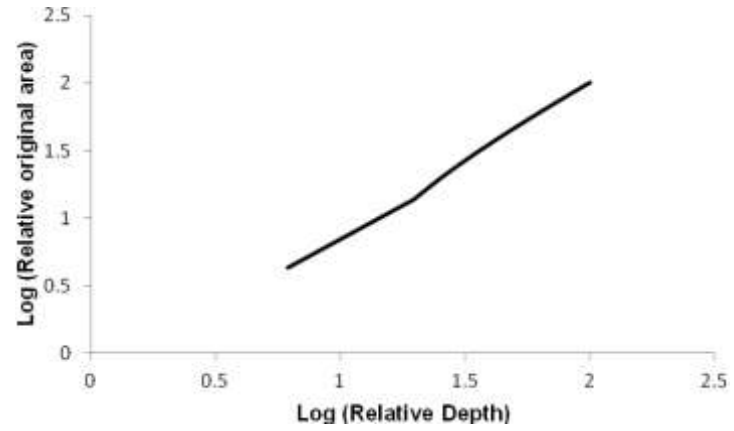


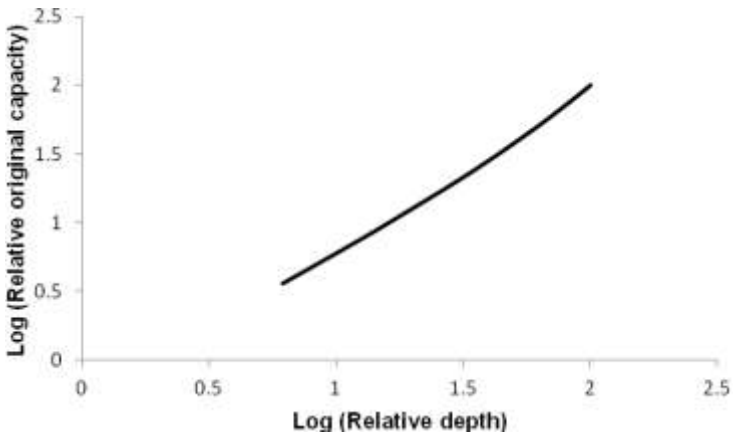


Ghod Project

State – ***Maharashtra***				
River	***Ghod***		Catchment area	***3628***
MDDL (m)	***541.02***		Original capacity (MCM) at MDDL	***61.52***
FRL (m)	***548.64***		Original capacity (MCM) at FRL	***216.31***
Year of first impoundment	***1965***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

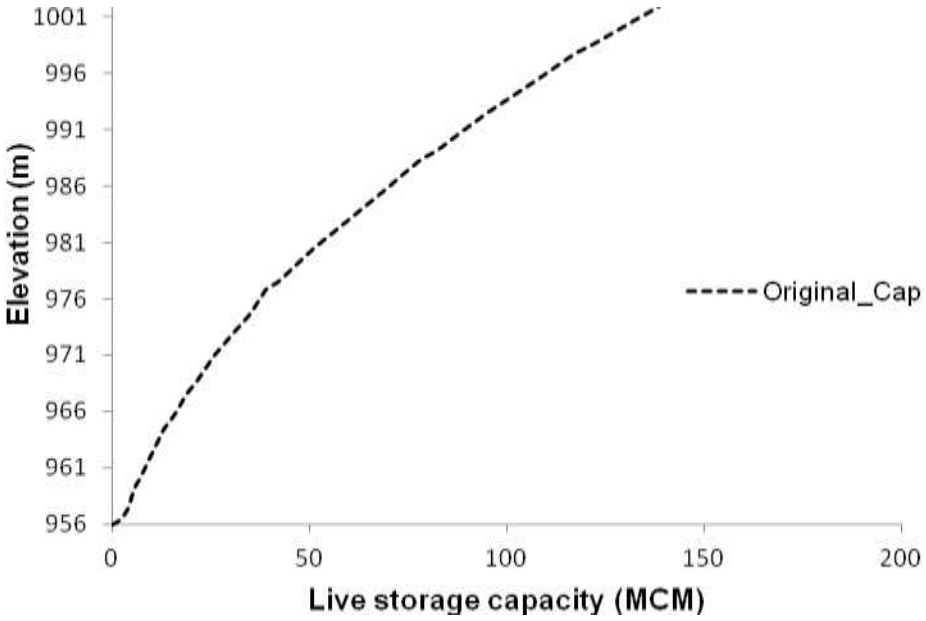


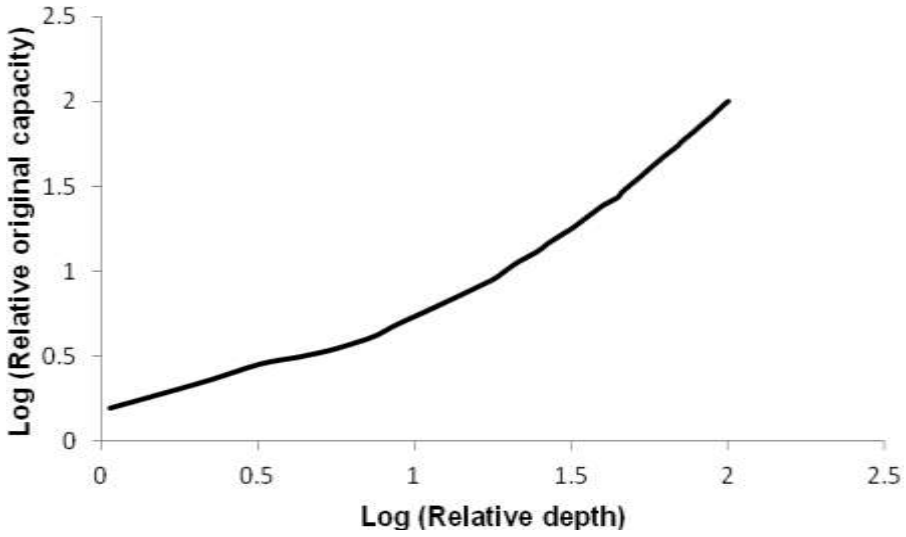




Sholayar Project

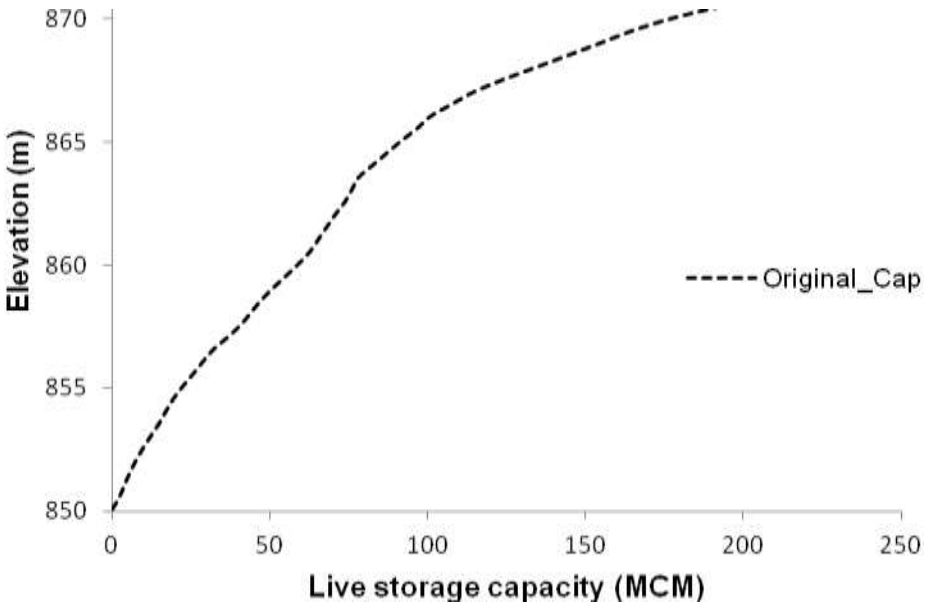
State – ***Tamil Nadu***				
River	***Sholayar***		Catchment area	***121.72***
MDDL (m)	***956.00***		Live capacity (MCM) at MDDL	***0.00***
FRL (m)	***1003.08***		Live capacity (MCM) at FRL	***143.00***
Year of first impoundment	***1971***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

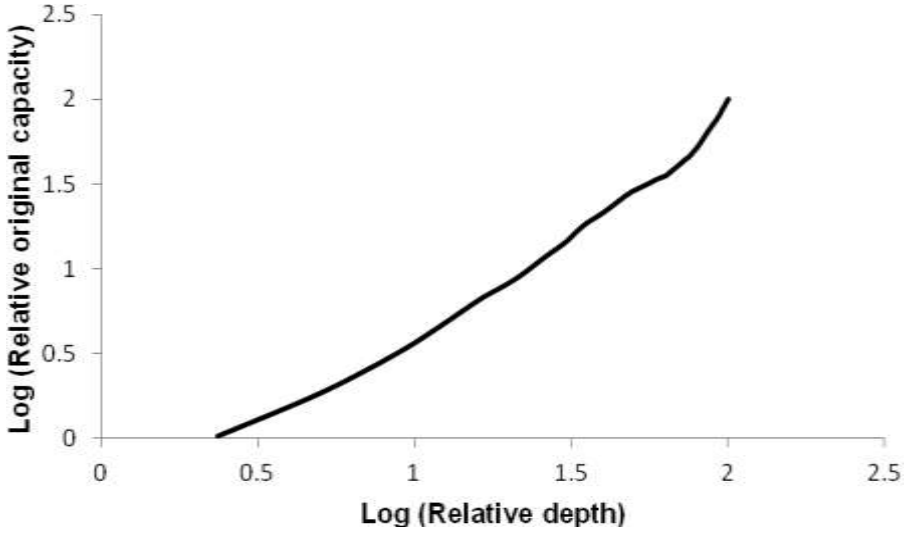




Harangi Project

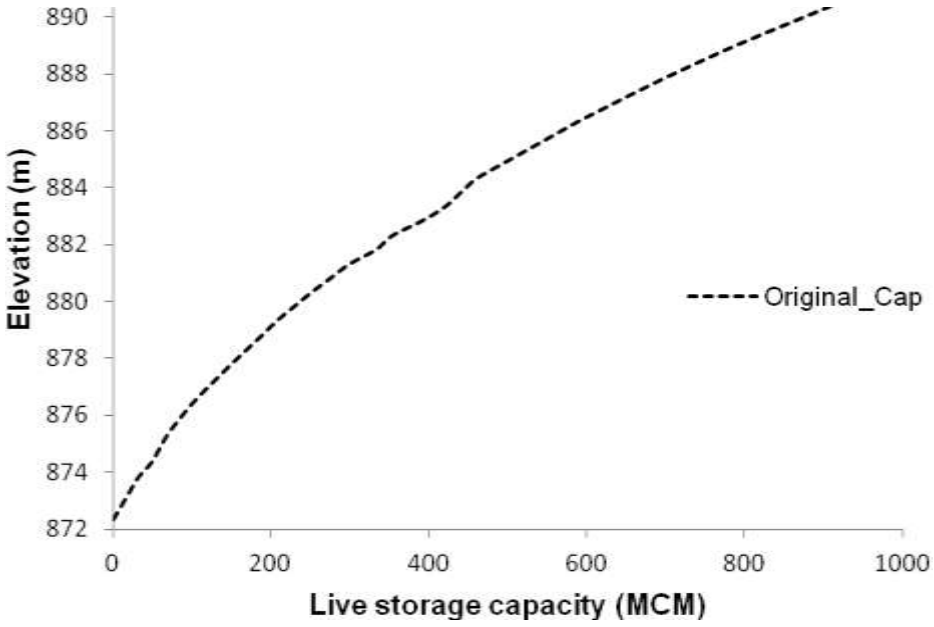
State – ***Karnataka***				
River	***Harangi***		Catchment area	***419.58***
MDDL (m)	***850.09***		Live capacity (MCM) at MDDL	***0.00***
FRL (m)	***871.42***		Live capacity (MCM) at FRL	***220.00***
Year of first impoundment	***1982***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

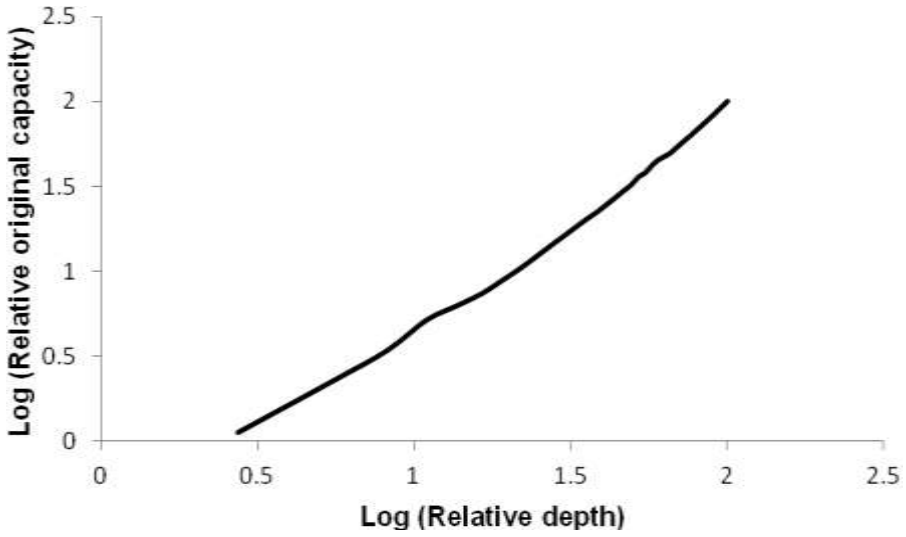




Hemavathy Project

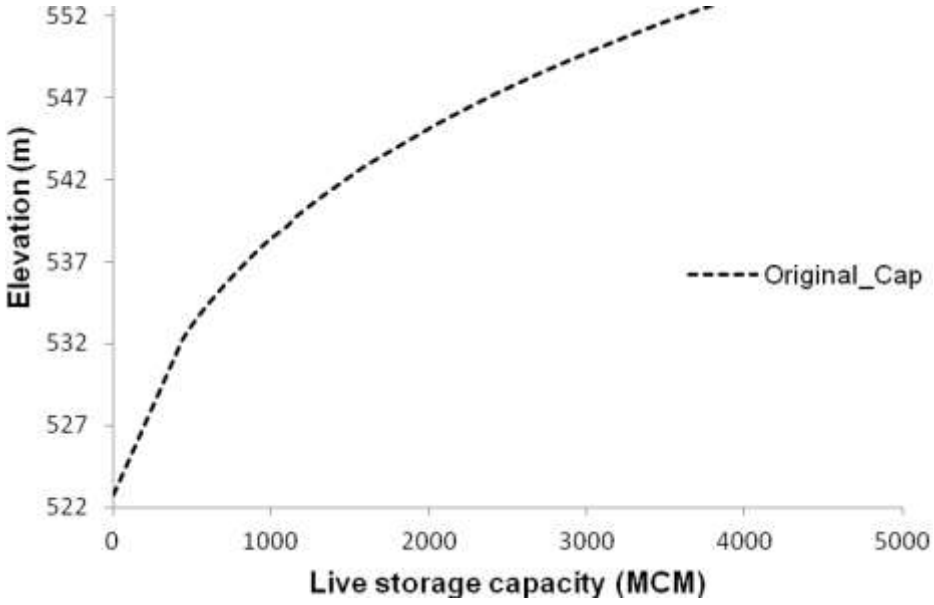
State – ***Karnataka***				
River	***Hemavathy***		Catchment area	***2810***
MDDL (m)	***872.34***		Live capacity (MCM) at MDDL	***0.00***
FRL (m)	***890.63***		Live capacity (MCM) at FRL	***927.00***
Year of first impoundment	***1979***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

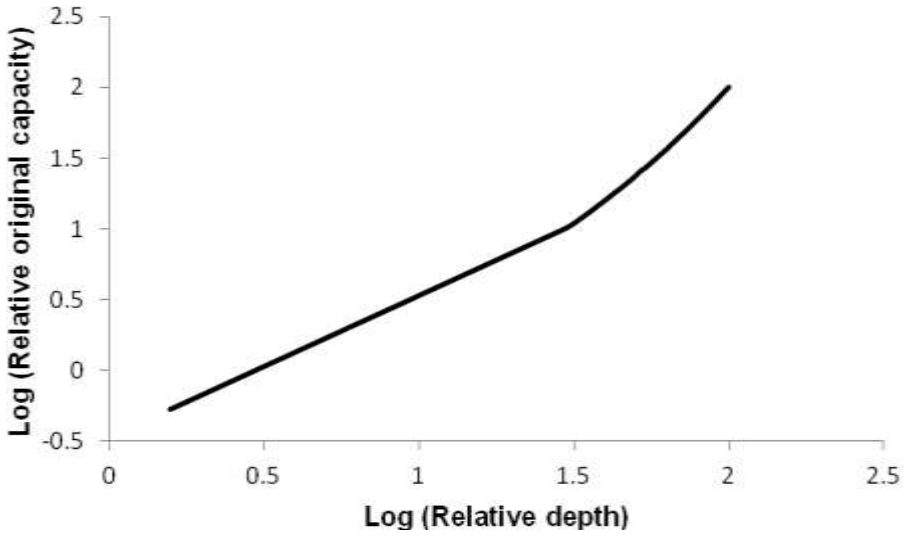




Lingnamakki Project

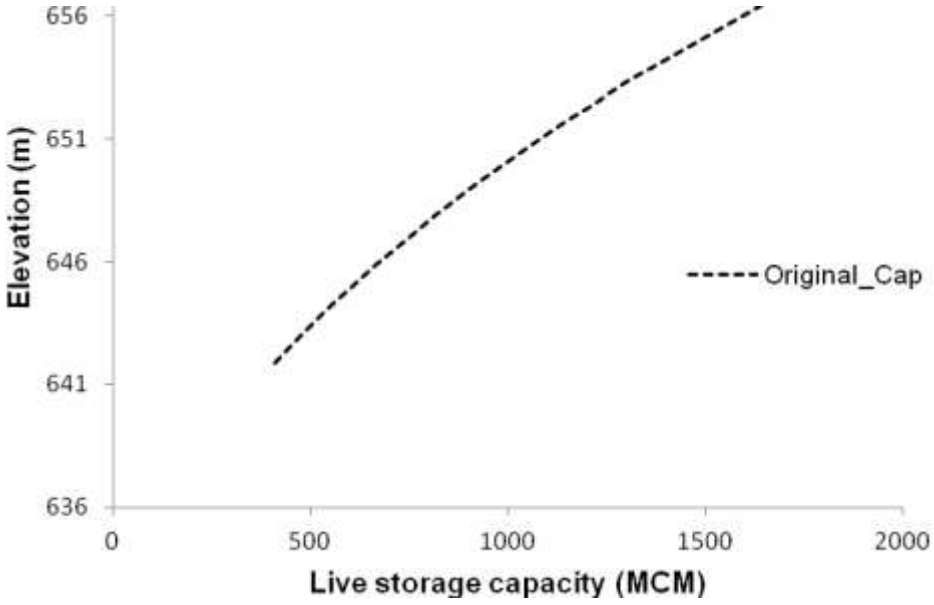
State – ***Karnataka***				
River	***Shravathy***		Catchment area	***1992.00***
MDDL (m)	***522.73***		Live capacity (MCM) at MDDL	***0.00***
FRL (m)	***554.43***		Live capacity (MCM) at FRL	***4294.00***
Year of first impoundment	***1964***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

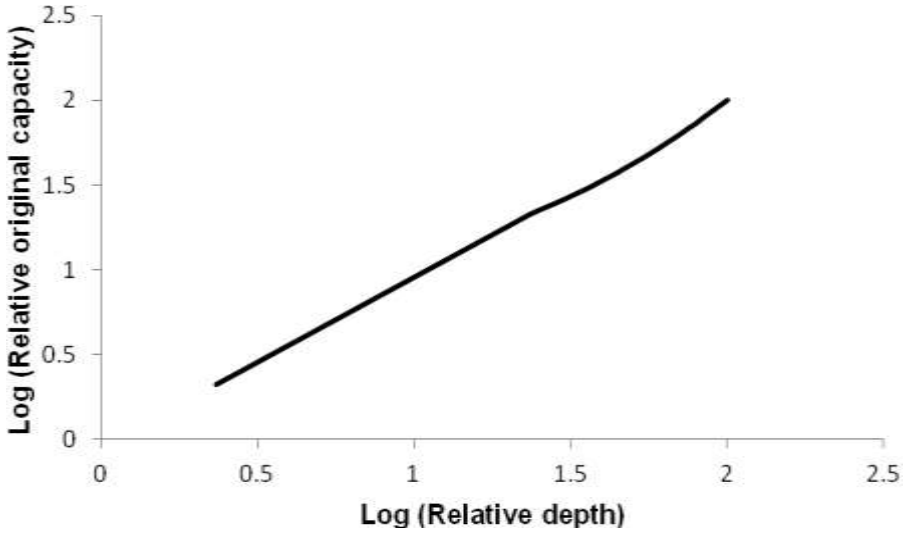




Bhadra Project

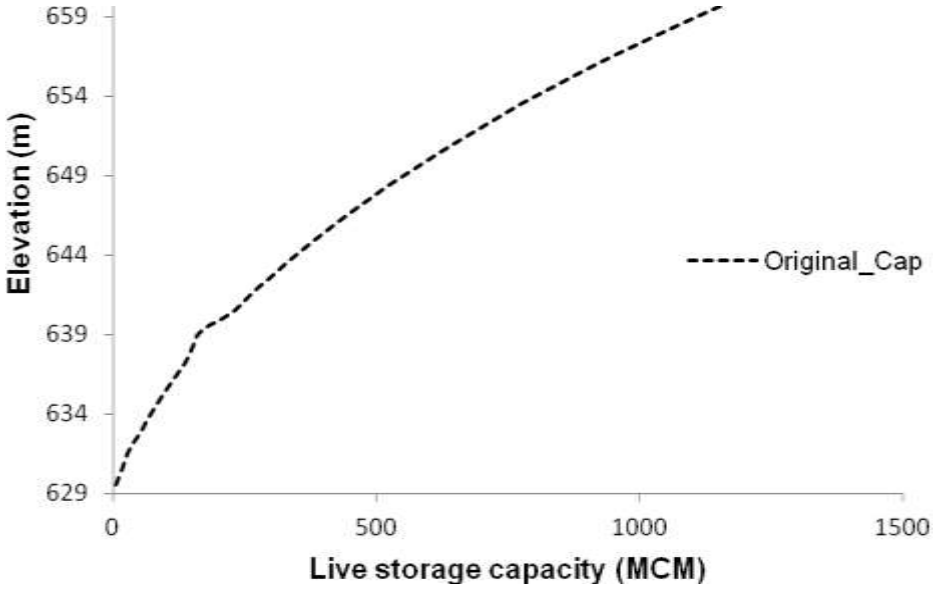
State – ***Karnataka***				
River	***Bhadra***		Catchment area	***1968***
MDDL (m)	***636.40***		Live capacity (MCM) at MDDL	***0.00***
FRL (m)	***657.76***		Live capacity (MCM) at FRL	***1785.00***
Year of first impoundment	***1965***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

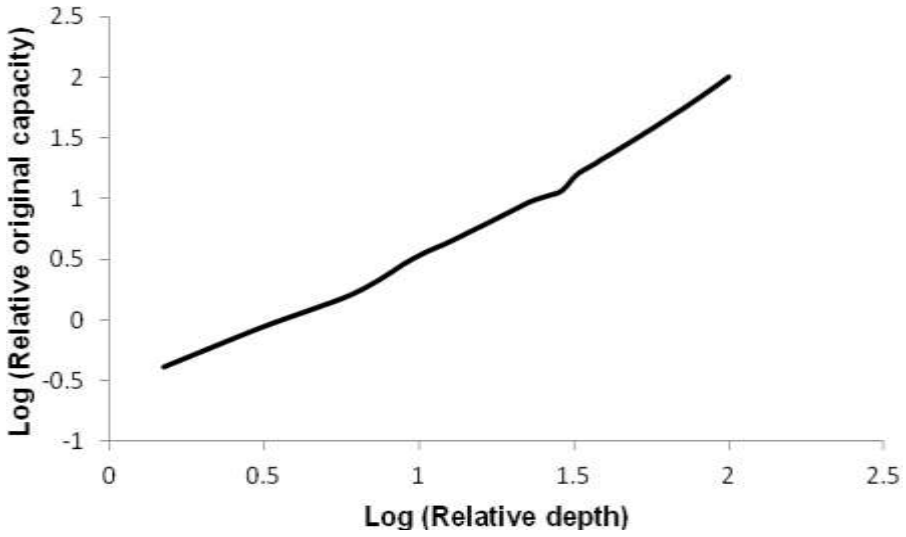




Ghataprabha Project

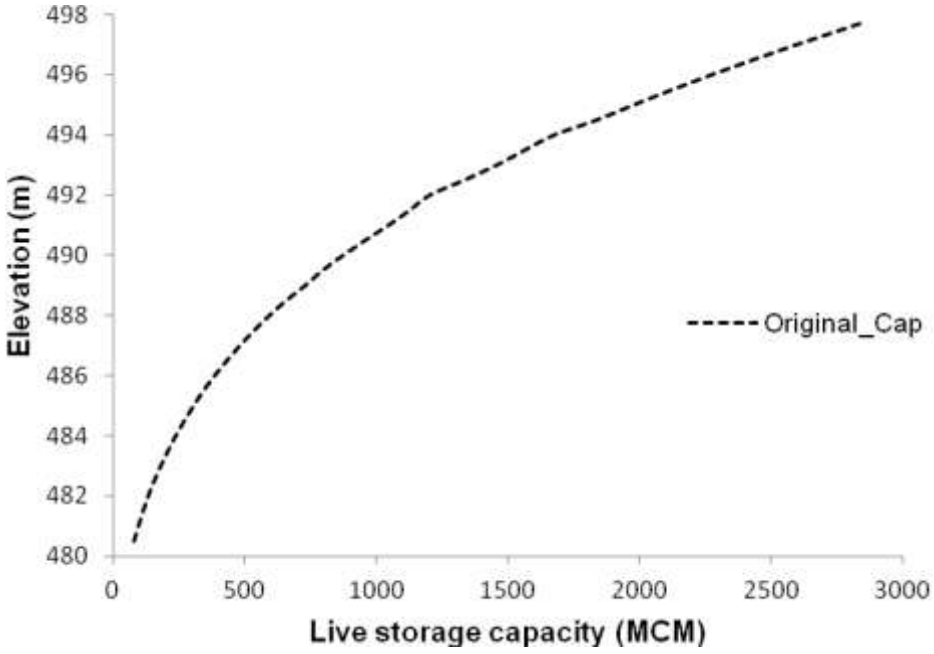
State – ***Karnataka***				
River	***Ghataprabha***		Catchment area	***1412***
MDDL (m)	***629.5***		Live capacity (MCM) at MDDL	***0.00***
FRL (m)	***662.95***		Live capacity (MCM) at FRL	***1391.00***
Year of first impoundment	***1980***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

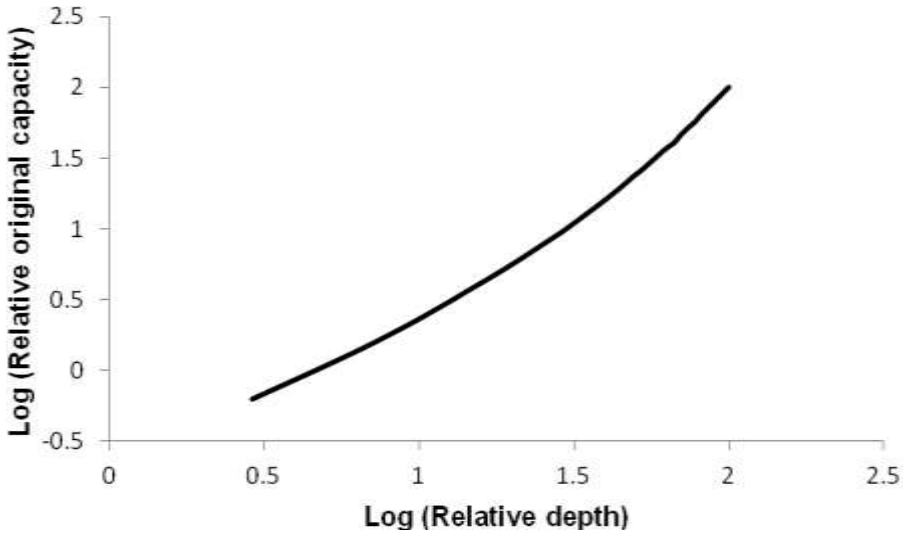




Tungbhadra Project

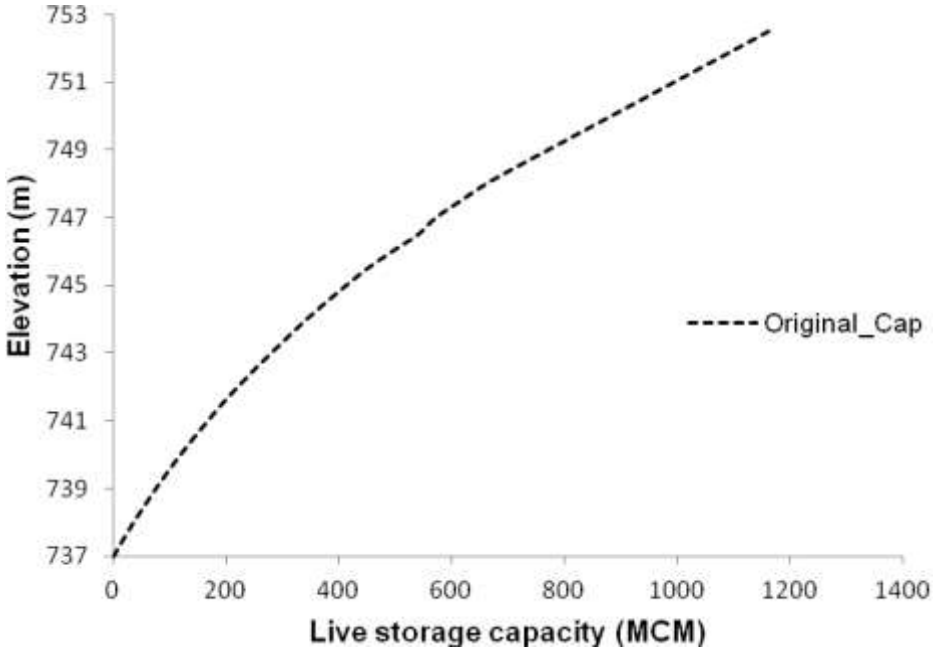
State – ***Karnataka***				
River	***Tungbhadra***		Catchment area	***28180***
MDDL (m)	***480.49***		Live capacity (MCM) at MDDL	***0.00***
FRL (m)	***497.73***		Live capacity (MCM) at FRL	***2851.00***
Year of first impoundment	***1953***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

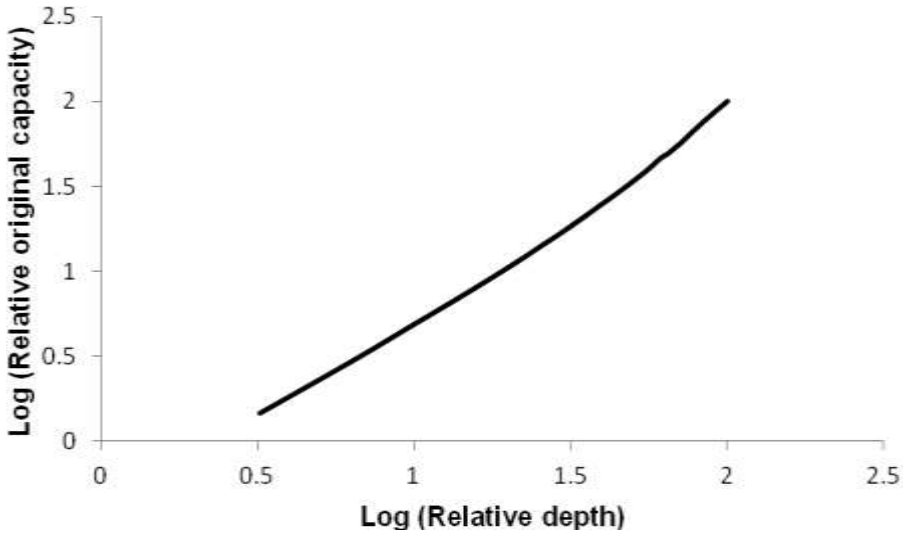




Krishna Raja Sagar Project

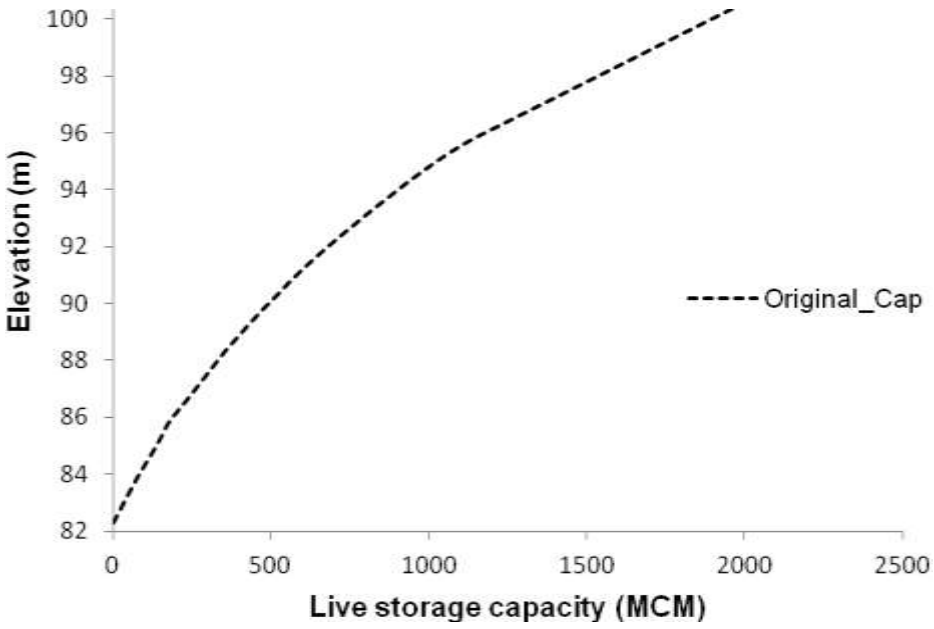
State – ***Karnataka***				
River	***Cauvery***		Catchment area	***10619.00***
MDDL (m)	***737.00***		Live capacity (MCM) at MDDL	***0.00***
FRL (m)	***752.50***		Live capacity (MCM) at FRL	***1163.00***
Year of first impoundment	***1931***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

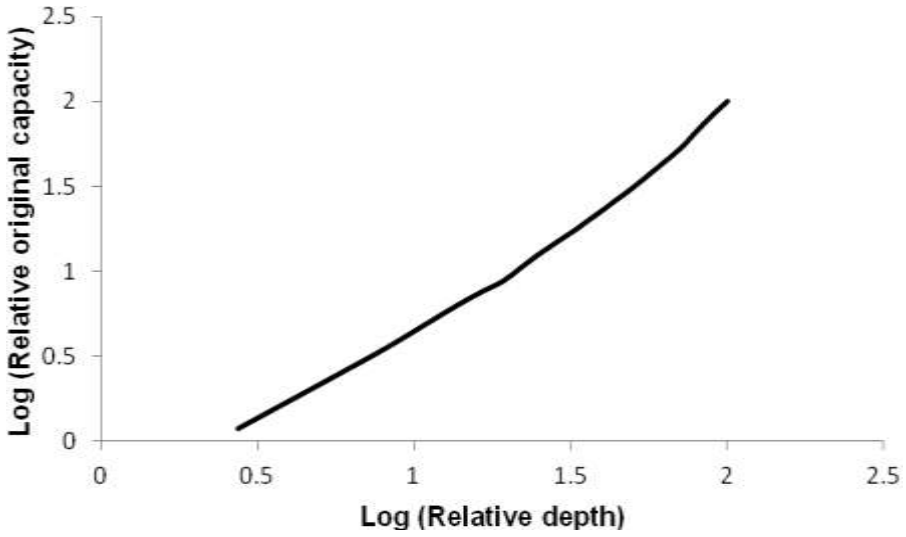




Somasila Project

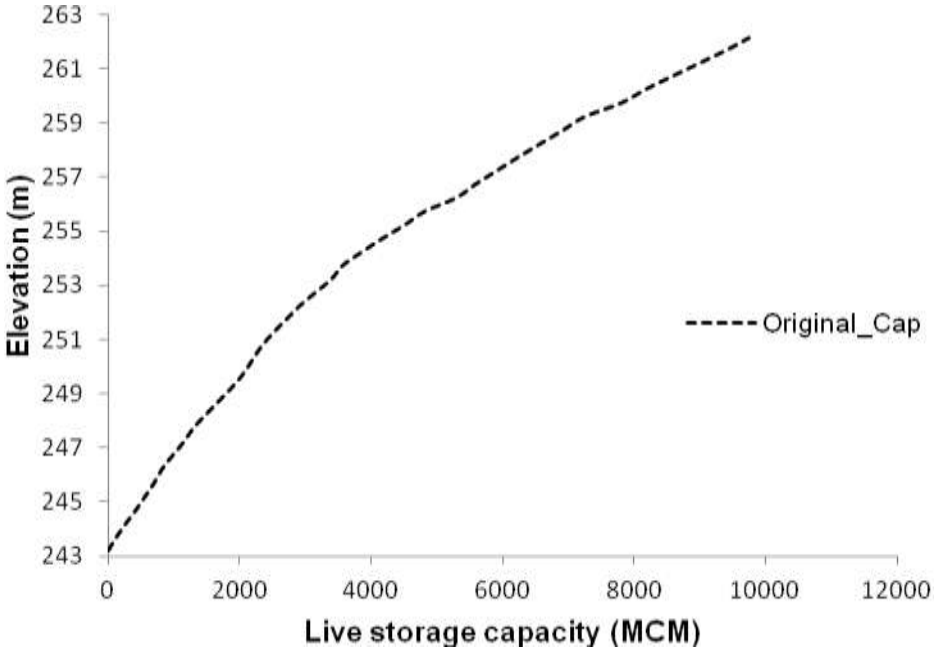
State – ***Andhra Pradesh***				
River	***Pennar***		Catchment area	***48645.00***
MDDL (m)	***82.3***		Live capacity (MCM) at MDDL	***0.00***
FRL (m)	***100.58***		Live capacity (MCM) at FRL	***1994.00***
Year of first impoundment	***1989***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

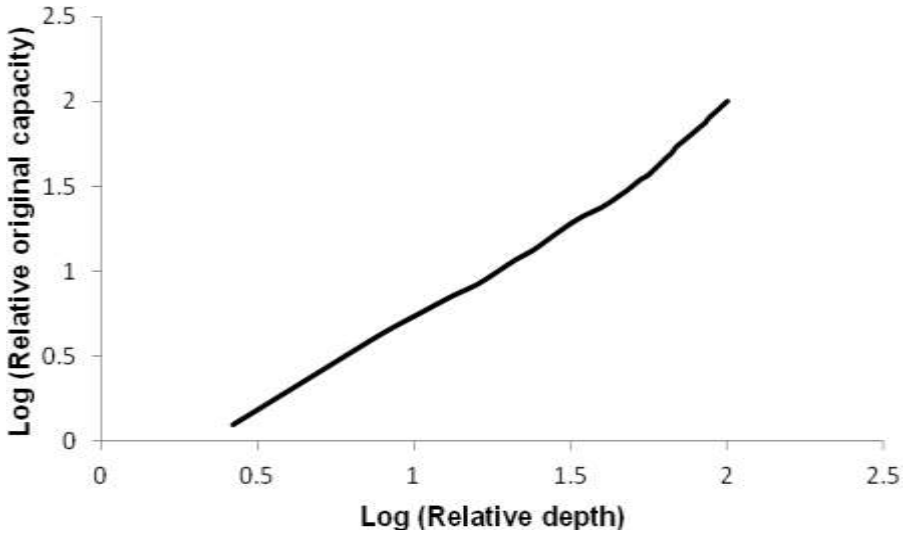




Indira Sagar Project

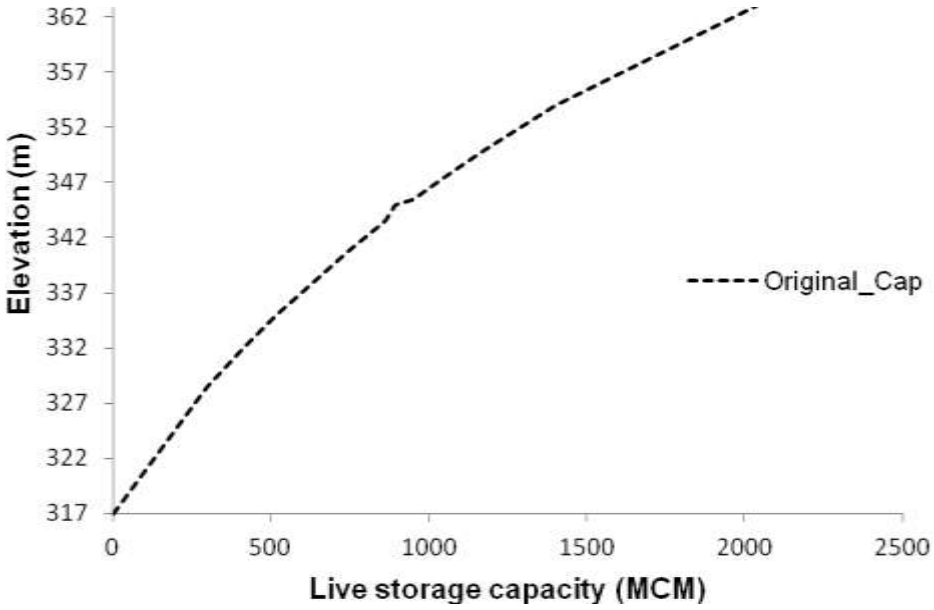
State – ***Madhya Pradesh***				
River	***Narmada***		Catchment area	***61642***
MDDL (m)	***243.23***		Original capacity (MCM) at MDDL	***0.00***
FRL (m)	***262.13***		Original capacity (MCM) at FRL	***9745.00***
Year of first impoundment	***2005***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

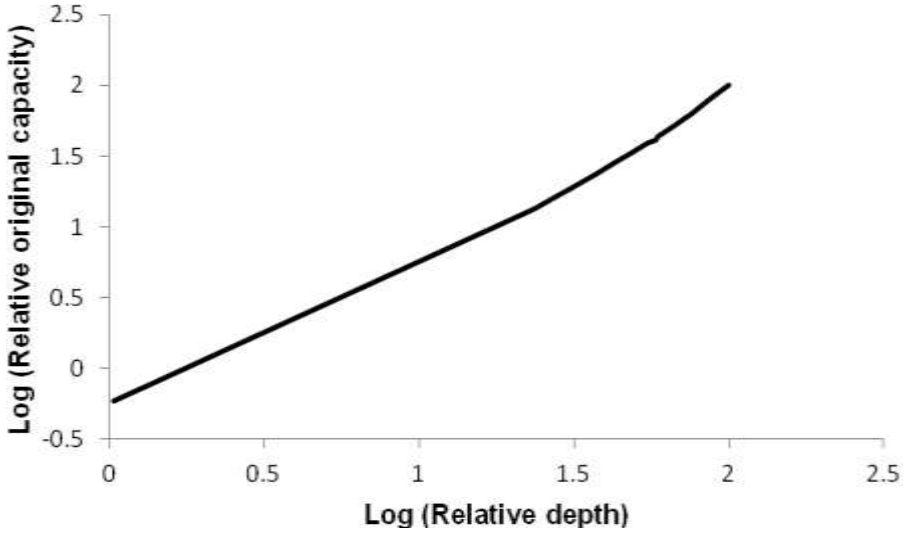




Ramganga Project

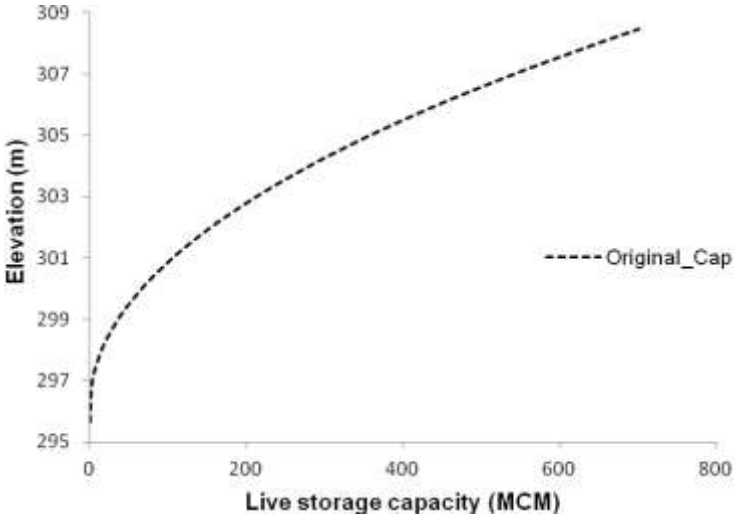
State – ***Uttarakhand***				
River	***Ramganga***		Catchment area	***3134***
MDDL (m)	***317.00***		Live capacity (MCM) at MDDL	***0.00***
FRL (m)	***365.30***		Live capacity (MCM) at FRL	***2196.00***
Year of first impoundment	***1974***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

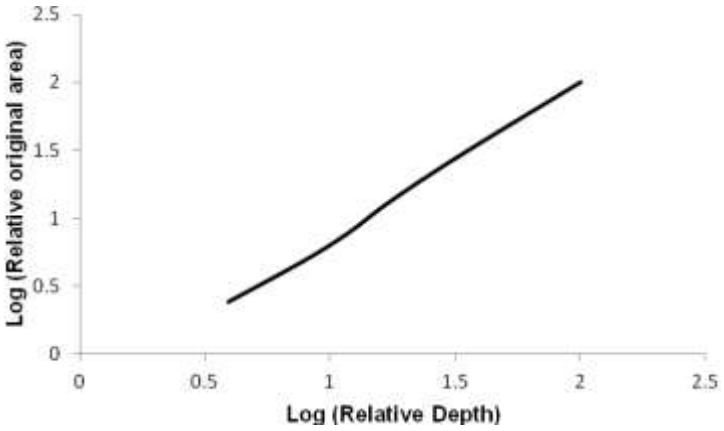


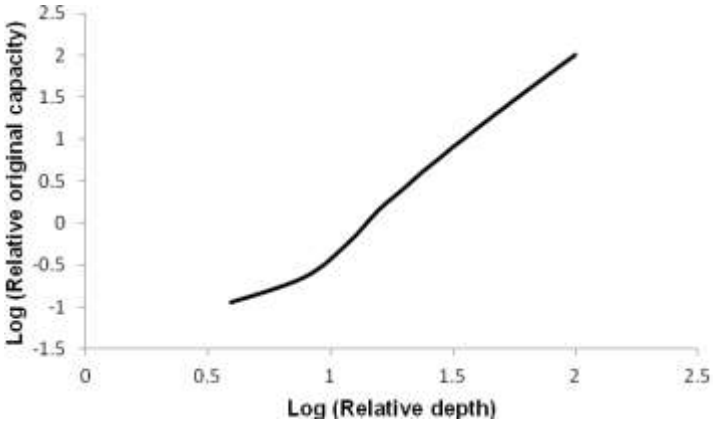


Matatila Project

State – ***Uttar Pradesh***				
River	***Betwa***		Catchment area	***20435***
MDDL (m)	***295.66***		Live capacity (MCM) at MDDL	***0.00***
FRL (m)	***308.46***		Live capacity (MCM) at FRL	***702.33***
Year of first impoundment	***1958***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

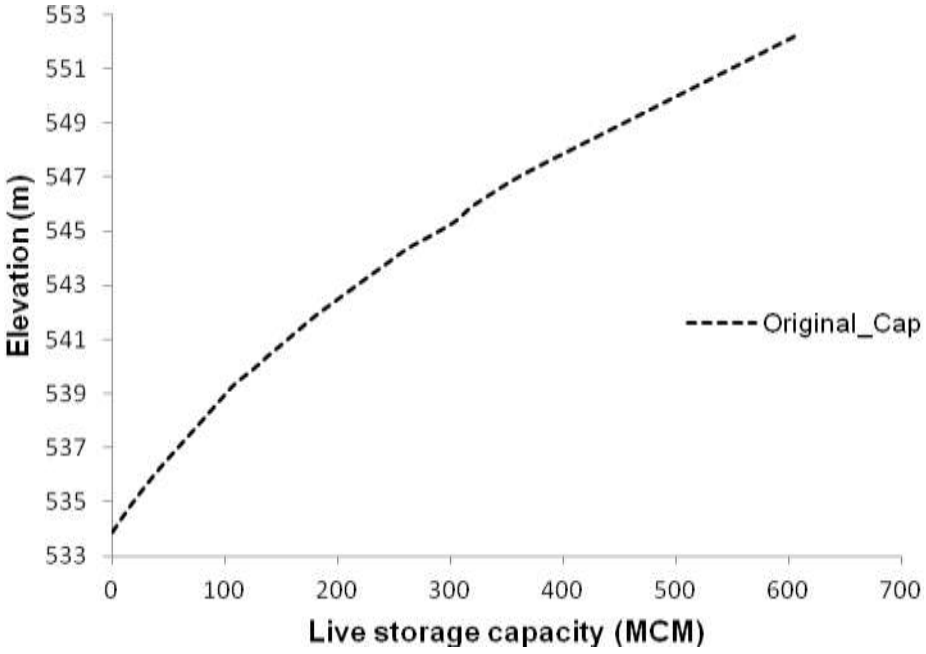


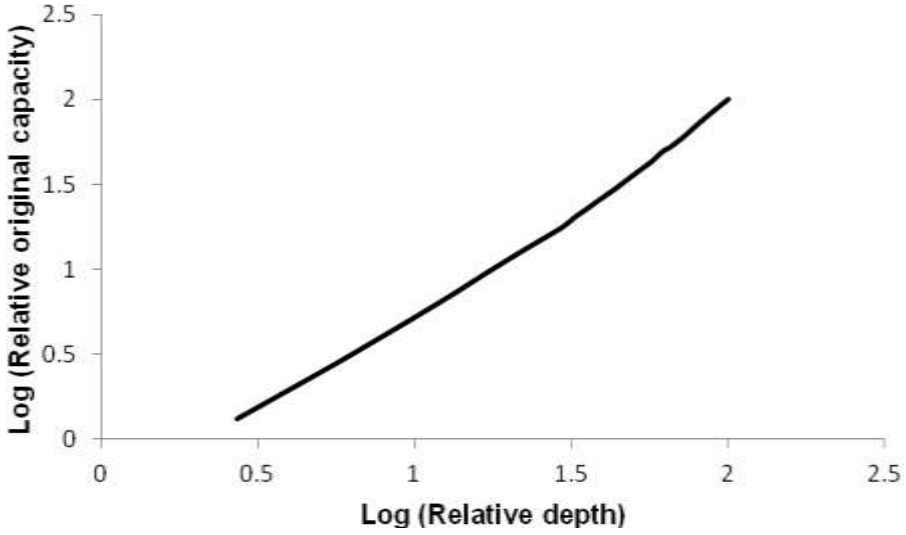




Mula Project

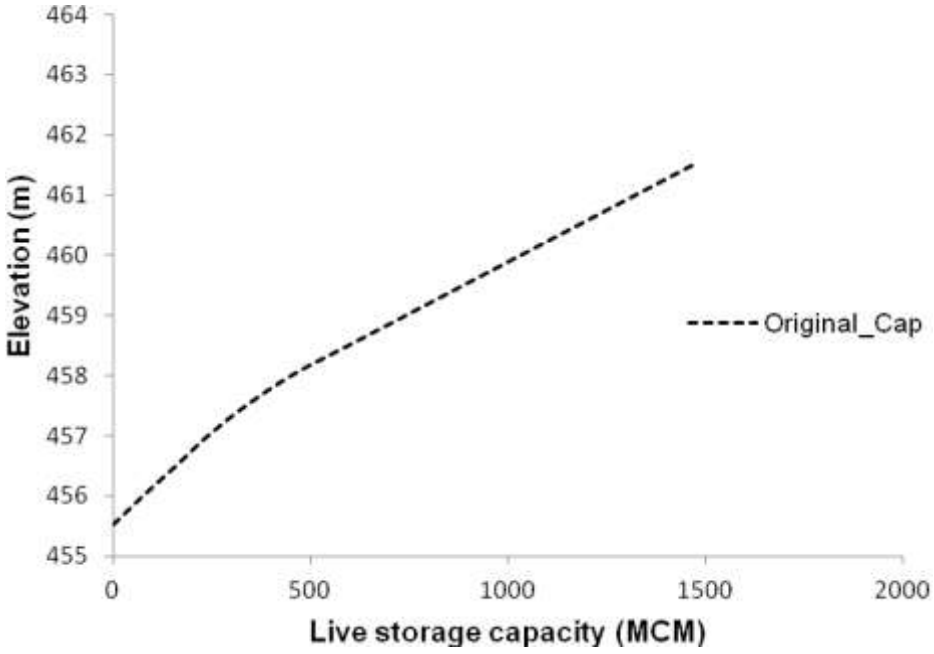
State – ***Maharashtra***				
River	***Mula***		Catchment area	***2274***
MDDL (m)	***533.9***		Live capacity (MCM) at MDDL	***0.00***
FRL (m)	***552.30***		Live capacity (MCM) at FRL	***609.00***
Year of first impoundment	***1972***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

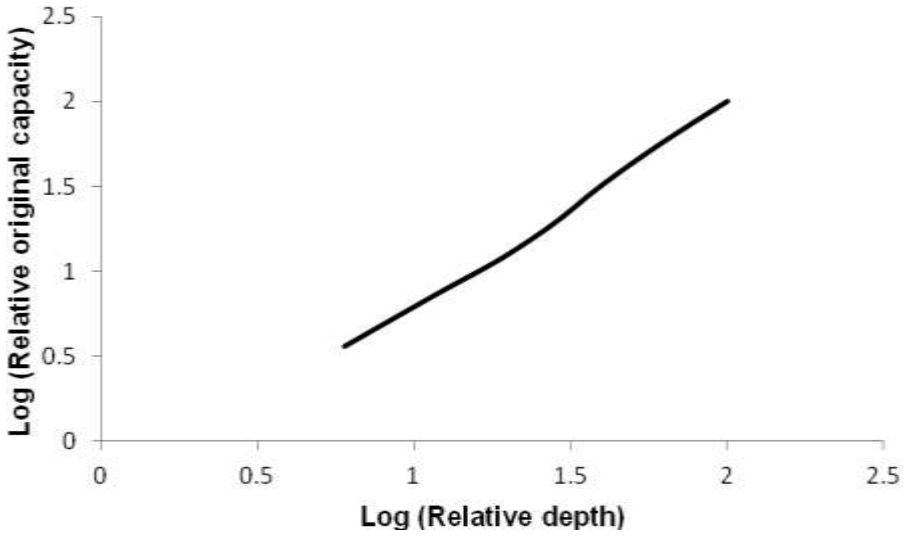




Jayakwadi (Paithon) Project

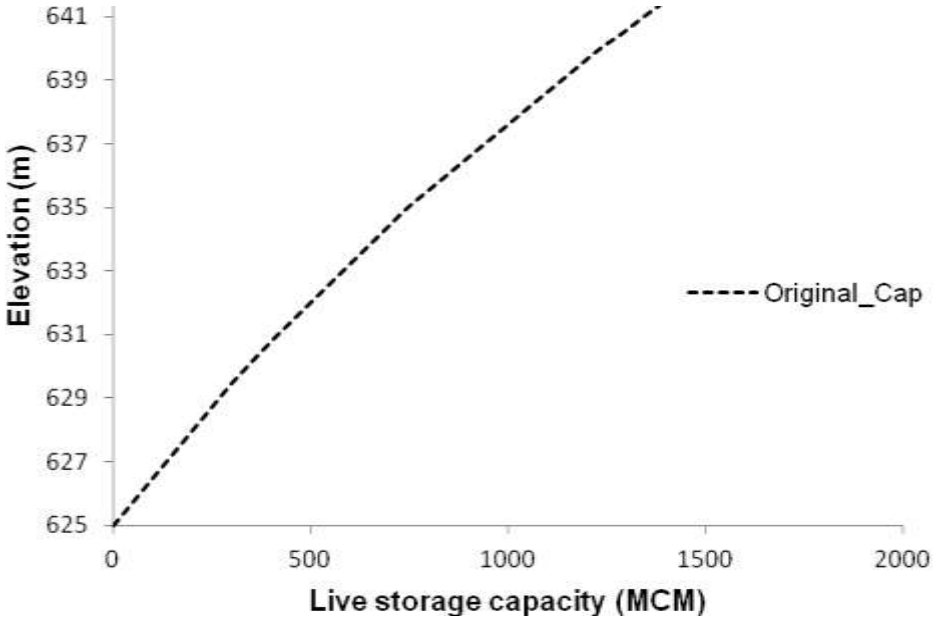
State – ***Maharashtra***				
River	***Godavari***		Catchment area	***21750***
MDDL (m)	***455.52***		Live capacity (MCM) at MDDL	***0.00***
FRL (m)	***463.91***		Live capacity (MCM) at FRL	***2171.00***
Year of first impoundment	***1976***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

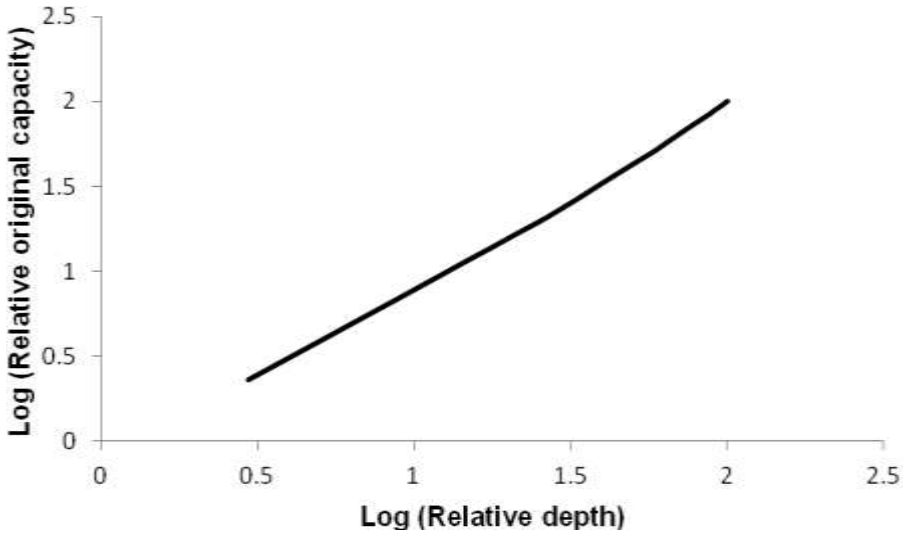




Upper Indravati Project

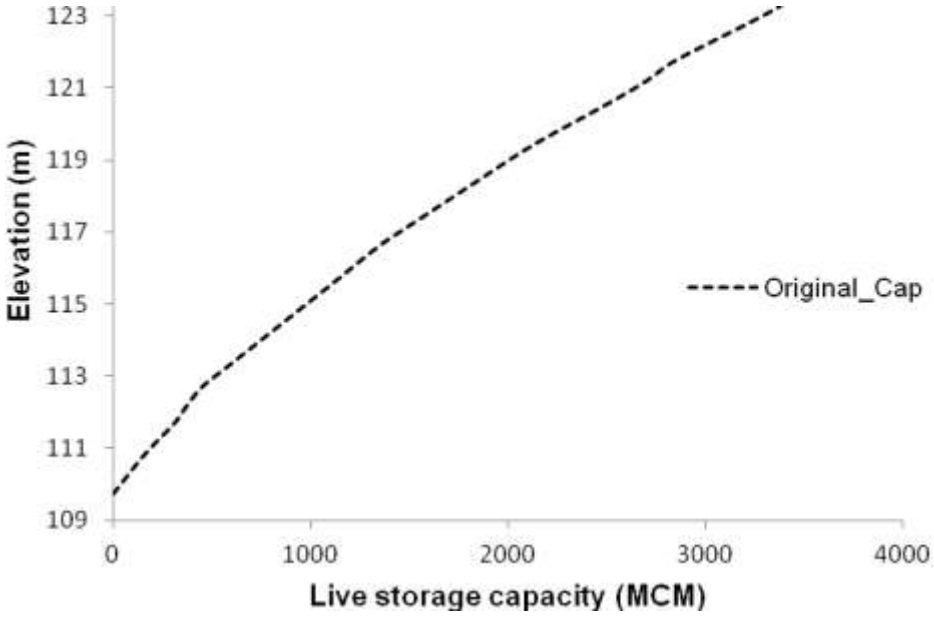
State – ***Odisha***				
River	***Indravati***		Catchment area	***26300***
MDDL (m)	***625***		Live capacity (MCM) at MDDL	***0.00***
FRL (m)	***642***		Live capacity (MCM) at FRL	***1456.00***
Year of first impoundment	***1996***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

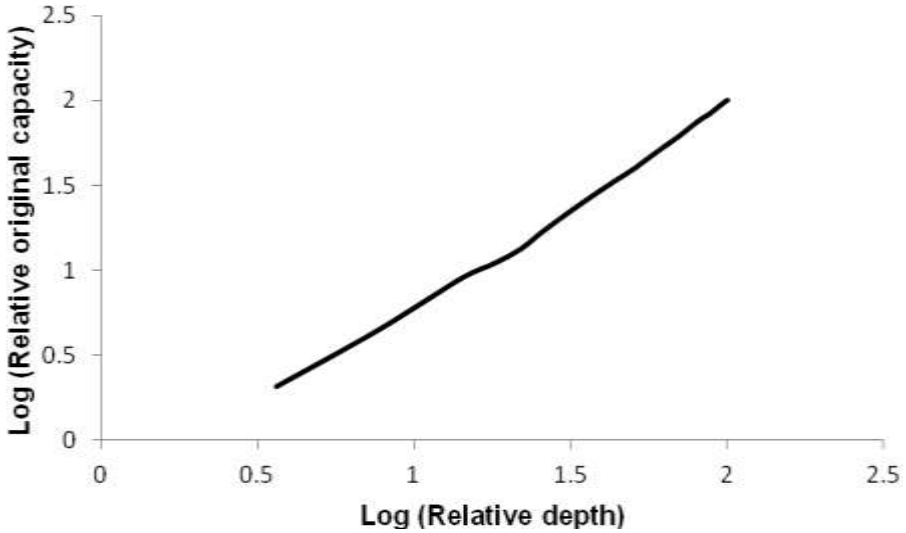




Rengali Project

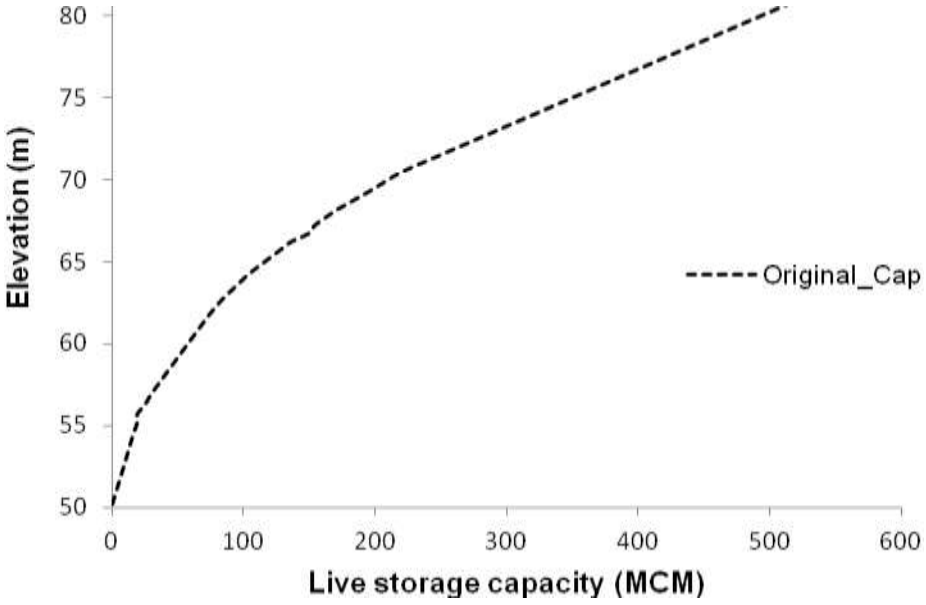
State – ***Odisha***				
River	***Brahmani***		Catchment area	***25250***
MDDL (m)	***109.72***		Live capacity (MCM) at MDDL	***0.00***
FRL (m)	***123.50***		Live capacity (MCM) at FRL	***3432.00***
Year of first impoundment	***1988***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

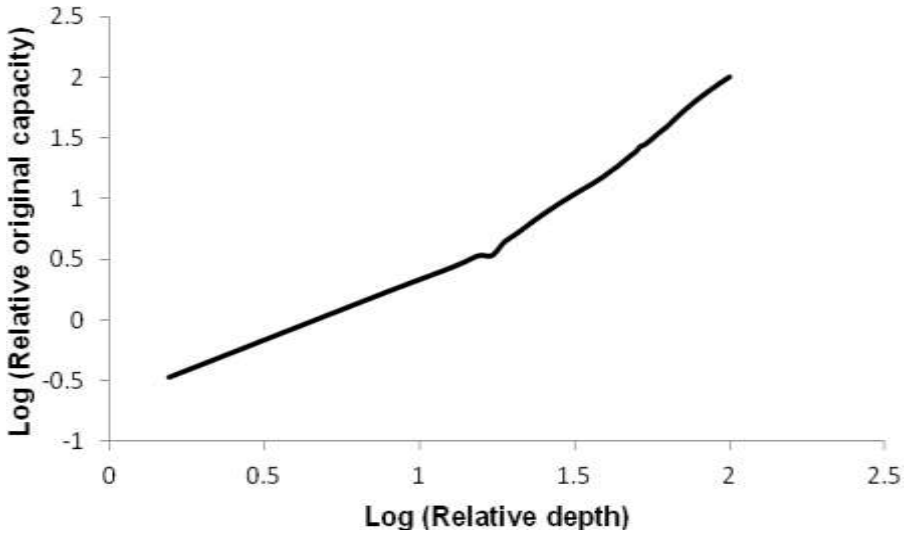




Salandi Project

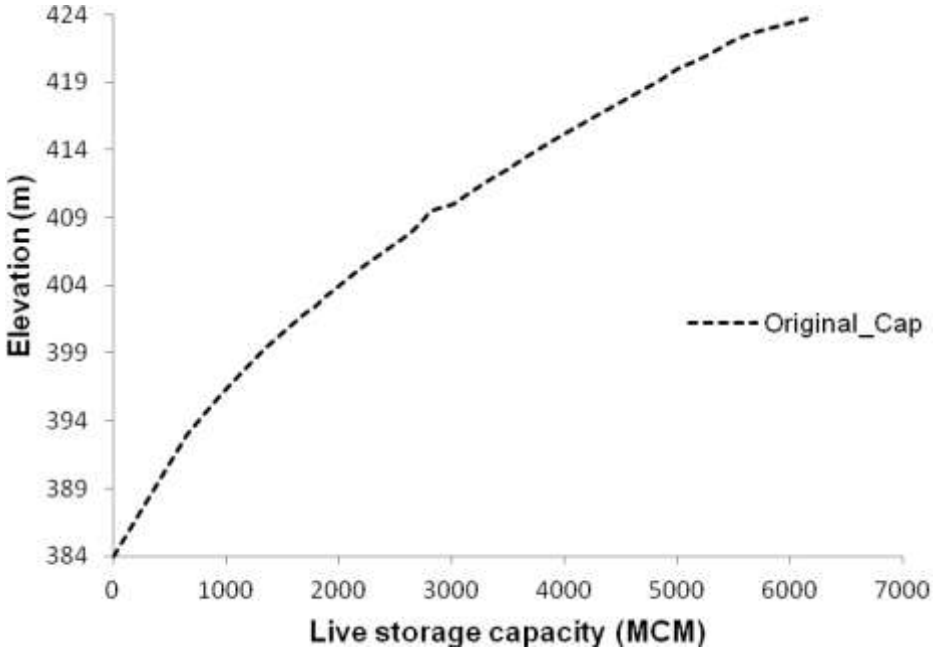
State – ***Odisha***				
River	***Salandi***		Catchment area	***673***
MDDL (m)	***50.24***		Live capacity (MCM) at MDDL	***0.00***
FRL (m)	***82.30***		Live capacity (MCM) at FRL	***558.00***
Year of first impoundment	***1965***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

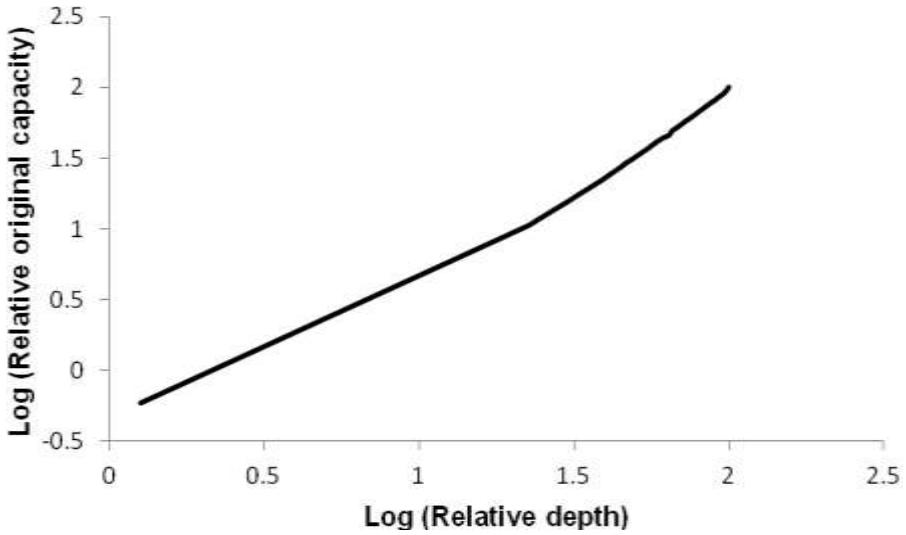




Pong Project

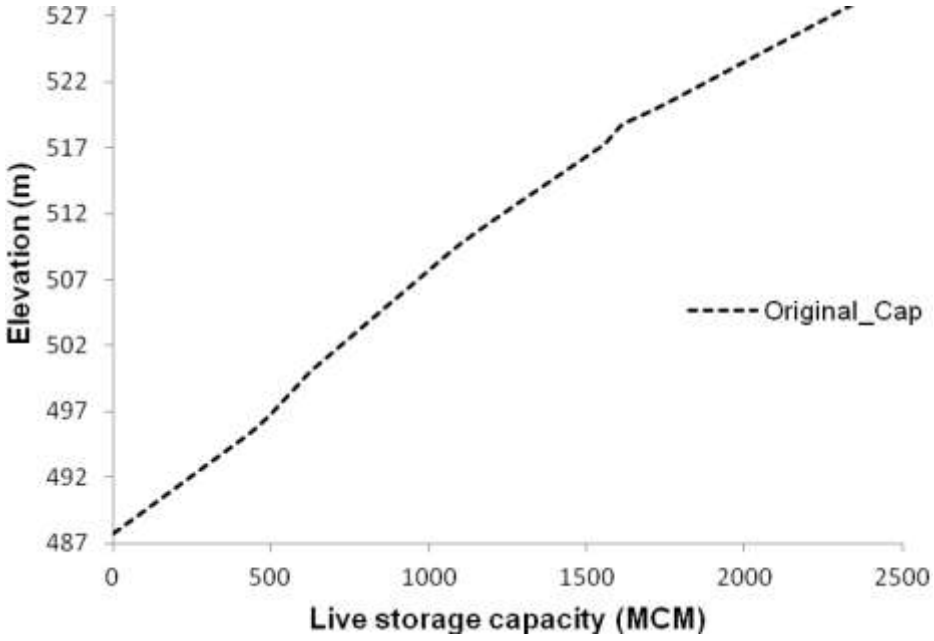
State – ***Himachal Pradesh***				
River	***Ravi***		Catchment area	***NA***
MDDL (m)	***384***		Live capacity (MCM) at MDDL	***0.00***
FRL (m)	***423.67***		Live capacity (MCM) at FRL	***6157.00***
Year of first impoundment	***1974***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

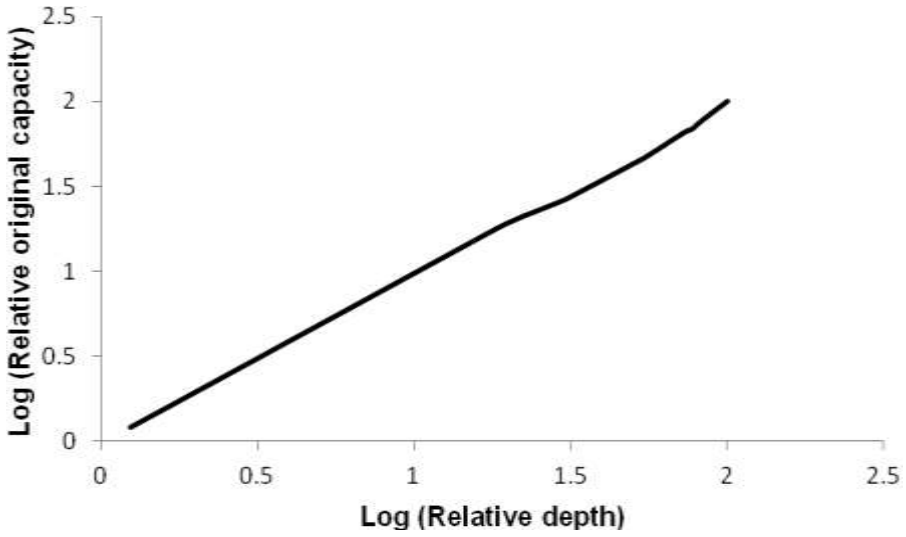




Thein dam Project

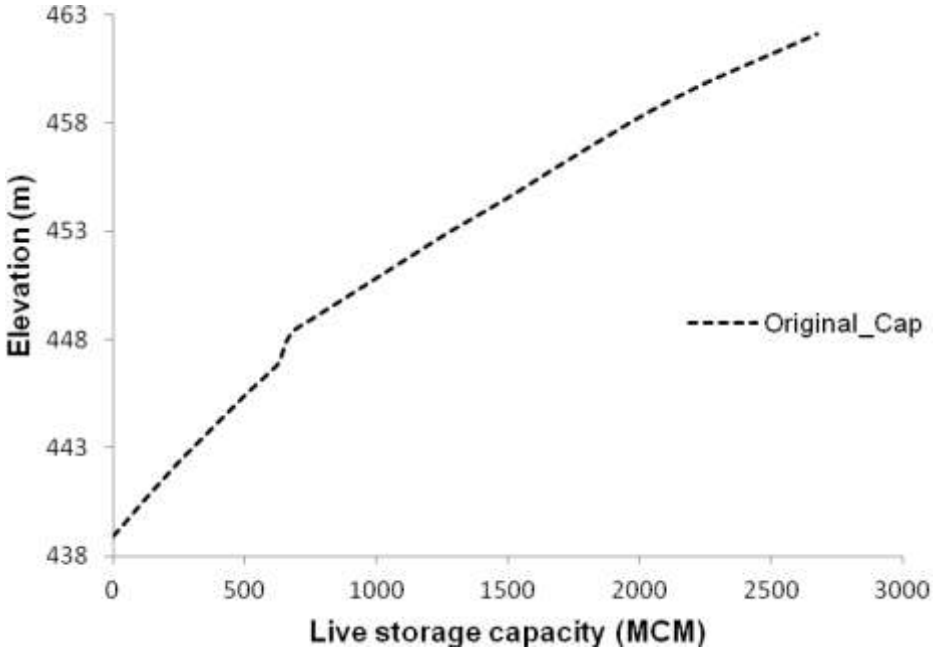
State – ***Punjab***				
River	***Ravi***		Catchment area	***60860***
MDDL (m)	***487.77***		Live capacity (MCM) at MDDL	***0.00***
FRL (m)	***527.91***		Live capacity (MCM) at FRL	***2344.00***
Year of first impoundment	***2000***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-

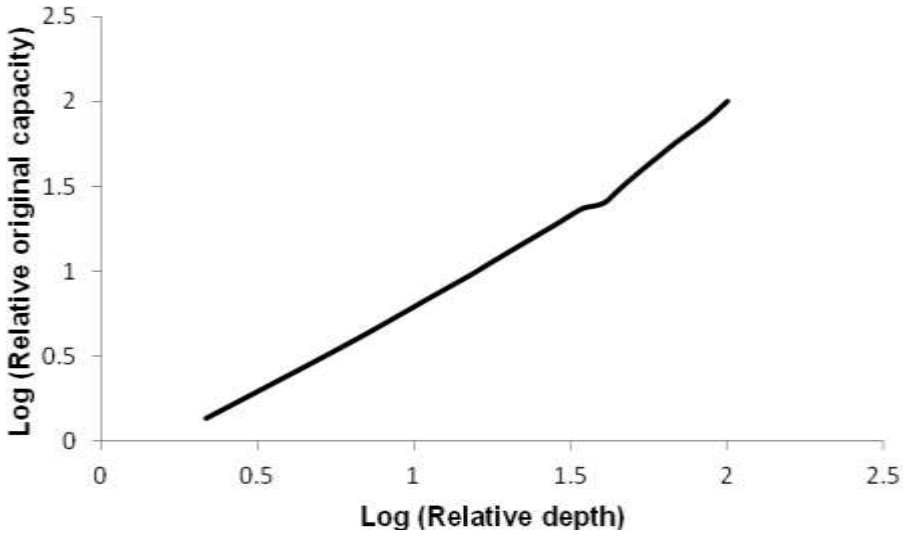




Balimela Project

State – ***Andhra Pradesh***				
River	***Sileru***		Catchment area	***4910***
MDDL (m)	***438.92***		Live capacity (MCM) at MDDL	***0.00***
FRL (m)	***462.08***		Live capacity (MCM) at FRL	***2676.00***
Year of first impoundment	***1988***		Year of capacity survey	-
Value of 'm'	-		Type of reservoir	-





CHAPTER - 4
ANALYSIS OF RESULT

4.1 Approach for Analysis

For analyzing the elevation-area-capacity relationships of reservoirs, different groups of reservoir plots of relative depth vs relative area (and relative capacity) have been formed depending on the type of reservoir and original/revised conditions. For each group, the relative depth – relative area and relative depth – relative capacity plots have been merged and an average mathematical relation that approximates the average of the various plots has been developed.

The original and revised data of reservoir elevation, area, and capacity have been plotted in different ways. First, relative depth vs relative area (and relative capacity) graphs for reservoirs in a State have been plotted and merged. Next, the graphs for various reservoirs in a State have been differentiated on the basis of type of reservoir (value of 'm') to investigate whether different types of reservoirs exhibit relative depth vs relative area (and relative capacity) curves in different regions. State-wise plots of curves are presented in the following.

Since the information related to type of reservoir (value of 'm') was not available for a large number of reservoirs under analysis in this study, the curves for relative depth vs relative area (and relative capacity) for original and revised conditions for all the reservoirs have been plotted separately and average relationships have been worked out for these conditions. Using the developed relationships, the area and capacity values in a few reservoirs have been estimated and plotted with respect to the original values.

In addition, the procedure proposed by J. Mohammadzadeh-Habili et. al (2009) have also been applied to the selected reservoirs and the results have been compared with the developed relationships. This method (referred to as ASCE method) requires the information related to the river bed elevation at dam site and reservoir area and capacity at FRL. This method provides the elevation-area-capacity values in the whole range of the reservoir (from river bed to FRL) whereas the mathematical relationships have been developed only for the live storage zone of a reservoir. Depending on the availability of requisite information, the two methods have been adopted to compute the elevation-area-capacity curves which have been plotted with the original curves.

4.2 Plots for Reservoirs in Gujarat State

For most of the reservoirs in Gujarat State, elevation vs original and revised capacity values were available but the reservoir area information was not available. Since the type of reservoir (value of 'm') could be obtained for most of the reservoirs in Gujarat State analyzed in this study, the reservoir plots of relative depth vs relative area (and relative capacity) have been grouped based on the type of reservoirs (in different colours) as shown below.

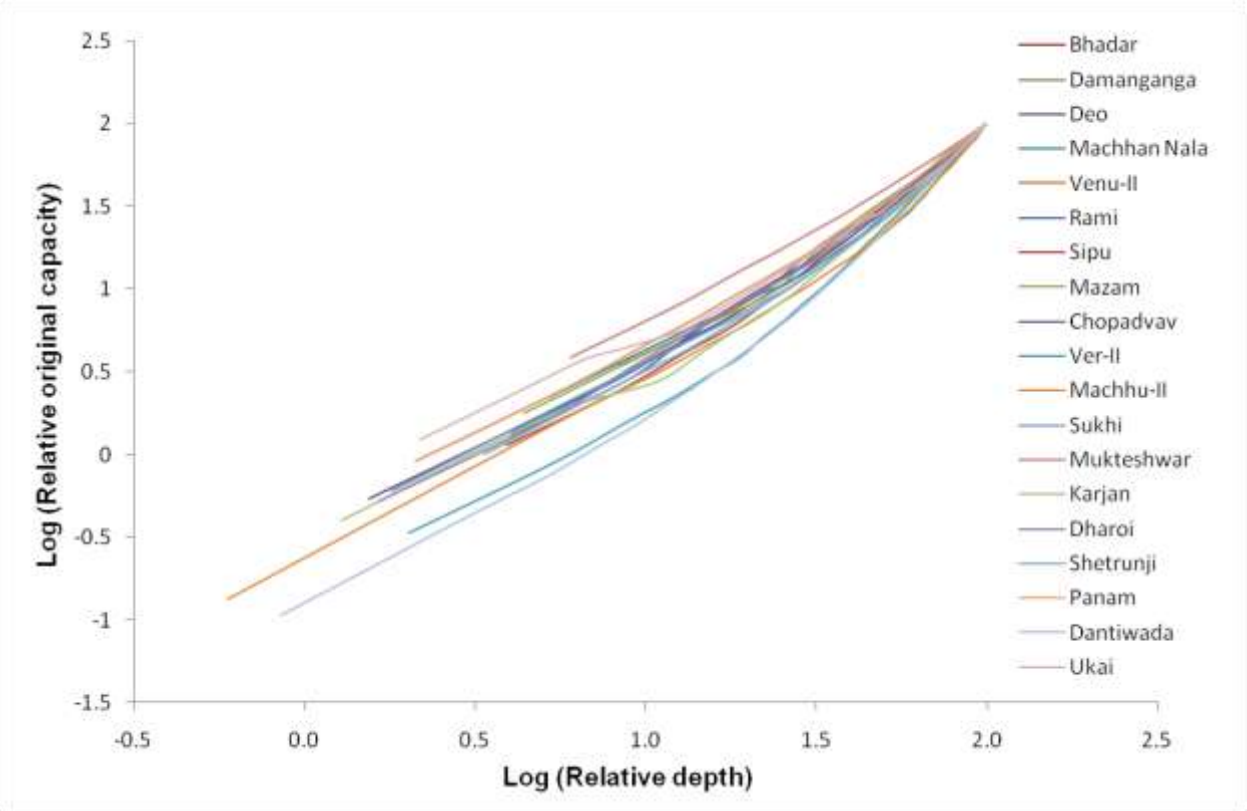


Figure – 4.1: Plot of original relative capacity curves for reservoirs in Gujarat State

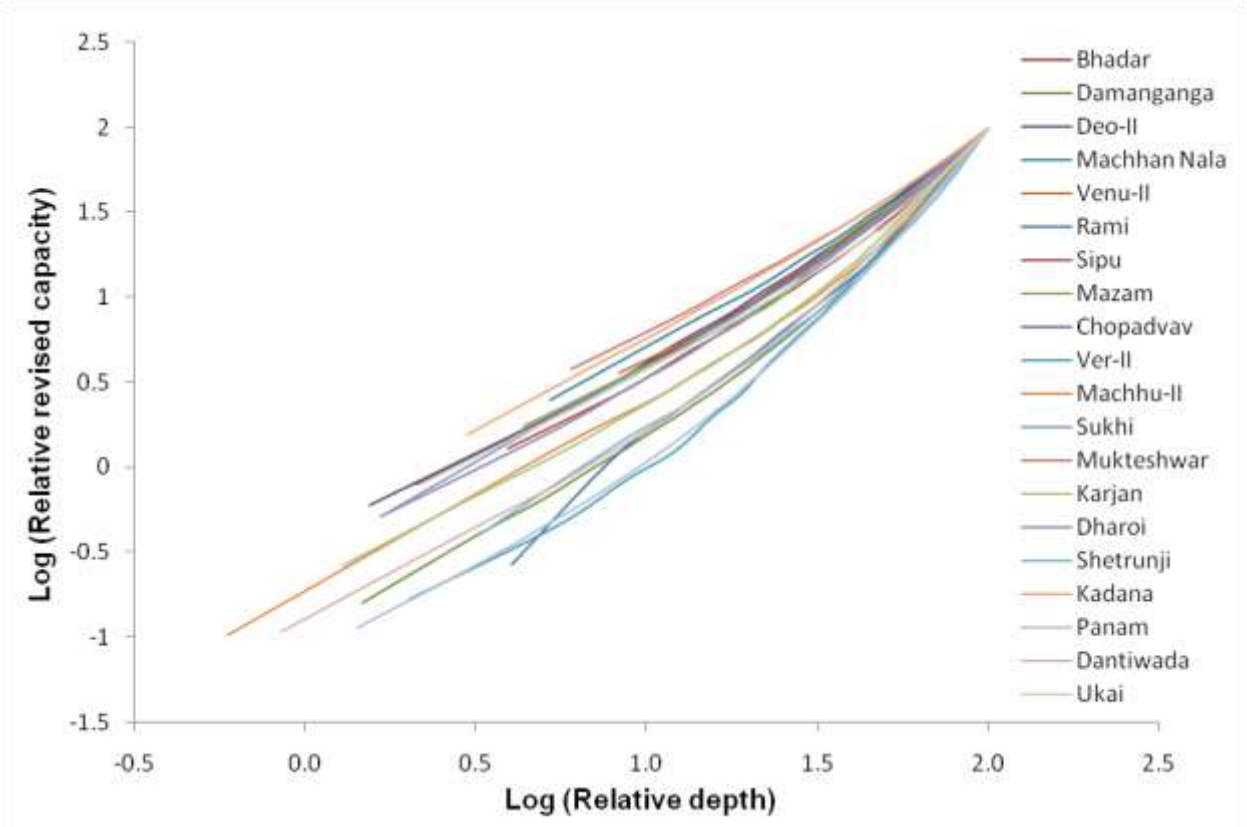


Figure – 4.2: Plot of revised relative capacity curves for reservoirs in Gujarat State

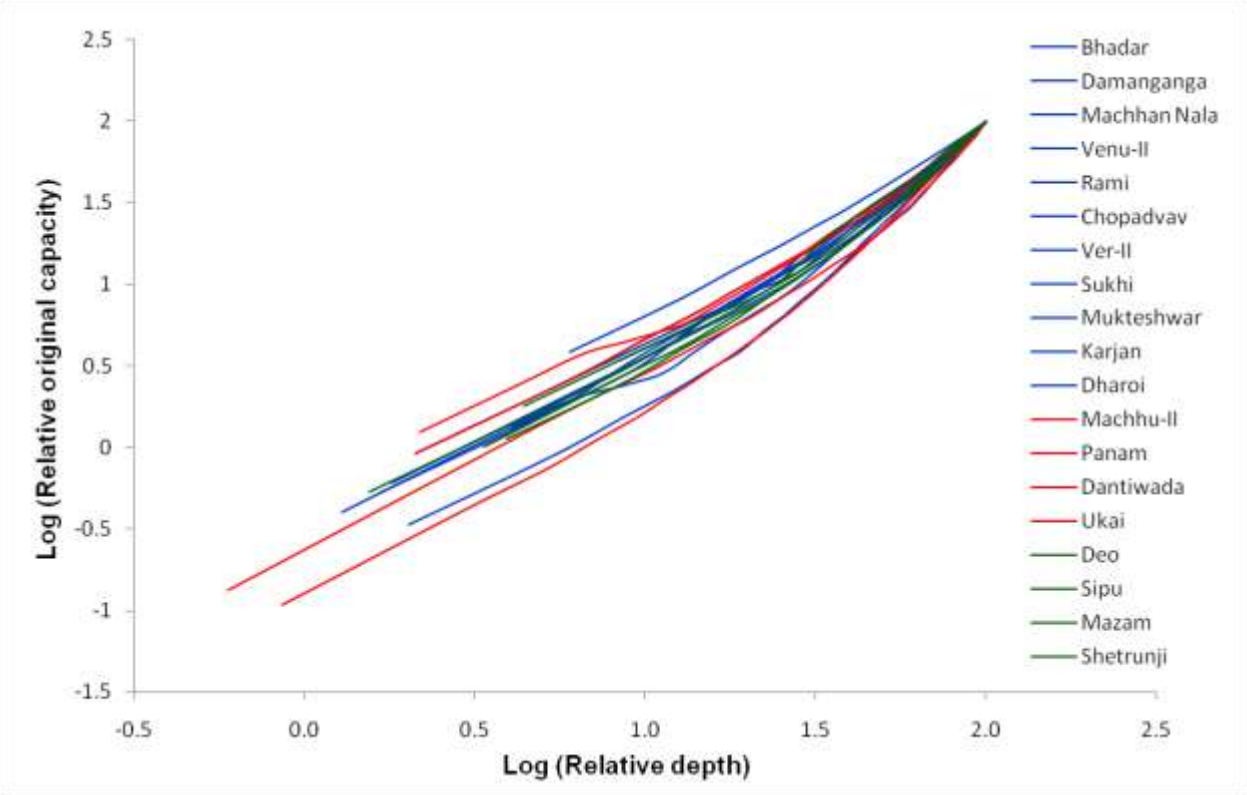


Figure – 4.3: Plot of original relative capacity curves for various types (‘m’) of reservoirs in Gujarat State (**Red – Type-I, Green – Type-II, Blue – Type-III**)

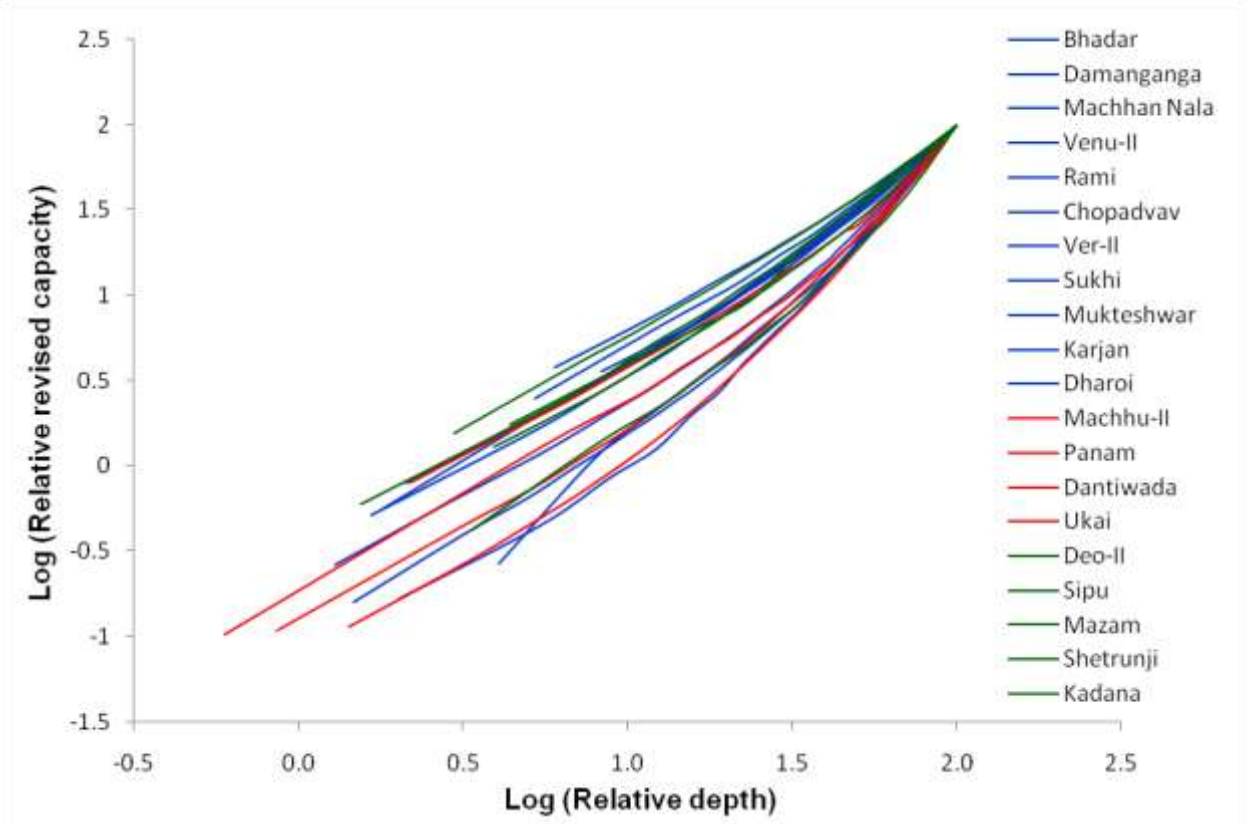


Figure – 4.4: Plot of revised relative capacity curves for various types (‘m’) of reservoirs in Gujarat State (**Red – Type-I, Green – Type-II, Blue – Type-III**)

From the plots of relative depth vs relative capacity for different reservoirs with varied values of 'm' in Gujarat State, it is inferred that different types of reservoirs do not occupy specific zones in dimensionless capacity plots and mostly get intermixed. Therefore, it does not seem necessary to derive separate relationships for different types of reservoirs.

4.3 Plots for Reservoirs in Maharashtra State

For most of the reservoirs in Maharashtra State, elevation vs original and revised area and capacity tables were available from the river bed up to the FRL. Since the type of reservoir (value of 'm') could be obtained for most of the reservoirs in Maharashtra State under analysis in this study, reservoir plots of relative depth vs relative area (and relative capacity) have been grouped based on the type of reservoirs (in different colours) as shown below.

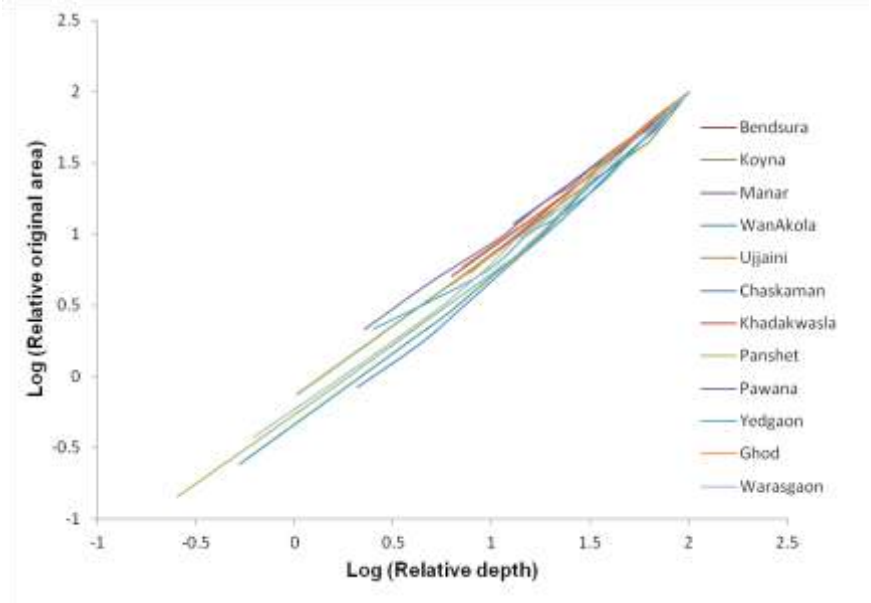


Figure – 4.5: Plot of original relative area curves for reservoirs in Maharashtra State

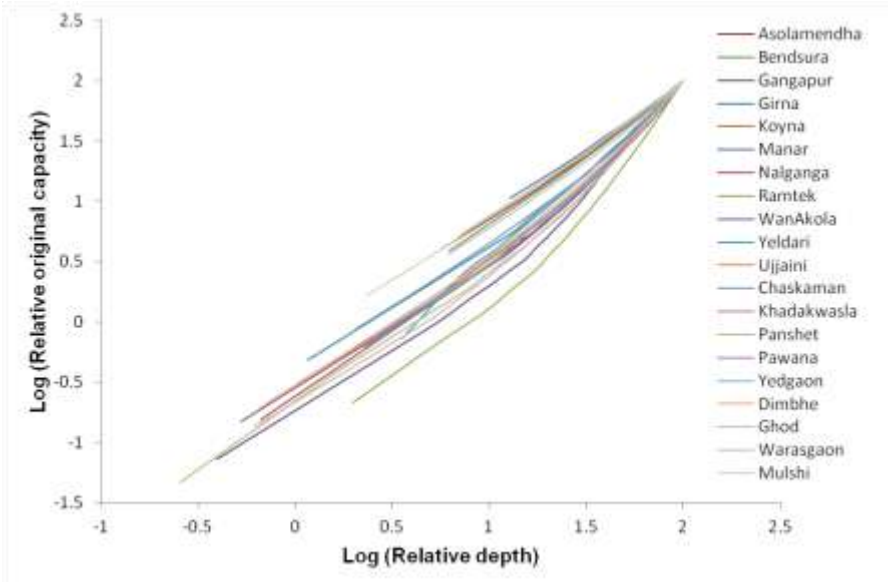


Figure – 4.6: Plot of original relative capacity curves for reservoirs in Maharashtra State

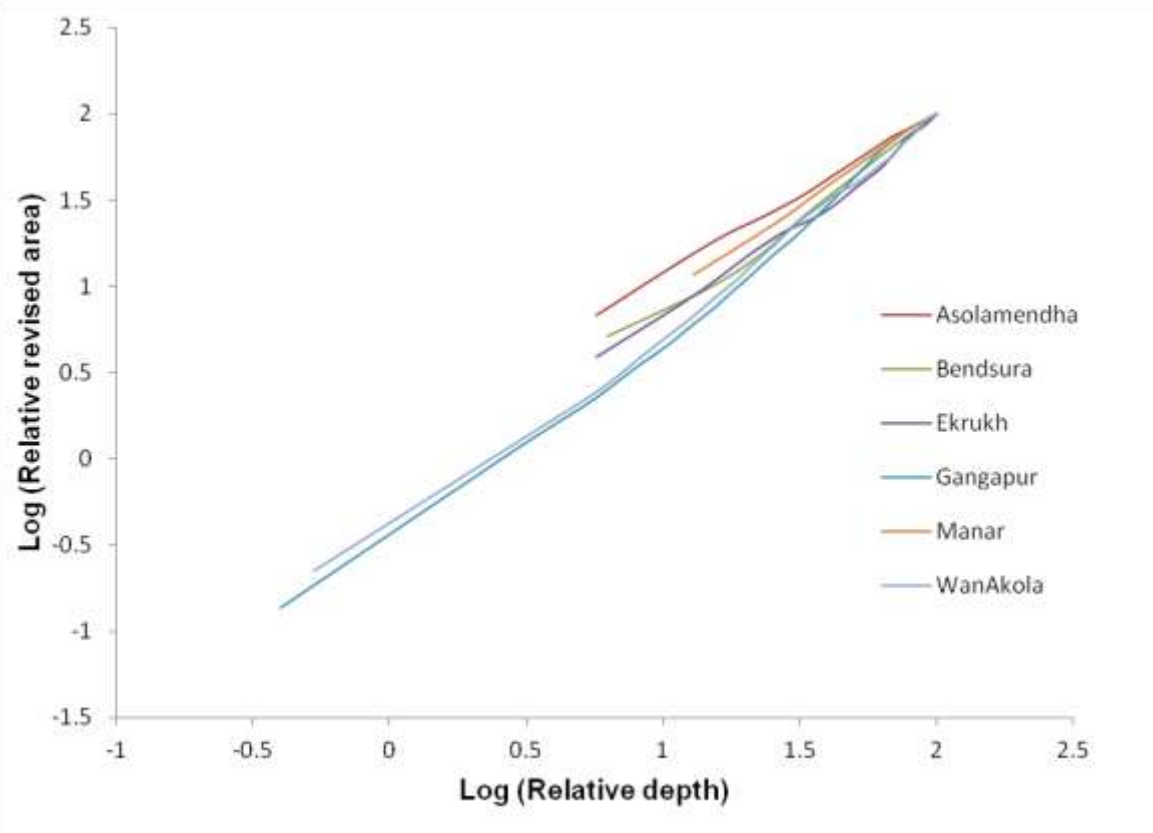


Figure – 4.7: Plot of revised relative area curves for reservoirs in Maharashtra State

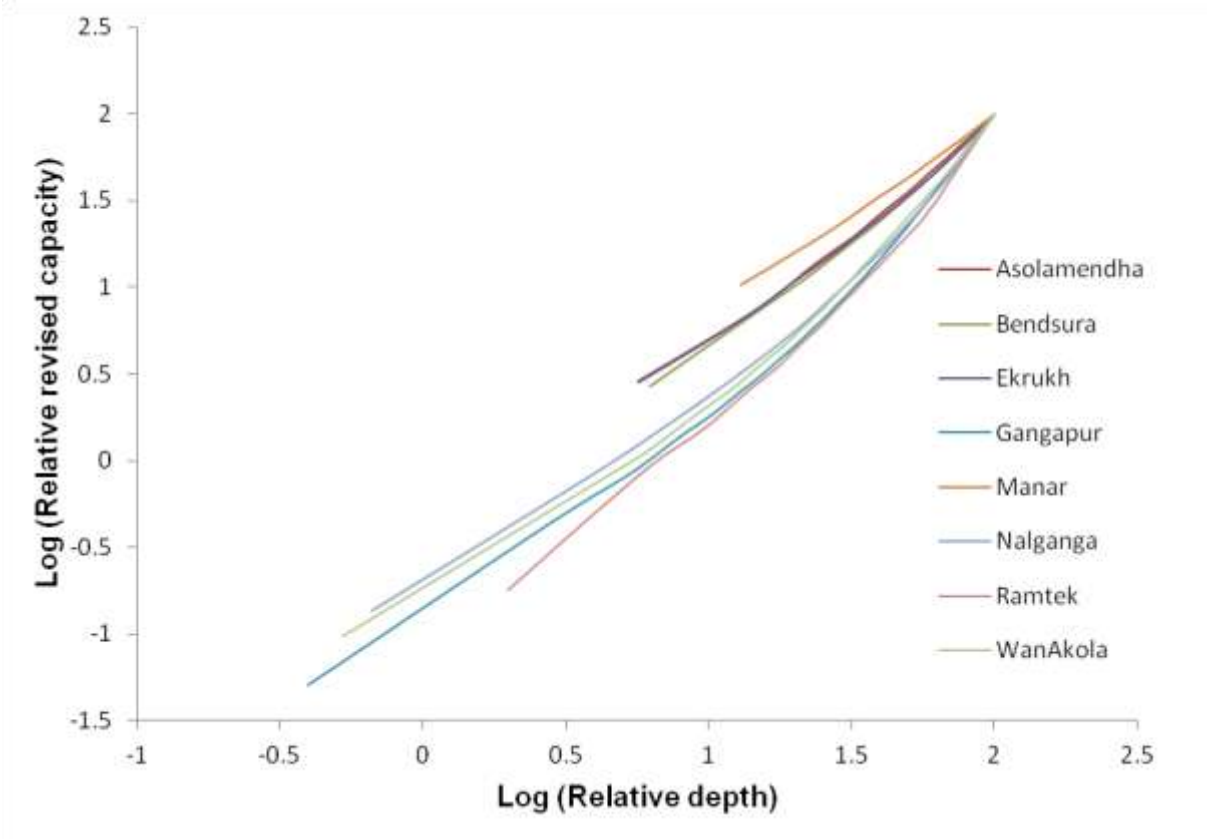


Figure – 4.8: Plot of revised relative capacity curves for reservoirs in Maharashtra State

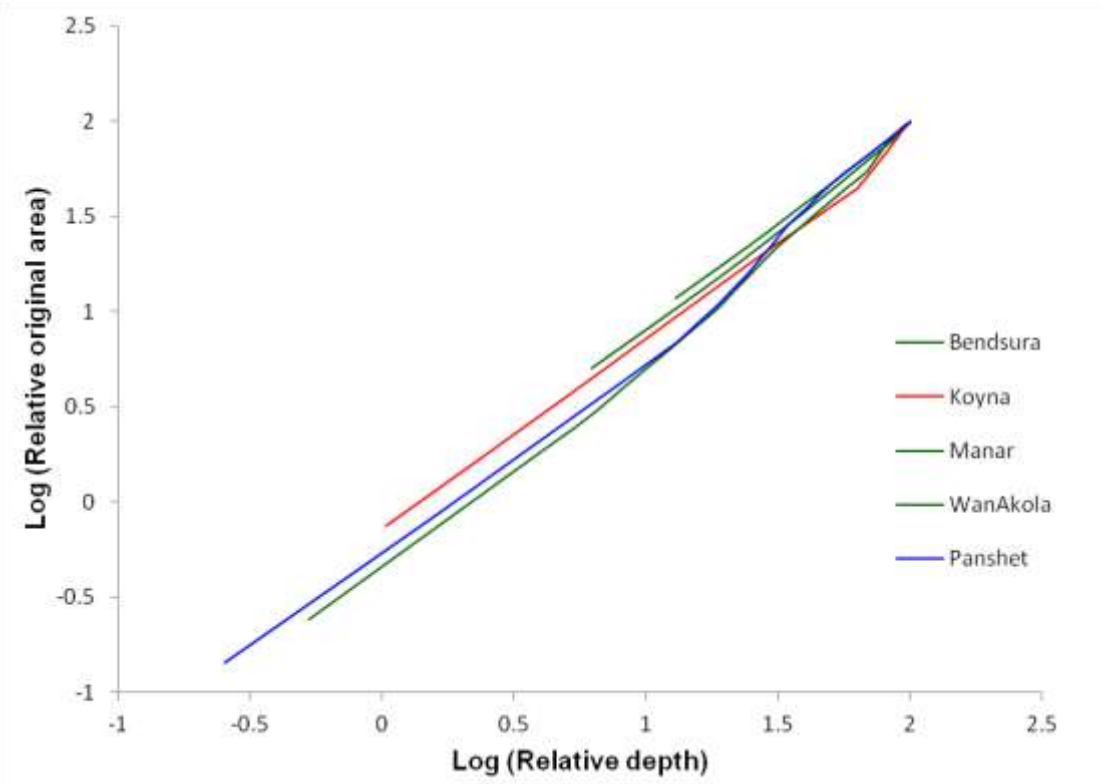


Figure – 4.9: Plot of original relative area curves for various types (‘m’) of reservoirs in Maharashtra State (**Green – Type-II, Blue – Type-III, Red – Type-IV**)

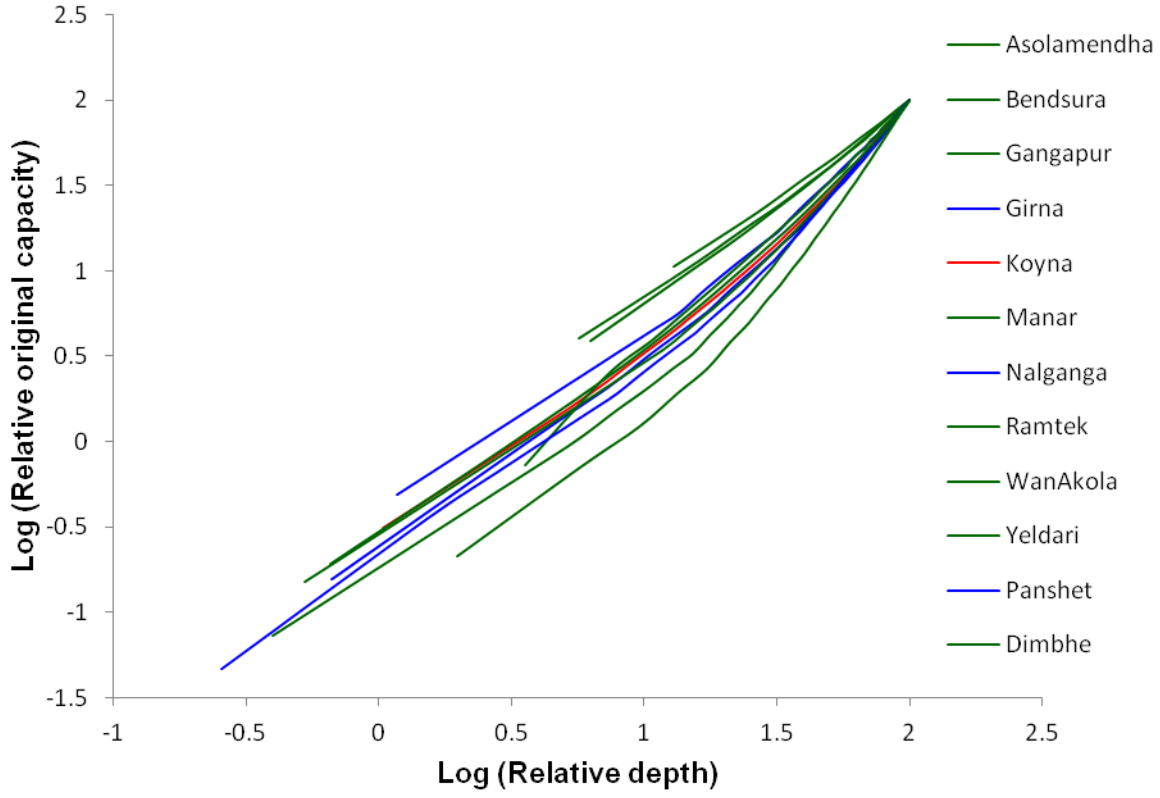


Figure – 4.10: Plot of original relative capacity curves for various types (‘m’) of reservoirs in Maharashtra State (**Green – Type-II, Blue – Type-III, Red – Type-IV**)

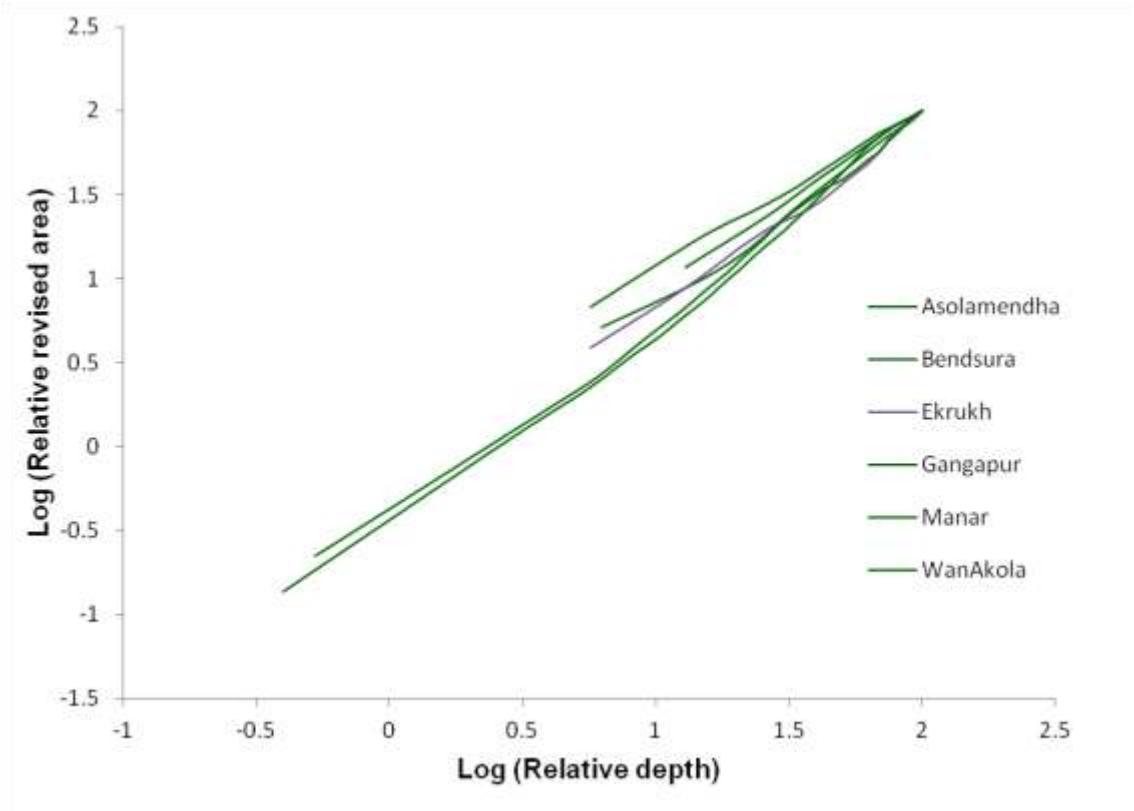


Figure – 4.11: Plot of revised relative area curves for various types ('m') of reservoirs in Maharashtra State (**Green – Type-II, Blue – Type-III, Red – Type-IV**)

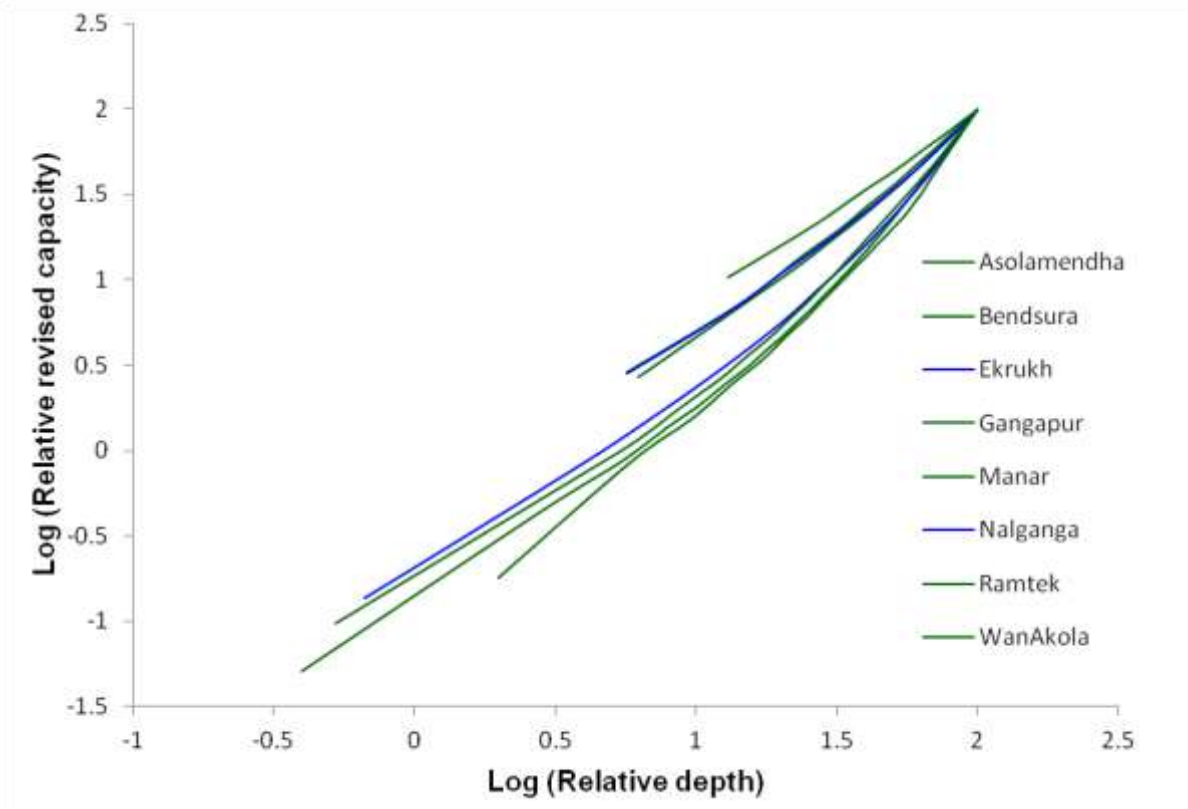


Figure – 4.12: Plot of revised relative capacity curves for various types ('m') of reservoirs in Maharashtra State (**Green – Type-II, Blue – Type-III, Red – Type-IV**)

From the plots of relative depth vs relative capacity for different reservoirs with varied values of 'm' in Maharashtra State also, it is inferred that different types of reservoirs do not occupy specific zones in dimensionless capacity plots. Thus, it does not seem necessary to derive separate relationships for different types of reservoirs.

4.4 Plots for Reservoirs in Andhra Pradesh State

For most of the reservoirs in Andhra Pradesh State, elevation vs original and revised area and capacity tables were available from the river bed up to the FRL. Since the type of reservoir (value of 'm') could be obtained for some of the reservoirs in Andhra Pradesh State under analysis in this study, reservoir plots of relative depth vs relative area (and relative capacity) have been grouped based on the type of reservoirs (in different colours) as shown below.

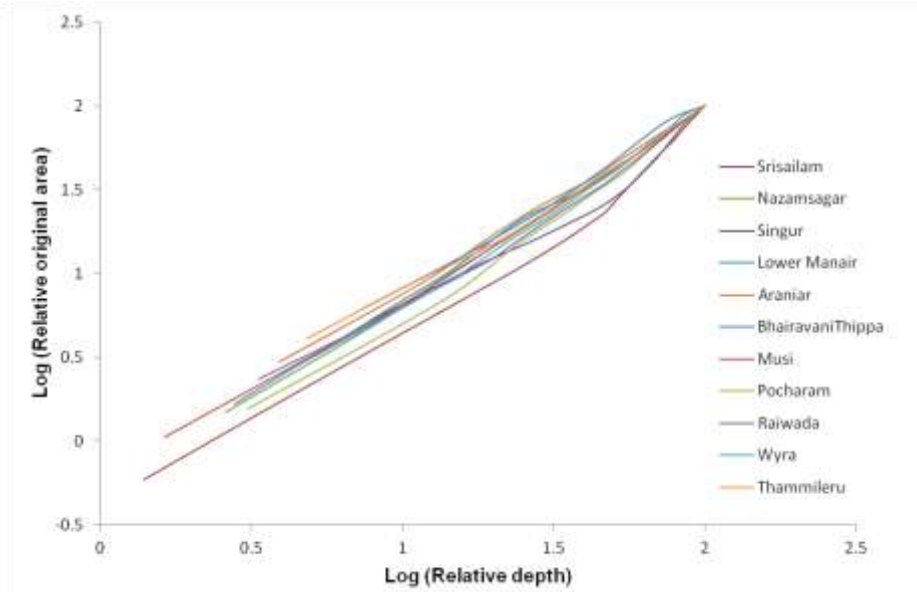


Figure – 4.13: Plot of original relative area curves for reservoirs in Andhra Pradesh State

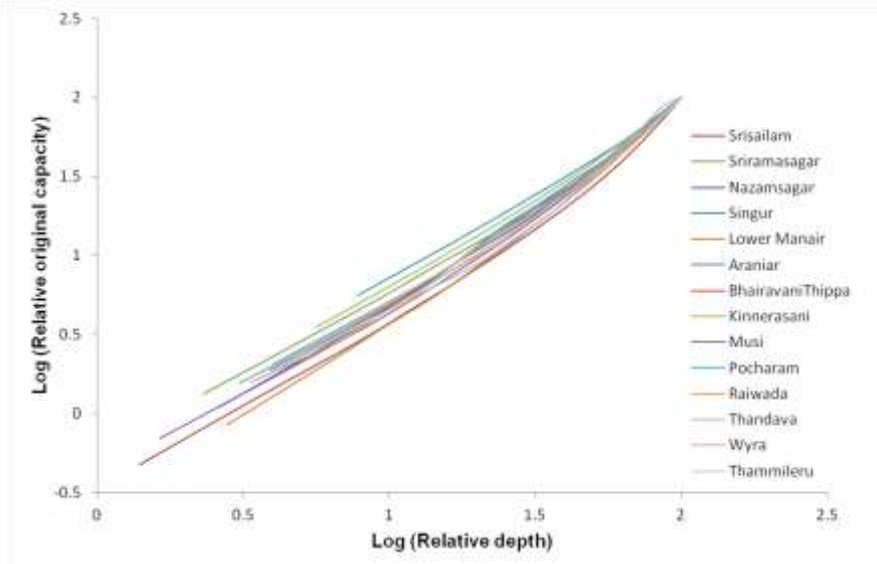


Figure – 4.14: Plot of original relative capacity curves for reservoirs in Andhra Pradesh State

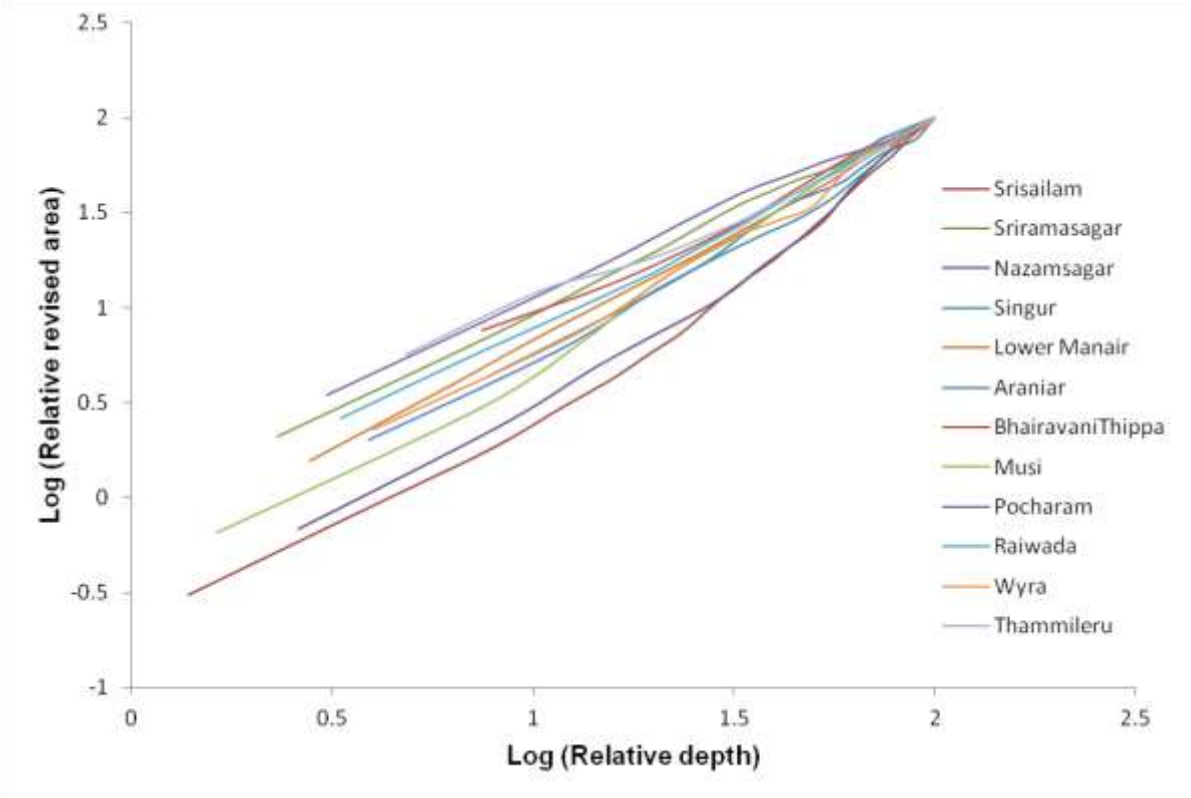


Figure – 4.15: Plot of relative revised area curves for reservoirs in Andhra Pradesh State

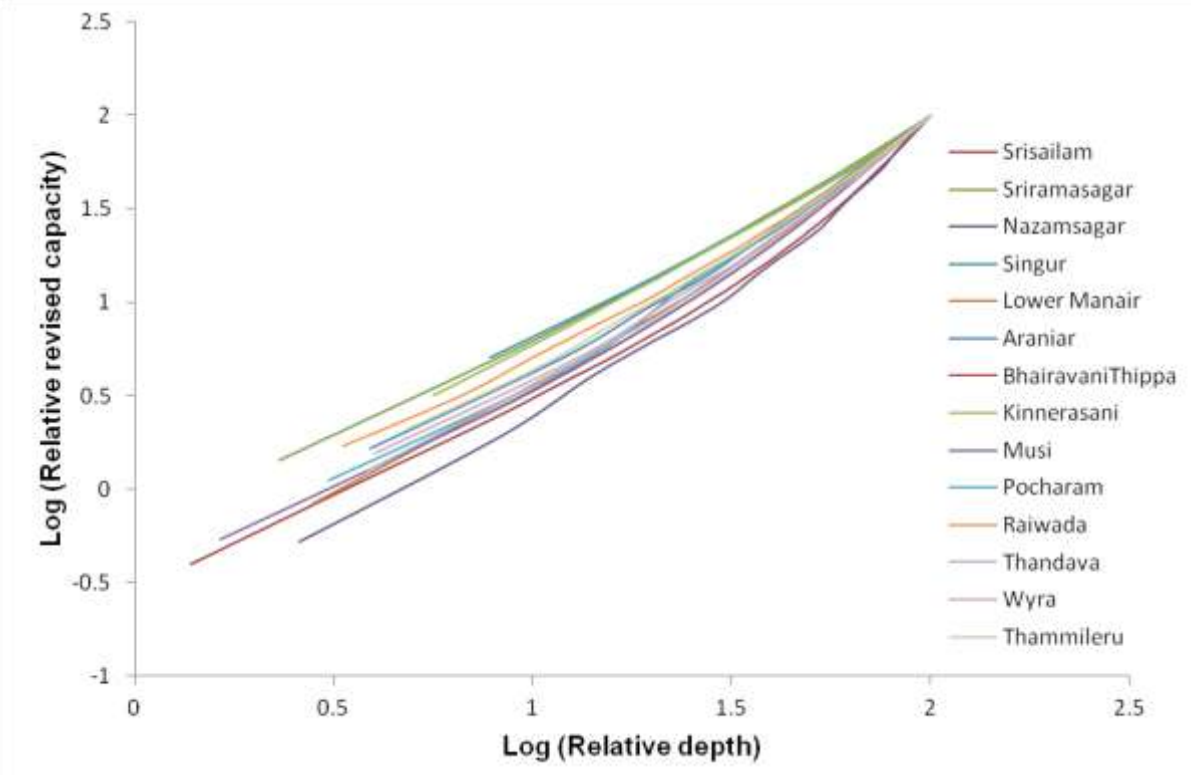


Figure – 4.16: Plot of relative revised capacity curves for reservoirs in Andhra Pradesh State

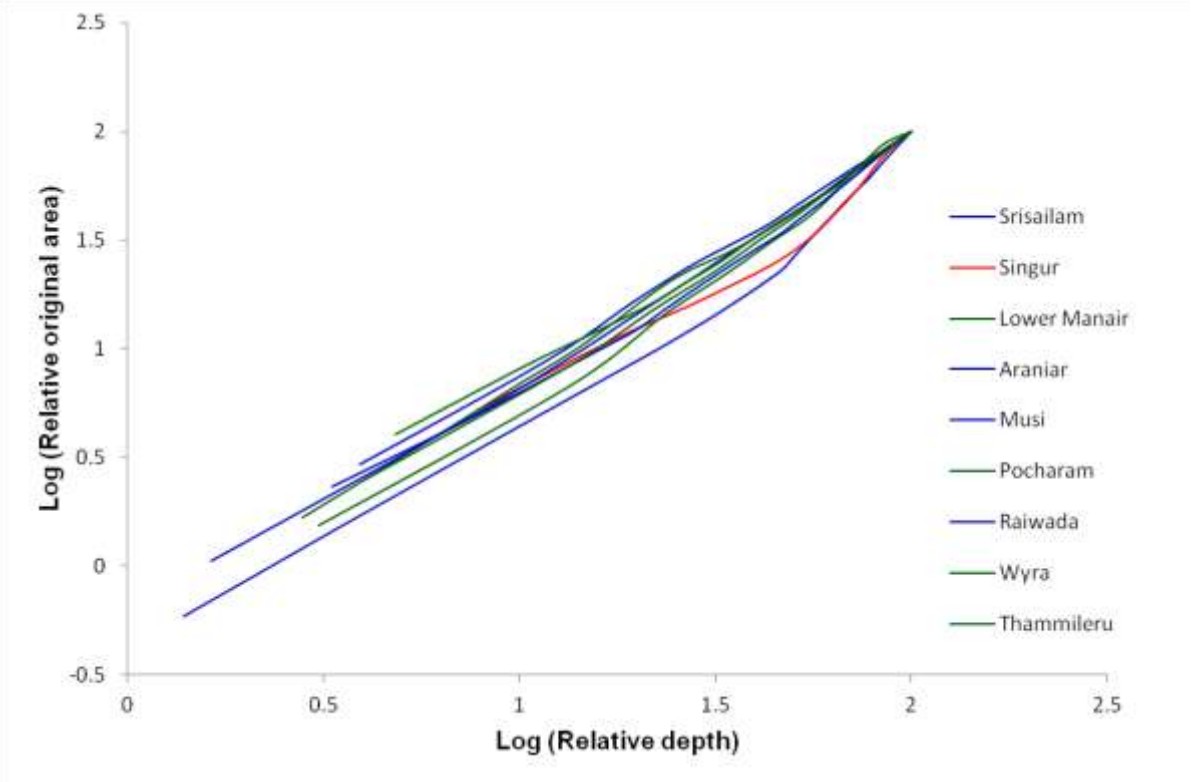


Figure – 4.17: Plot of relative original area curves for various types ('m') of reservoirs in A.P. State (**Red – Type-I**, **Green – Type-II**, **Blue – Type-III**)

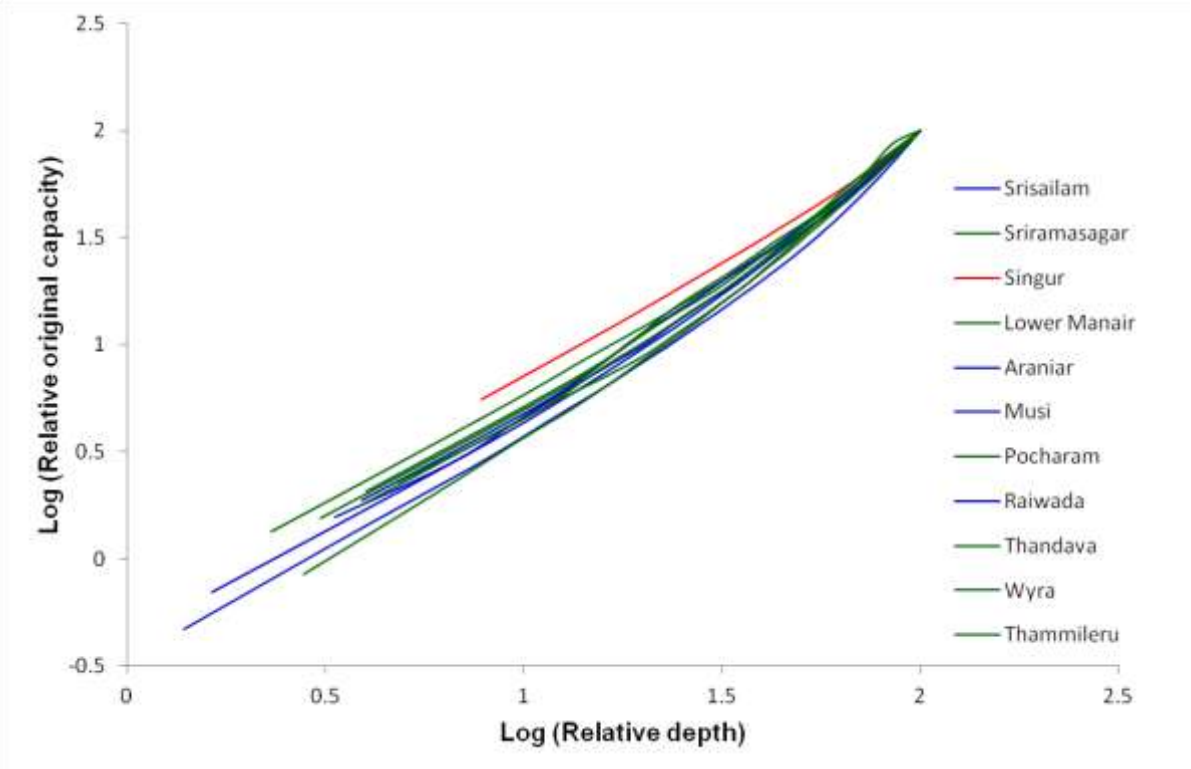


Figure – 4.18: Plot of relative original capacity curves for various types ('m') of reservoirs in A.P. State (**Red – Type-I**, **Green – Type-II**, **Blue – Type-III**)

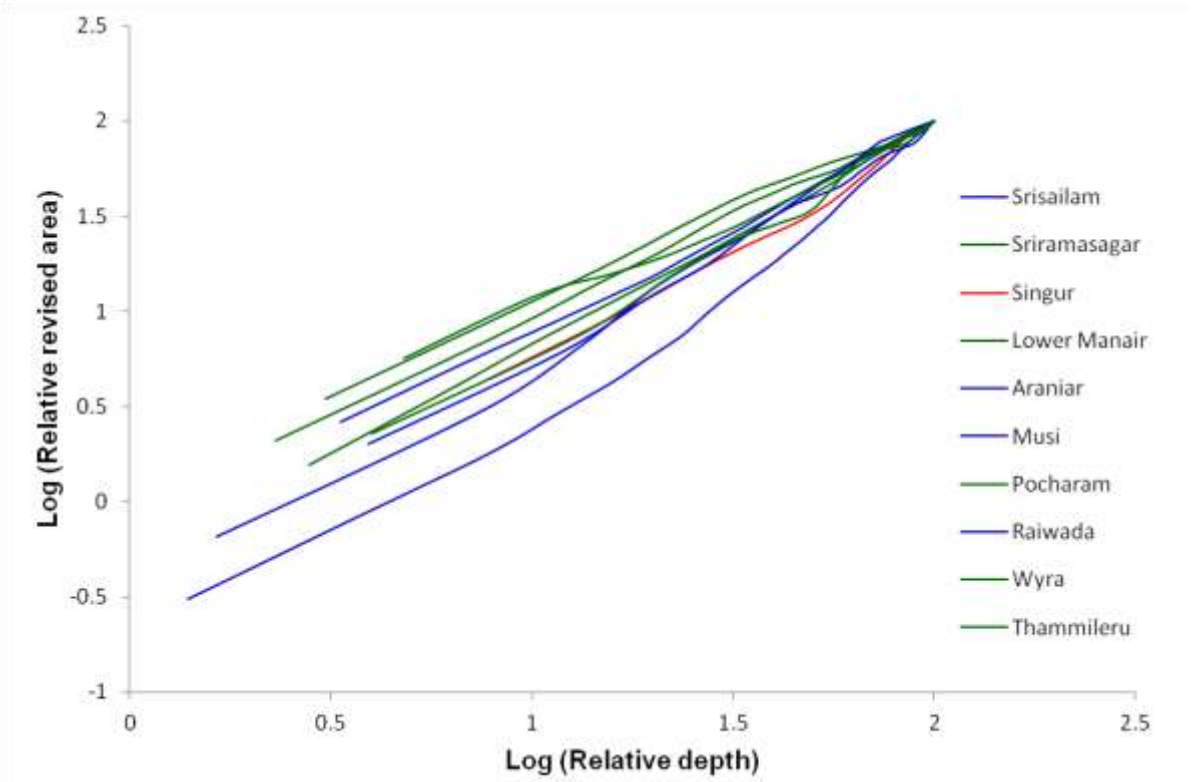


Figure – 4.19: Plot of relative revised area curves for various types ('m') of reservoirs in A.P. State (**Red – Type-I**, **Green – Type-II**, **Blue – Type-III**)

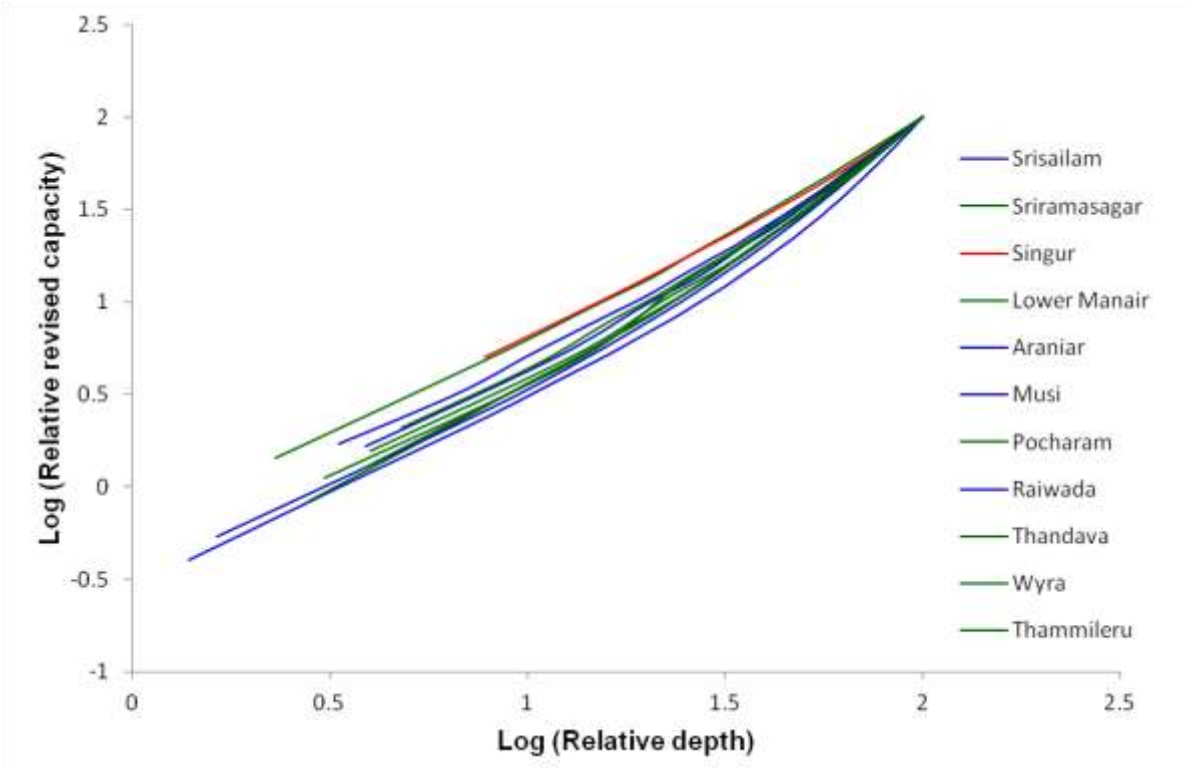


Figure – 4.20: Plot of relative revised capacity curves for various types ('m') of reservoirs in A.P. State (**Red – Type-I**, **Green – Type-II**, **Blue – Type-III**)

From the plots of relative depth vs relative capacity for different reservoirs with varied values of 'm' in Andhra Pradesh State also, it is inferred that different types of reservoirs do not occupy specific zones in dimensionless capacity plots. Thus, it does not seem necessary to derive separate relationships for different types of reservoirs.

4.4 Integrated Plots for various Reservoirs used in the study

In the present study, in addition to the available EAC tables for reservoirs in the Gujarat, Maharashtra, and A.P. State, EAC data of a number of other reservoirs have been analyzed. In total, EAC data of 78 reservoirs has been analyzed. For most of these additional reservoirs (in addition to the reservoirs in Gujarat, Maharashtra, and Andhra Pradesh States), the EAC tables were available only within the live storage zone and it was not possible to compute the type of reservoir ('m') from the available data. Therefore, dimensionless plots of all the reservoirs have been combined to work out the average mathematical relationships. Based on the original and revised capacity survey estimates, relative area and relative capacity curves have been prepared for the original and revised conditions. From the available plots, average dimensionless curves have been plotted and their mathematical equations have been derived. The dimensionless plots of relative area and capacity under different conditions are presented in the following.

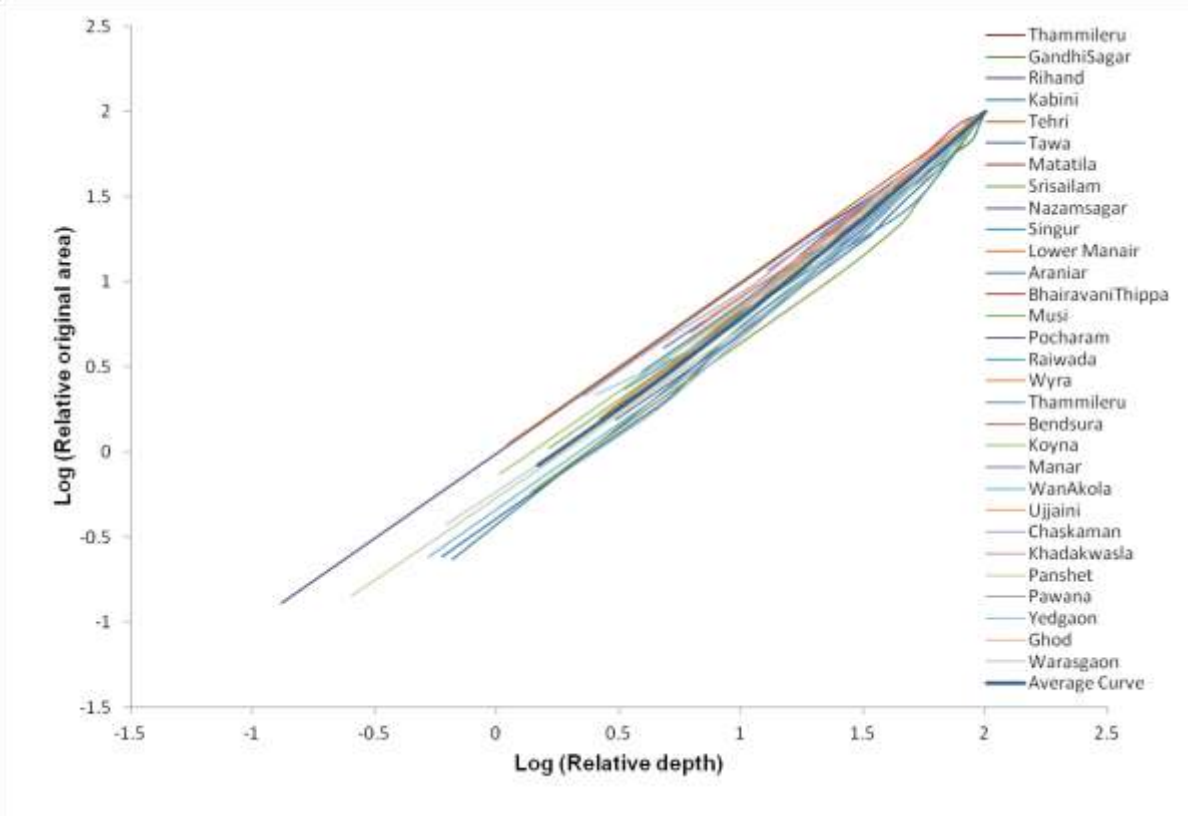


Figure – 4.21: Plot of relative original area curves for various reservoirs used in the analysis

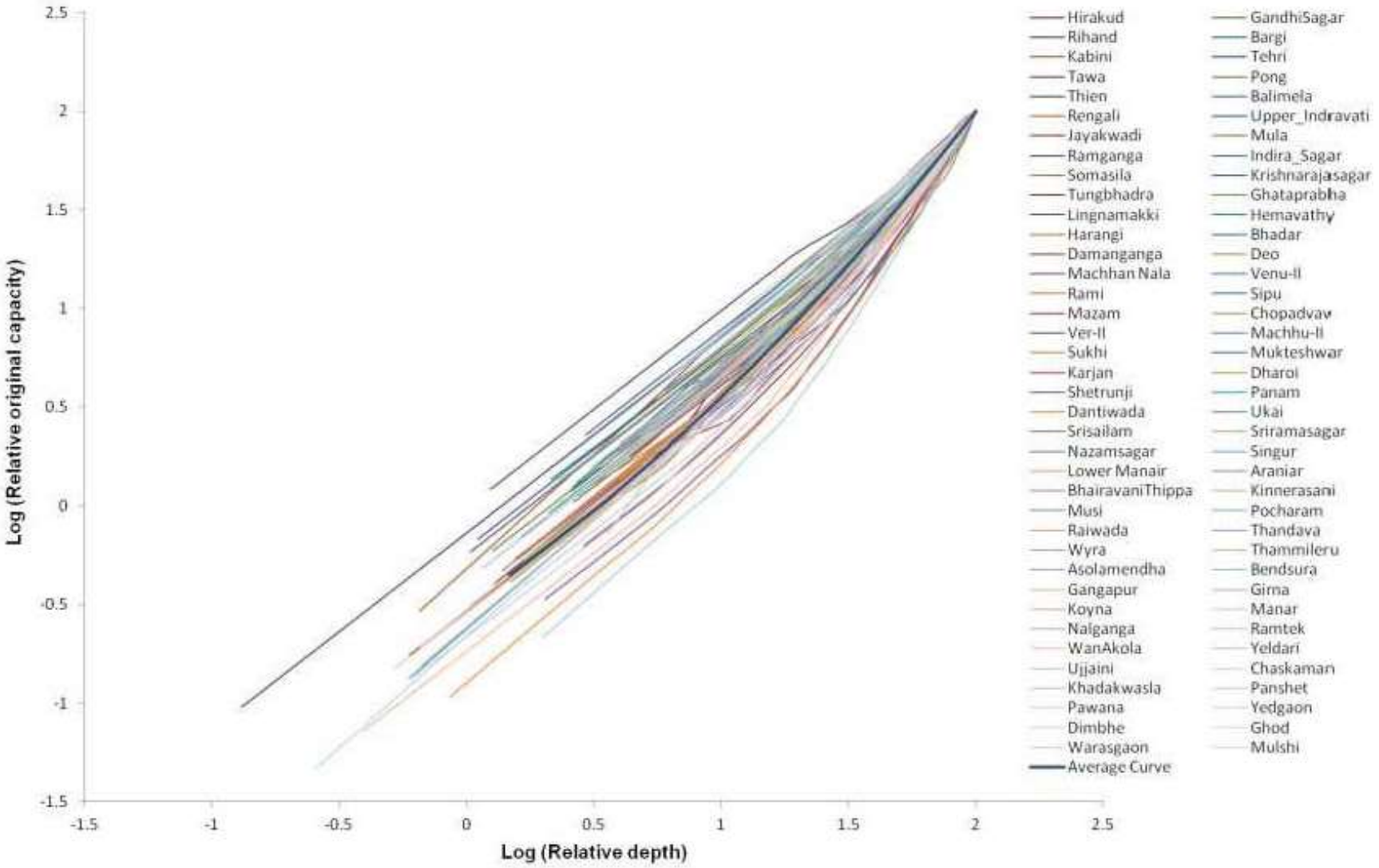


Figure – 4.22: Plot of relative original capacity for various Indian reservoirs used in the analysis

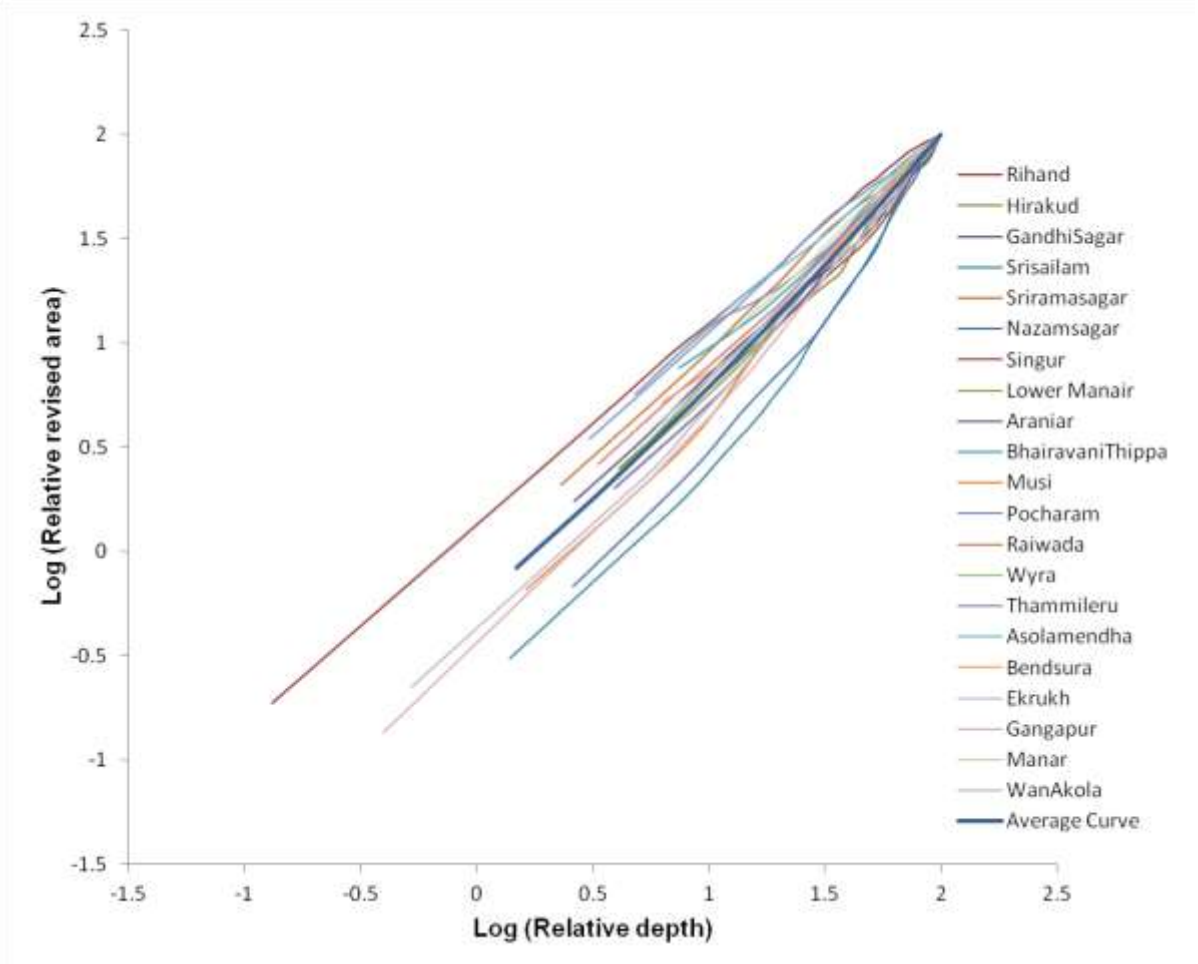


Figure – 4.23: Plot of relative revised area curves for various reservoirs used in the analysis

From the plot of the average curve to the relative area curves under original and revised condition, it is observed that the same curve (with same mathematical equation) represents average characteristics in the two cases. The mathematical relation for the dimensionless area curve is:

$$\mathbf{Log_{10}\ (Relative\ area) = 0.09 * X^2 + 0.94 * X - 0.24} \qquad \textbf{...(4.1)}$$

where X is the relative depth of reservoir within the live storage zone (MDDL to FRL) above the MDDL. Using this relationship, reservoir area at any elevation within the live storage zone can be determined. In the later sections, the use of this equation is demonstrated for a few reservoirs and the results are compared with the observed values.

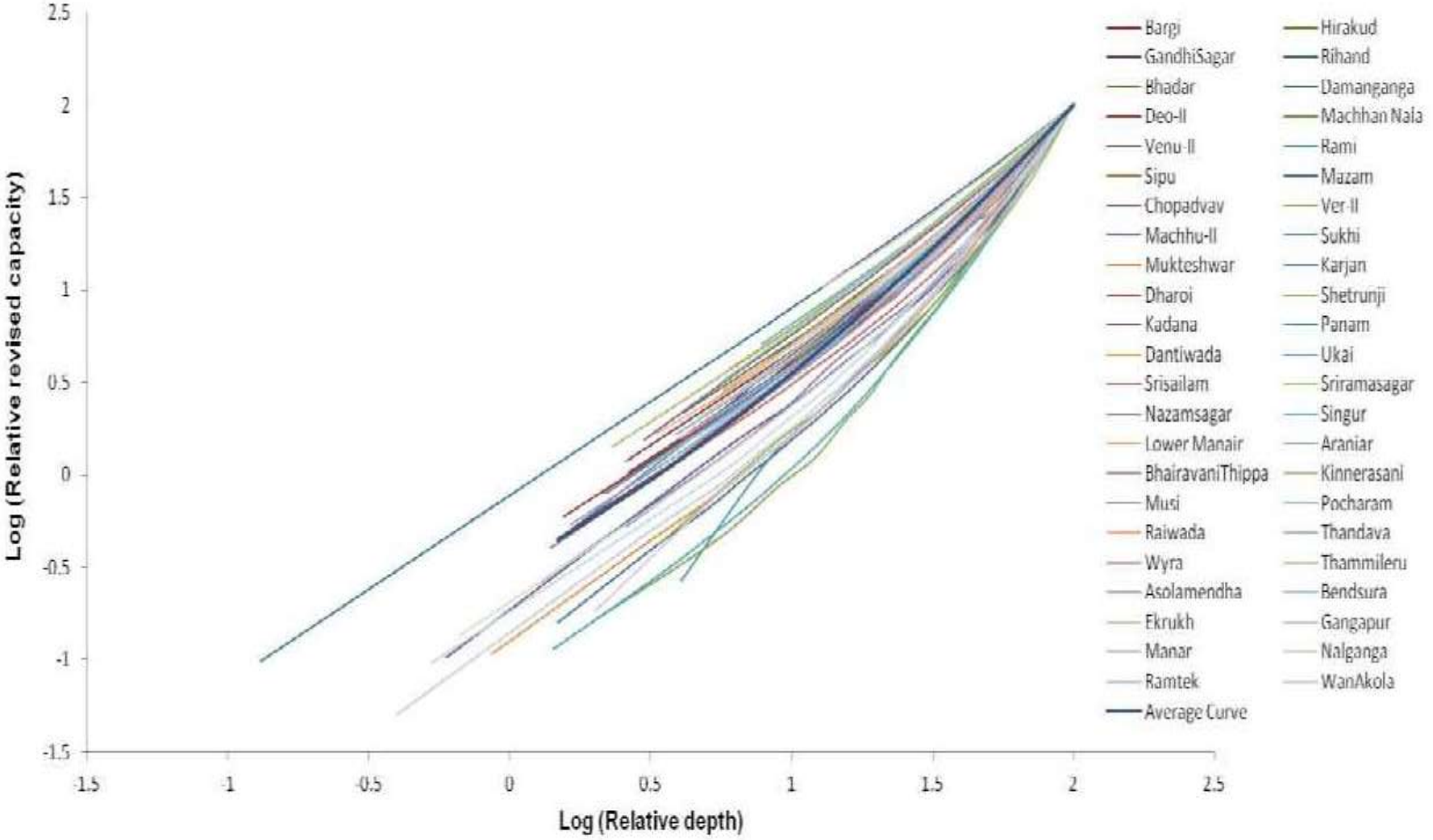


Figure – 4.24: Plot of relative revised capacity for various Indian reservoirs used in the analysis

From the plot of the average curve to the relative capacity curves under original and revised condition, it is observed that the same curve (with same mathematical equation) represents average characteristics in the two cases. The mathematical relation for the dimensionless area curve is:

$$\mathbf{Log_{10}\ (Relative\ capacity) = 0.2 * X^2 + 0.85 * X - 0.5} \qquad \textbf{...(4.2)}$$

where X is the relative depth of reservoir within the live storage zone (MDDL to FRL) above the MDDL. Using this relationship, reservoir capacity at any elevation within the live storage zone can be determined. In the subsequent sections, the use of this equation is demonstrated for a few reservoirs and the results are compared with the observed values.

4.5 Steps for Using Developed Mathematical Relationships

In the present study, mathematical relations have been developed to compute the reservoir area and capacity within the live storage zone of a reservoir (between MDDL and FRL). Data requirement for the method includes the area and capacity of the reservoir at MDDL and FRL. The steps of computation are as follows:

a) Total depth (m) within the live storage zone is determined and the relative depths at various elevations at which reservoir area and capacity are required are worked out.

b) Relative depth is converted to percent value and its Log_{10} is estimated. This gives the value of variable X.

c) For determining the area (sq. km) at any elevation, Equation-4.1 is used and the Log_{10}(Relative area) value is worked out. Similarly, for determining the capacity (MCM) at any elevation, Equation-4.2 is used and the Log_{10}(Relative capacity) value is worked out.

d) From the estimated value of Log_{10}(Relative area), relative area 'A_r' (as percent) is determined and the area 'A' at the specified depth is obtained by using the following equation:

$$A = A_r * (A_{FRL} - A_{MDDL})/100 + A_{MDDL} \qquad ...(4.3)$$

where A_{FRL} and A_{MDDL} are the reservoir areas (sq. km) at FRL and MDDL respectively.

e) In the same way, from the estimated value of Log_{10}(Relative capacity), relative capacity 'C_r' (as percent) is determined and the capacity 'C' at the specified depth is obtained by using the following equation:

$$C = C_r * (C_{FRL} - C_{MDDL})/100 + C_{MDDL} \qquad ...(4.4)$$

where C_{FRL} and C_{MDDL} are the reservoir capacities (MCM) at FRL and MDDL respectively.

4.7 Steps for Using Methodology Proposed by J. Mohammadzadeh-Habili et. al (2009)

J. Mohammadzadeh-Habili et. al (2009) have developed mathematical relationships for reservoir area capacity curves. The similarity between the natural logarithmic function curve and the reservoir capacity curve has been used to obtain the mathematical equation for dimensionless capacity curve. The obtained equation has only one unknown dimensionless parameter, named the "reservoir coefficient" *N* . The reservoir area equation and equation of reservoir coefficient are obtained by differentiating the reservoir capacity equation. This method approximates the Elevation-Area and Elevation-Capacity curves within the full range of reservoir depth. Data requirement for the method includes river bed level (m) at the dam site, reservoir area (sq. km) and capacity (MCM) at FRL. Though the details of the method can be reviewed in the paper, brief steps of methodology are described below:

a) Total depth (m) of the reservoir from river bed level to FRL is determined and the relative depths at various elevations at which reservoir area and capacity are required are worked out.

b) Reservoir Coefficient 'N' is worked out by using the following equation:

$$N = 2 * \ln(2) * C_{FRL}/(A_{FRL} * D_{FRL}) \quad ...(4.5)$$

C_{FRL}, A_{FRL}, and D_{FRL} are the reservoir capacity (MCM), area (sq. km), and total depth (in m from river bed level) at FRL.

c) Let 'y' be the intermediate depth above river bed at which capacity (C_y) and Area (A_y) are required. If y_m represents the maximum depth, C_m represents the maximum capacity, A_m represents the maximum area, and p (= y/y_m) represents the relative depth, then equations for C_y and A_y are given as follows:

$$C_y = C_m * [e^{(\ln(2)*p)} - 1]^{1/N} \quad ...(4.6)$$

$$A_y = 0.5 * A_m * e^{(p*\ln(2))} * [e^{(p*\ln(2))} - 1]^{(1-N)/N} \quad ...(4.7)$$

d) Using the equations 4.6 and 4.7, the reservoir capacity and area can be computed at any elevation above the river bed. It needs to be mentioned here that the method is quite sensitive to the specification of river bed elevation as it affects the reservoir coefficient and area capacity relationships.

In the present study, the developed mathematical relationships (within the live storage zone) and the method proposed by J. Mohammadzadeh-Habili et. al (2009) (in this study, it is referred to as ASCE method) have been used to investigate their applicability for Indian reservoirs. A number of reservoirs, for which the data requirements of the two methods could be met, have been selected and comparative plots of areas and capacities from the two methods have been prepared in conjunction with the original curves. It is seen that the two methods approximate the intermediate areas and capacities quite close to the observed values.

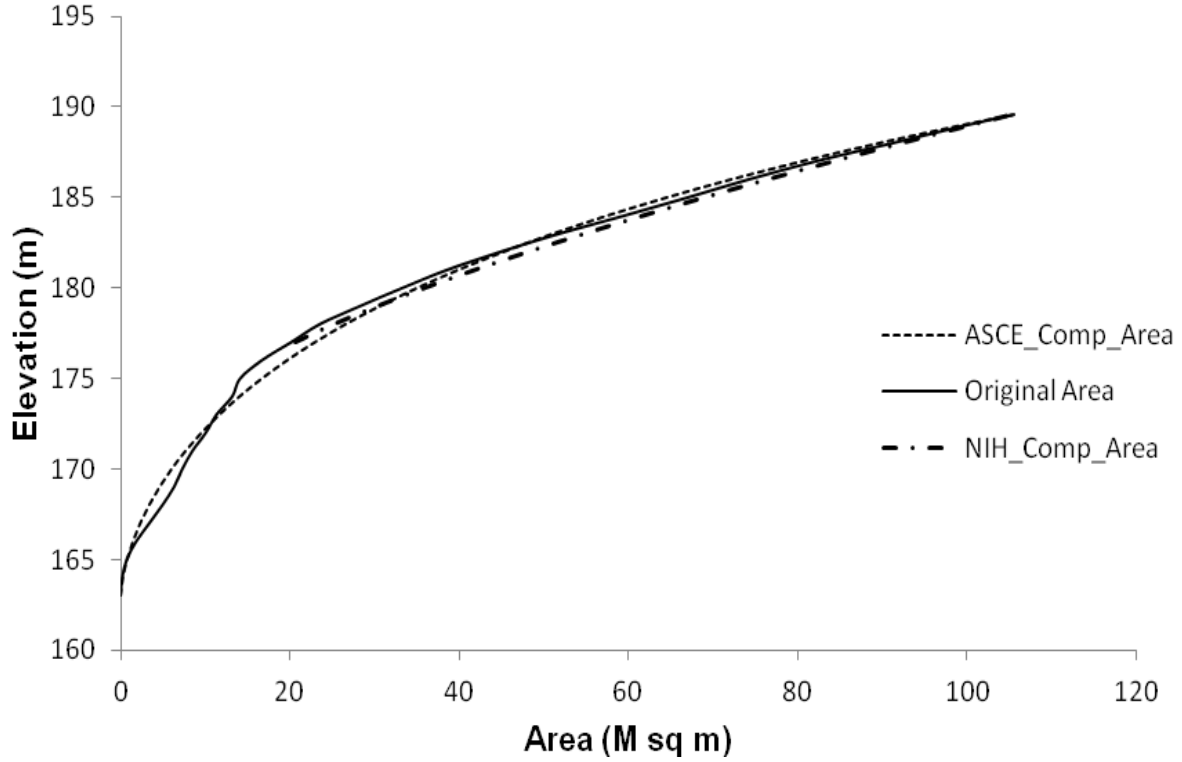


Figure – 4.25: Plot of observed and computed elevation - area curves for Dharoi reservoir

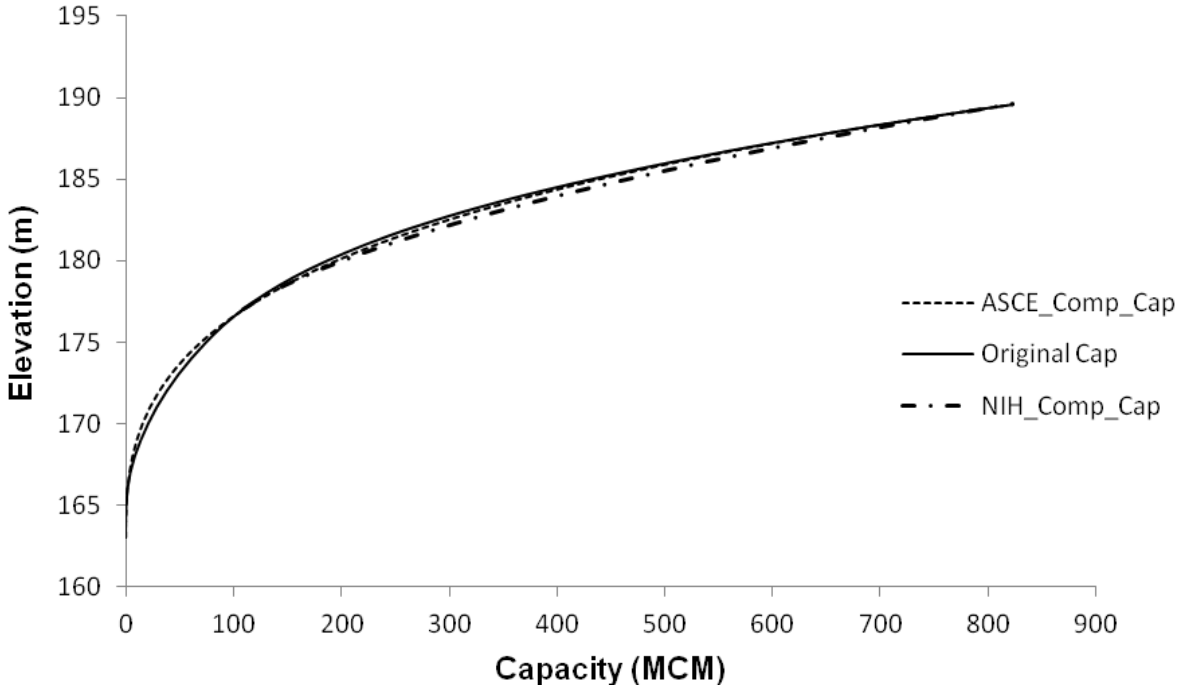


Figure – 4.26: Plot of observed and computed elevation – capacity curves for Dharoi reservoir

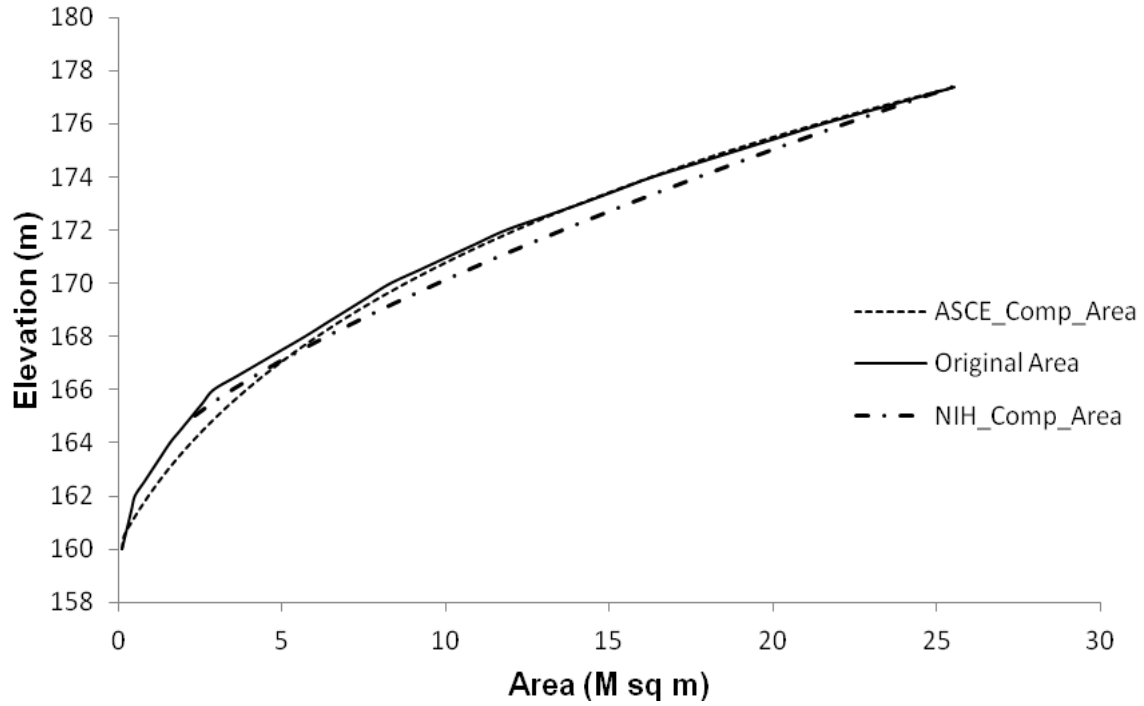


Figure – 4.27: Plot of observed and computed elevation - area curves for Guhai reservoir

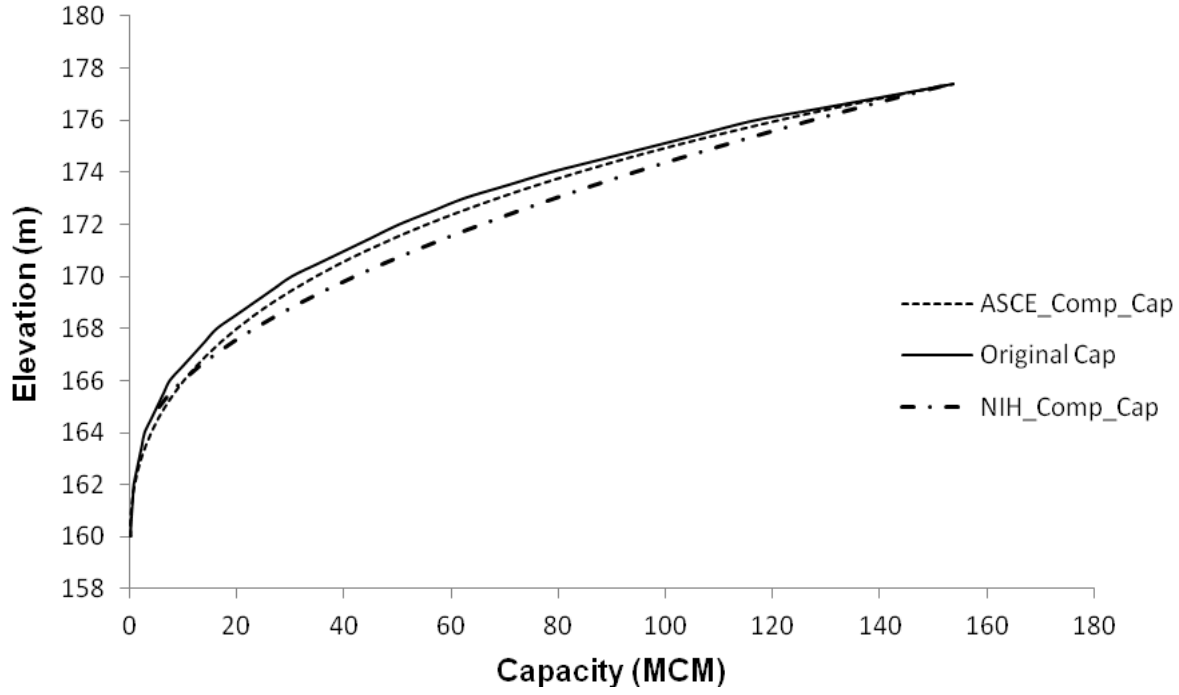


Figure – 4.28: Plot of observed and computed elevation – capacity curves for Guhai reservoir

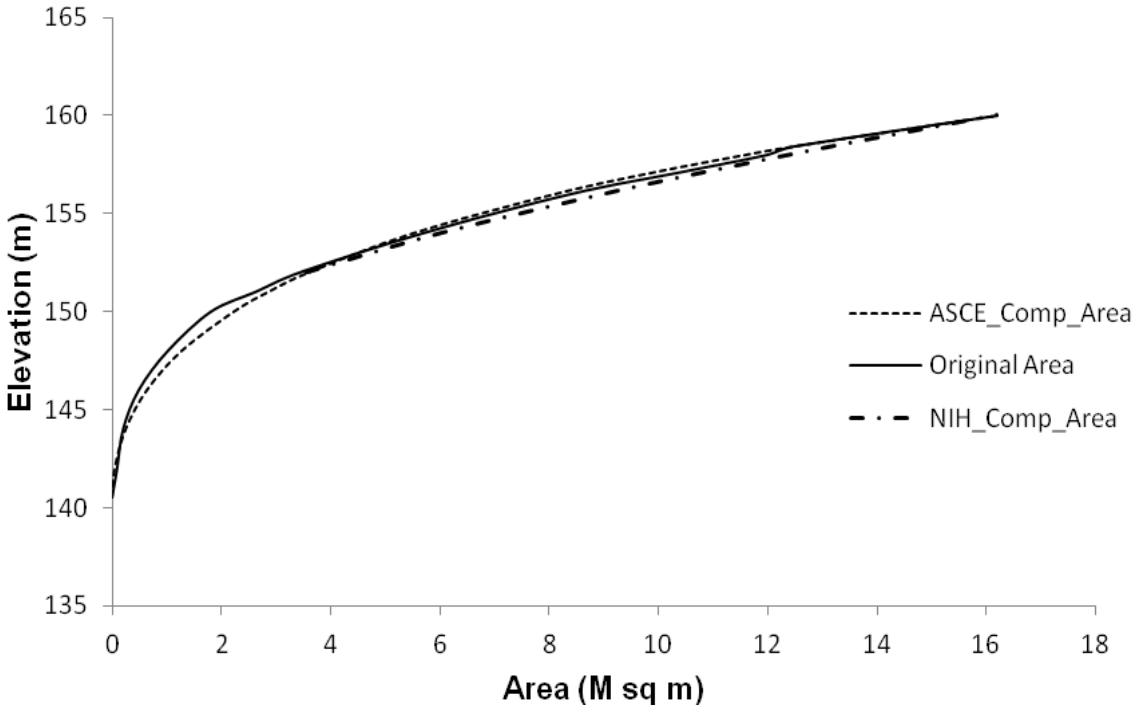


Figure – 4.29: Plot of observed and computed elevation - area curves for Mazam reservoir

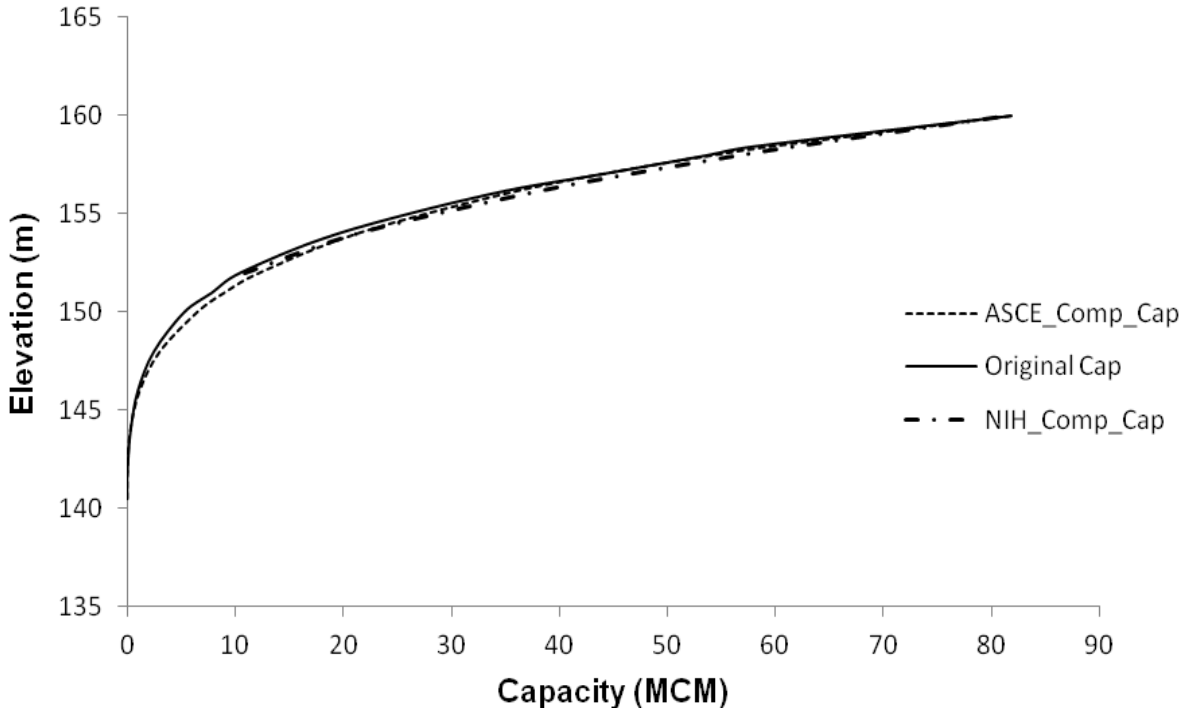


Figure – 4.30: Plot of observed and computed elevation – capacity curves for Mazam reservoir

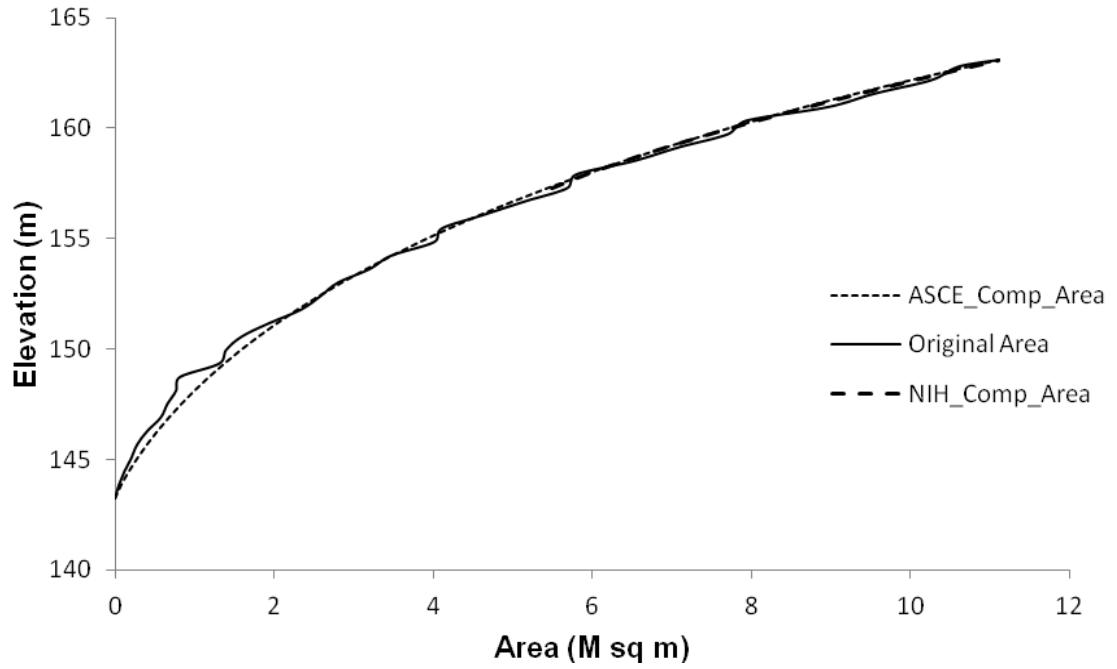


Figure – 4.31: Plot of observed and computed elevation - area curves for Meshwo reservoir

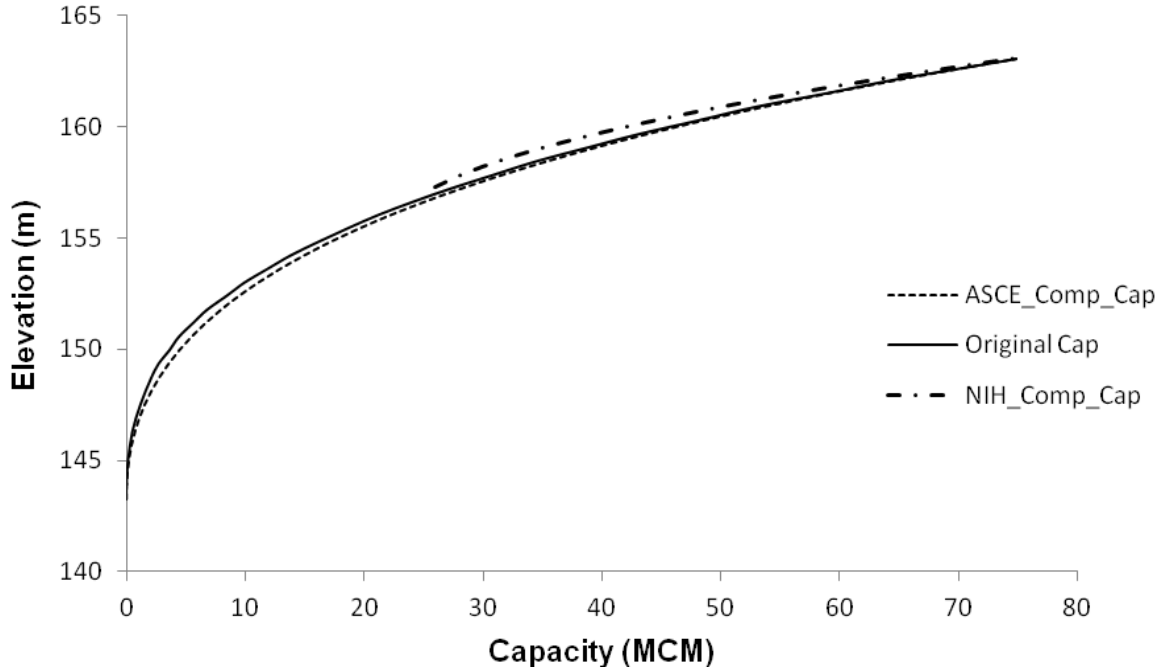


Figure – 4.32: Plot of observed and computed elevation – capacity curves for Meshwo reservoir

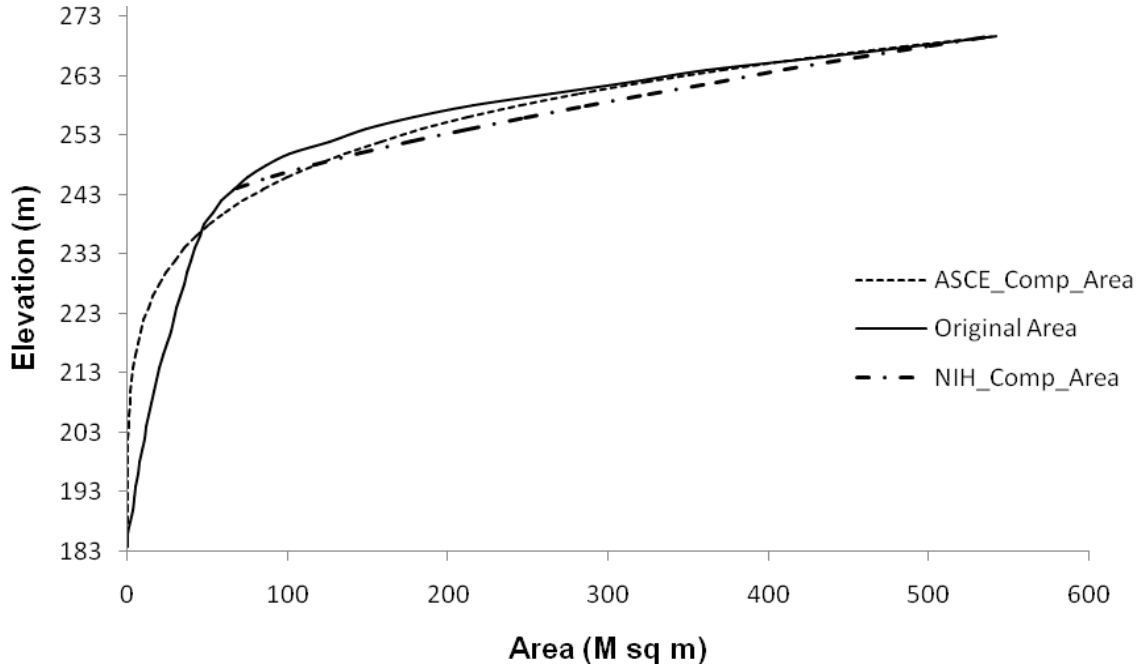


Figure – 4.33: Plot of observed and computed elevation - area curves for Srisailam reservoir

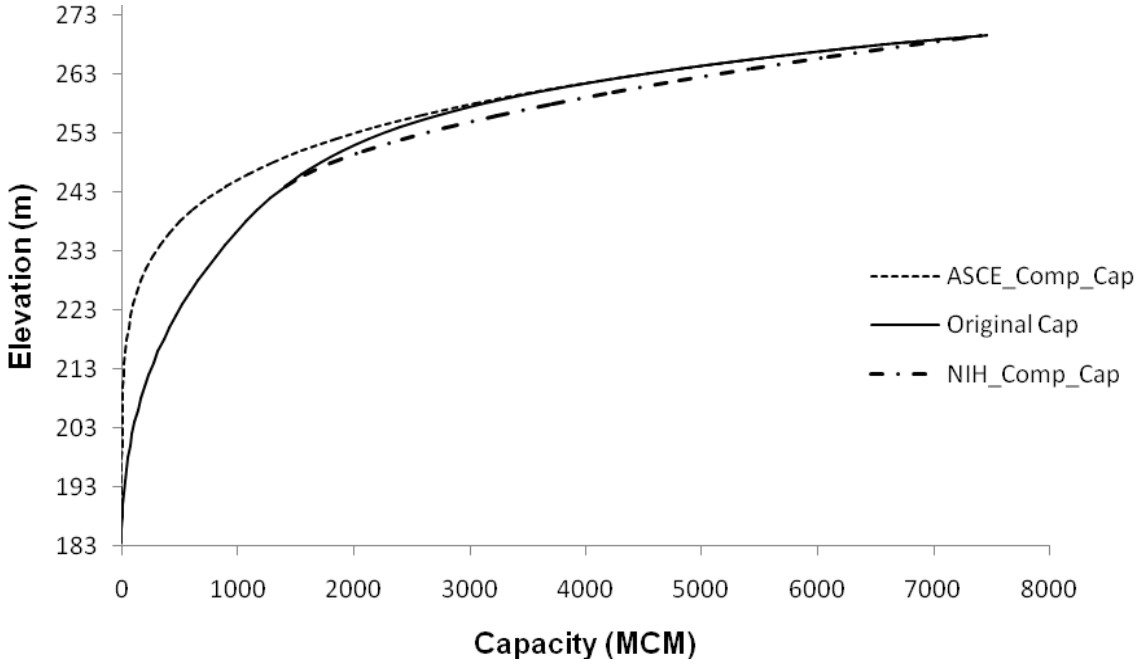


Figure – 4.34: Plot of observed and computed elevation – capacity curves for Srisailam reservoir

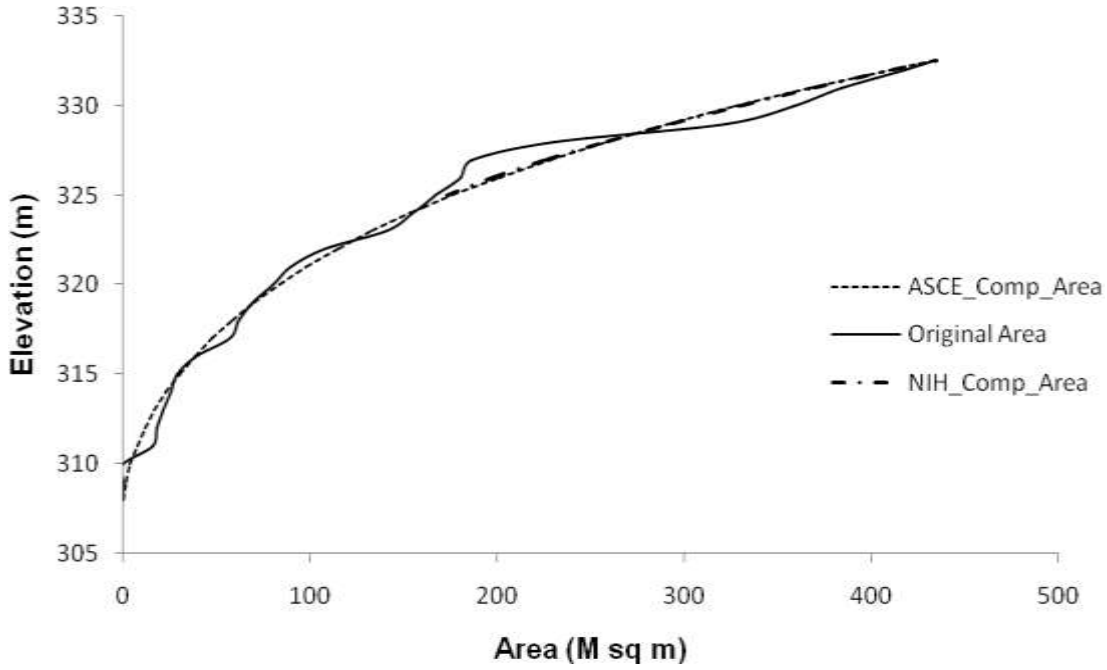


Figure – 4.35: Plot of observed and computed elevation - area curves for Sriramasagar reservoir

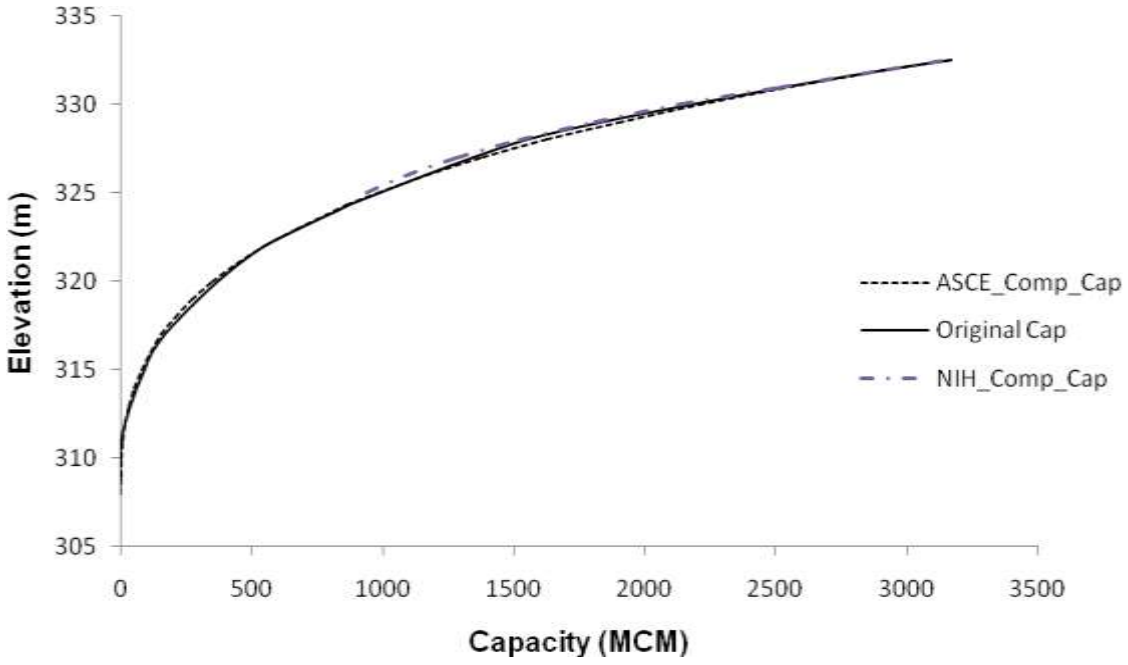


Figure – 4.36: Plot of observed and computed elevation – capacity curves for Sriramasagar reservoir

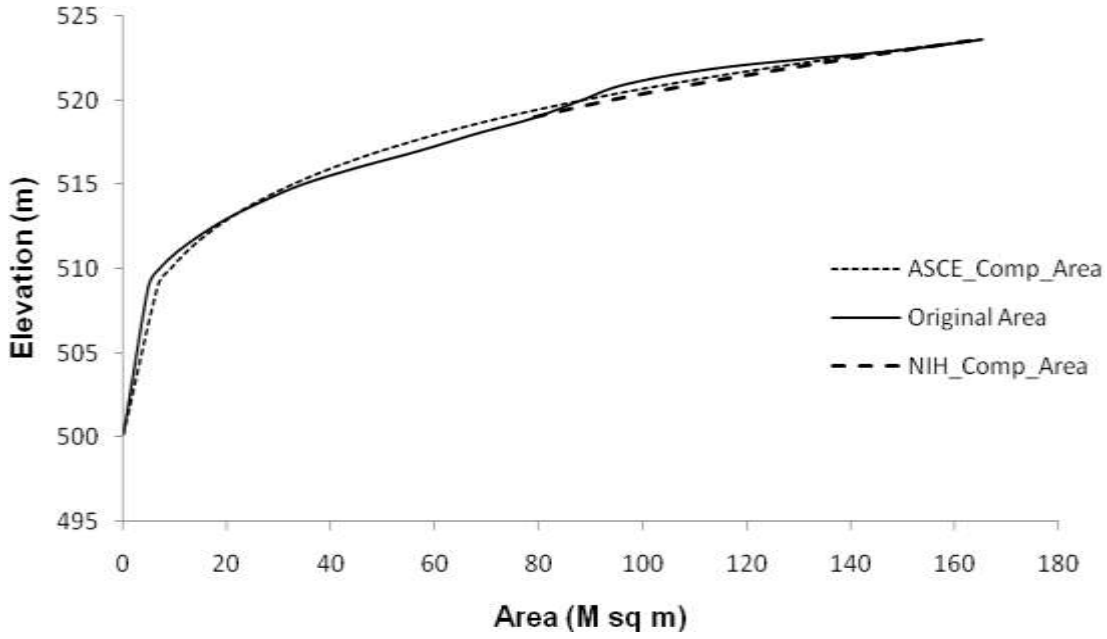


Figure – 4.37: Plot of observed and computed elevation - area curves for Singur reservoir

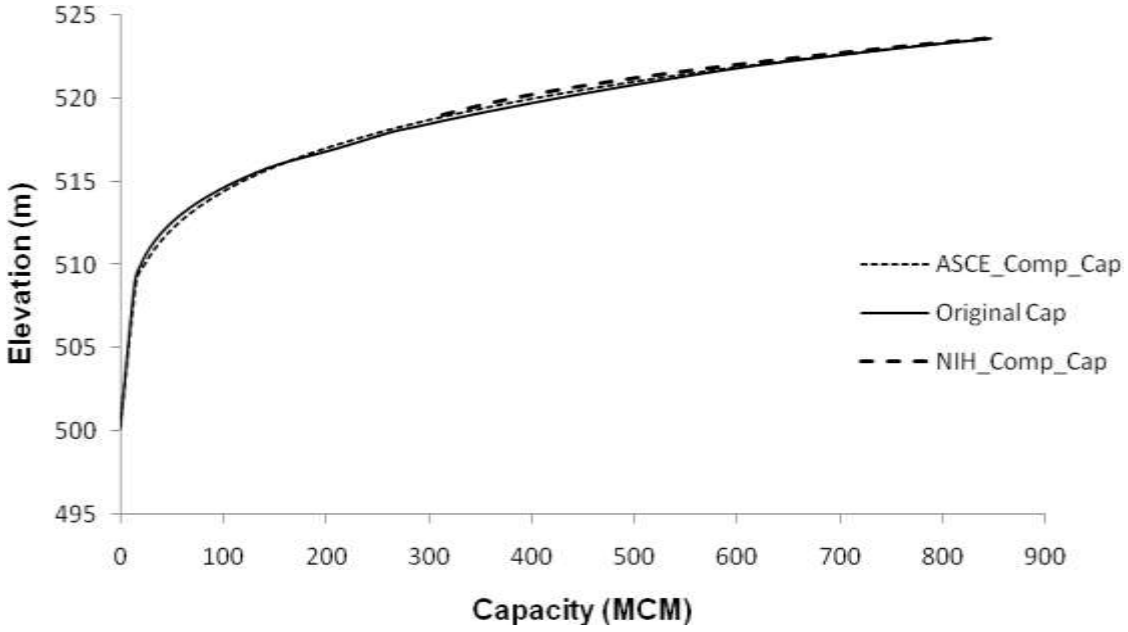


Figure – 4.38: Plot of observed and computed elevation – capacity curves for Singur reservoir

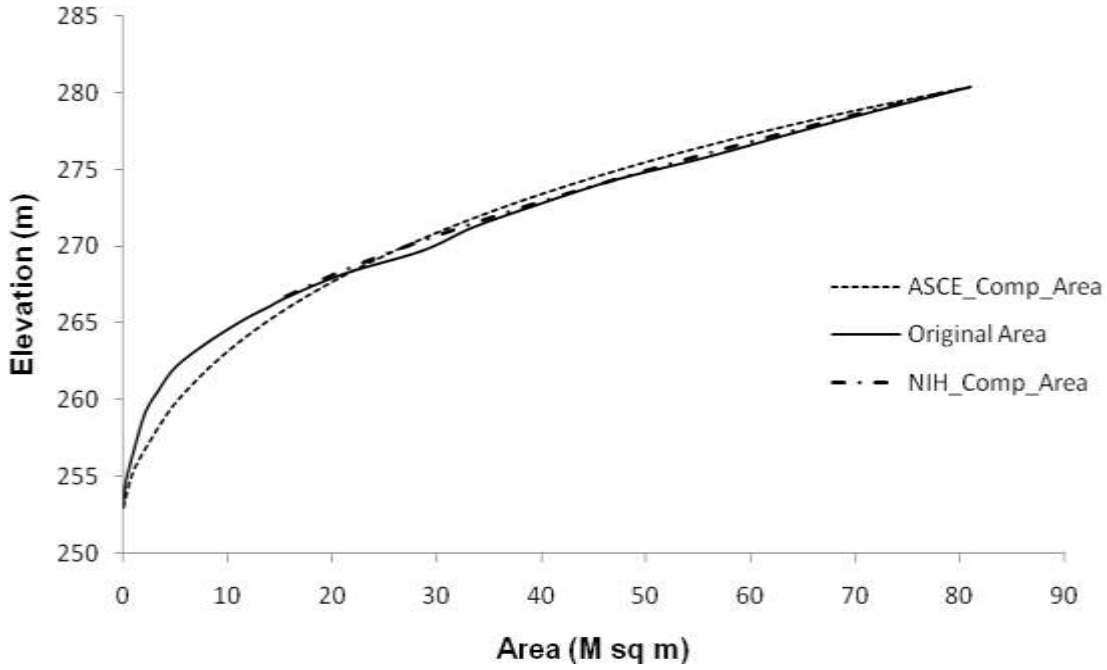


Figure – 4.39: Plot of observed and computed elevation - area curves for Lower Manair reservoir

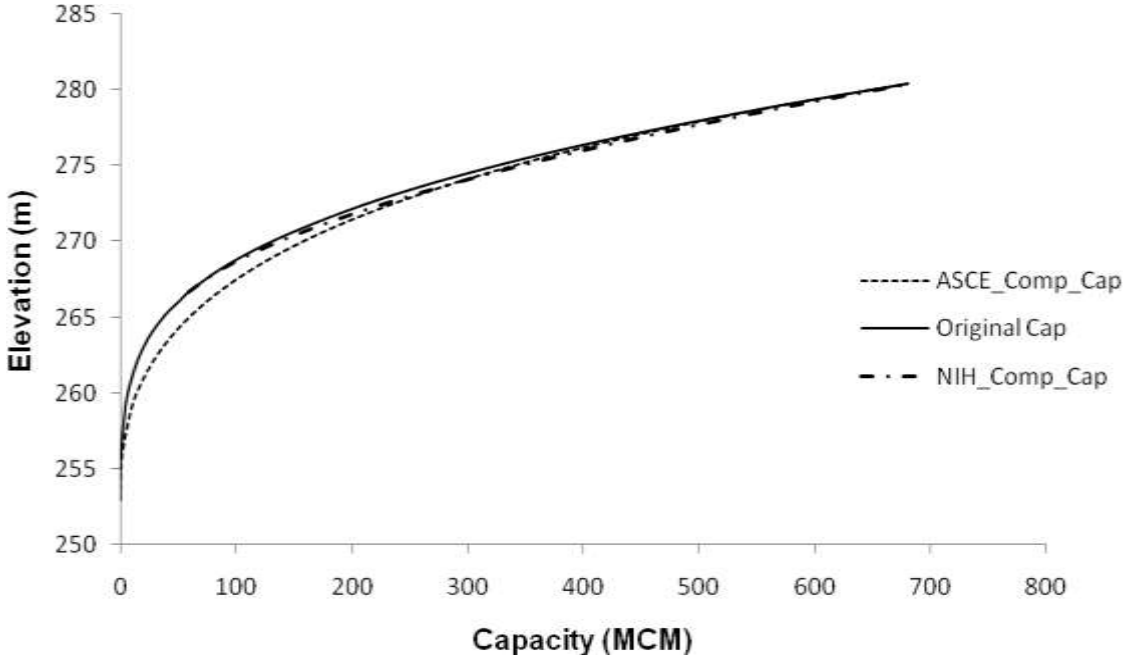


Figure – 4.40: Plot of observed and computed elevation – capacity curves for Lower Manair reservoir

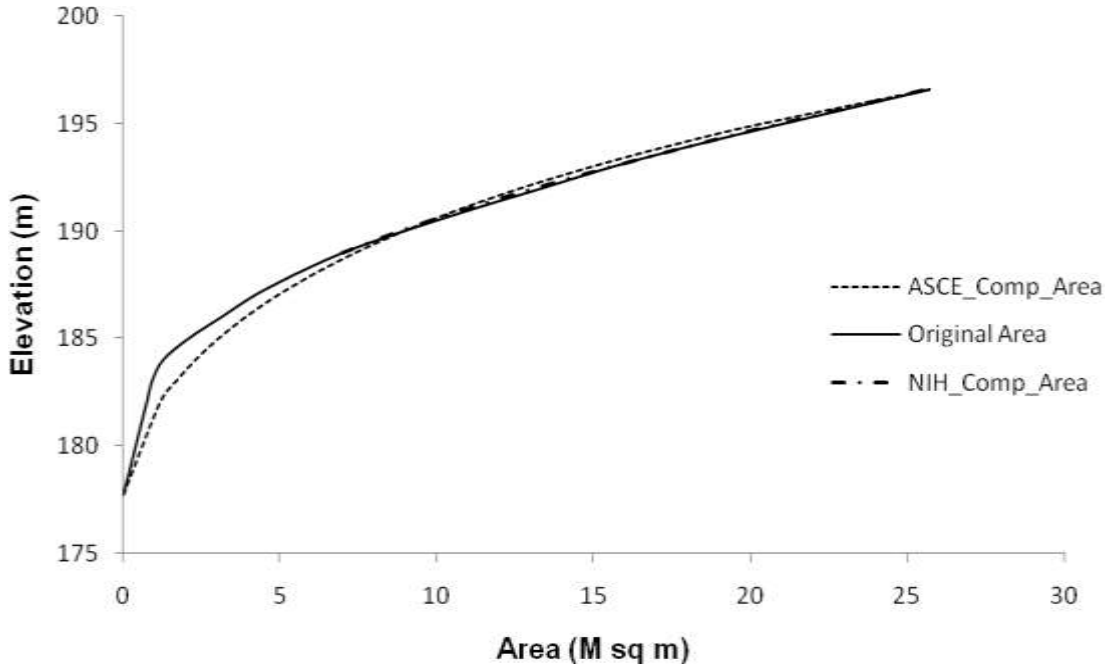


Figure – 4.41: Plot of observed and computed elevation - area curves for Musi reservoir

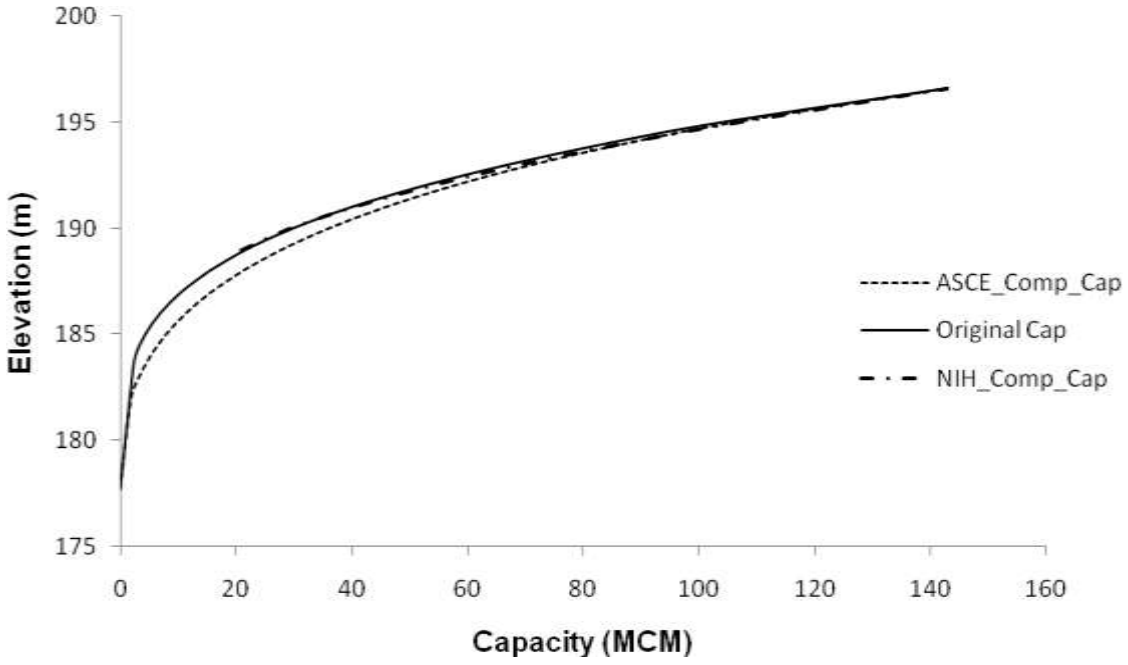


Figure – 4.42: Plot of observed and computed elevation – capacity curves for Musi reservoir

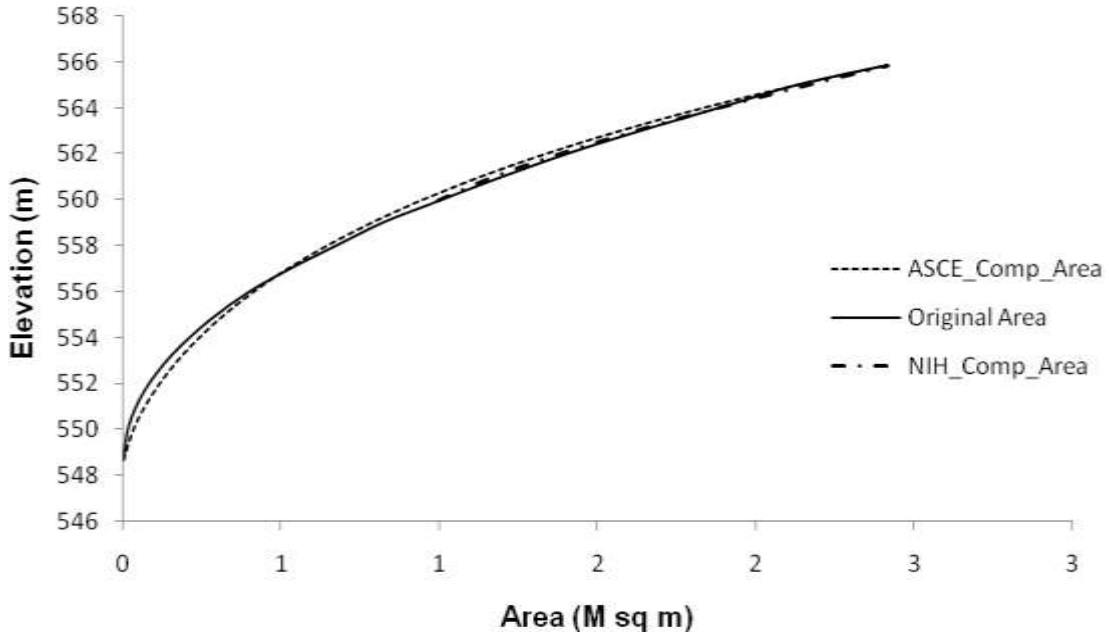


Figure – 4.43: Plot of observed and computed elevation - area curves for Bendsura reservoir

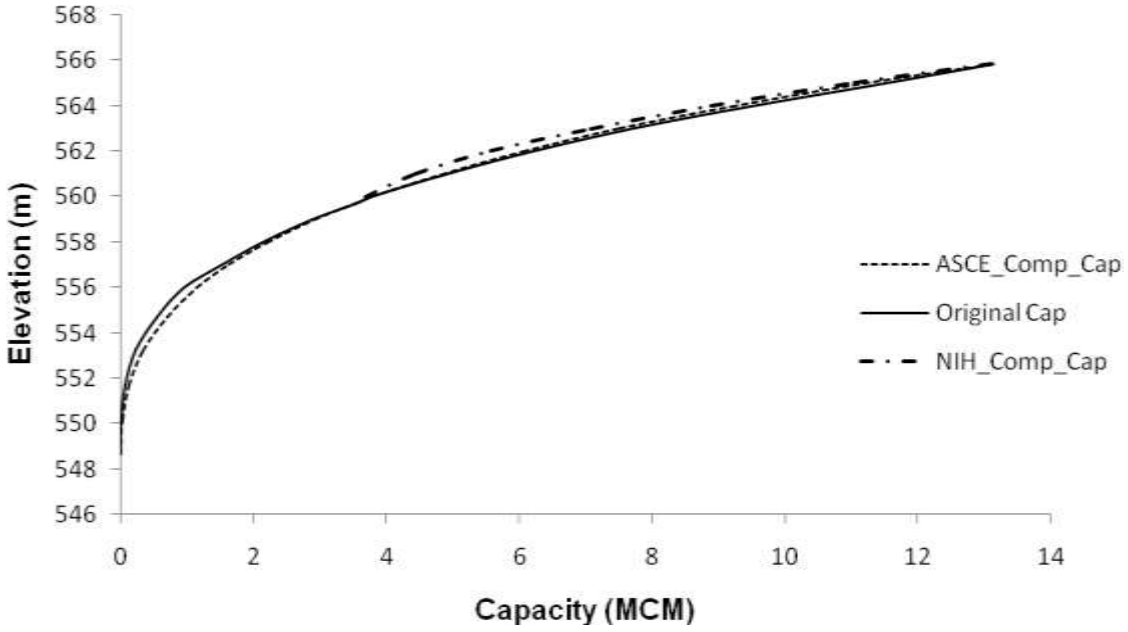


Figure – 4.44: Plot of observed and computed elevation – capacity curves for Bendsura reservoir

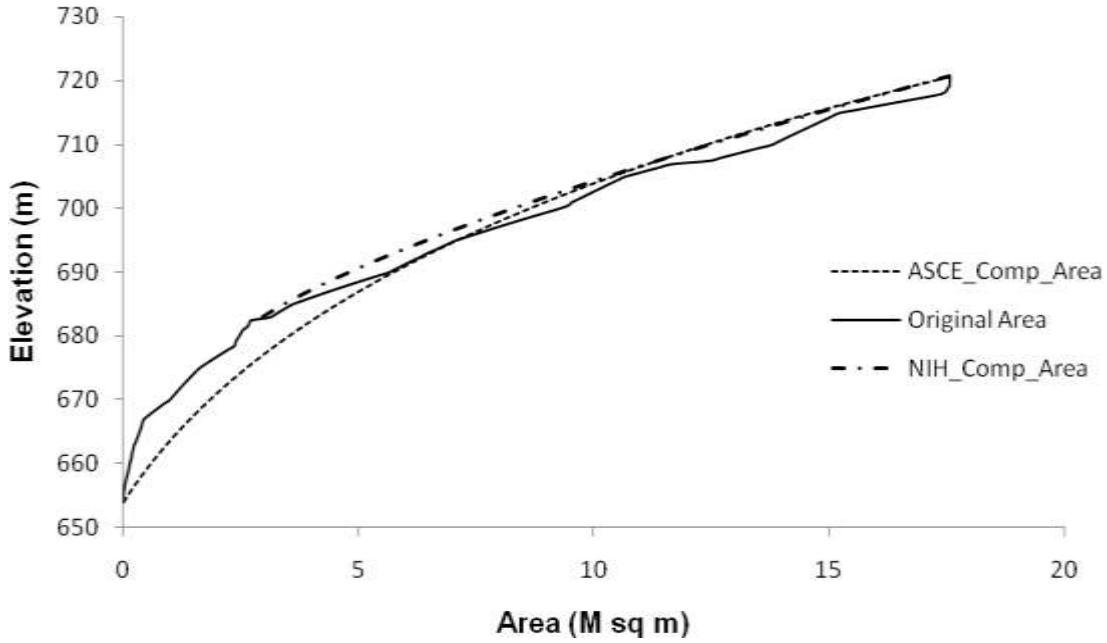


Figure – 4.45: Plot of observed and computed elevation - area curves for Dimbhe reservoir

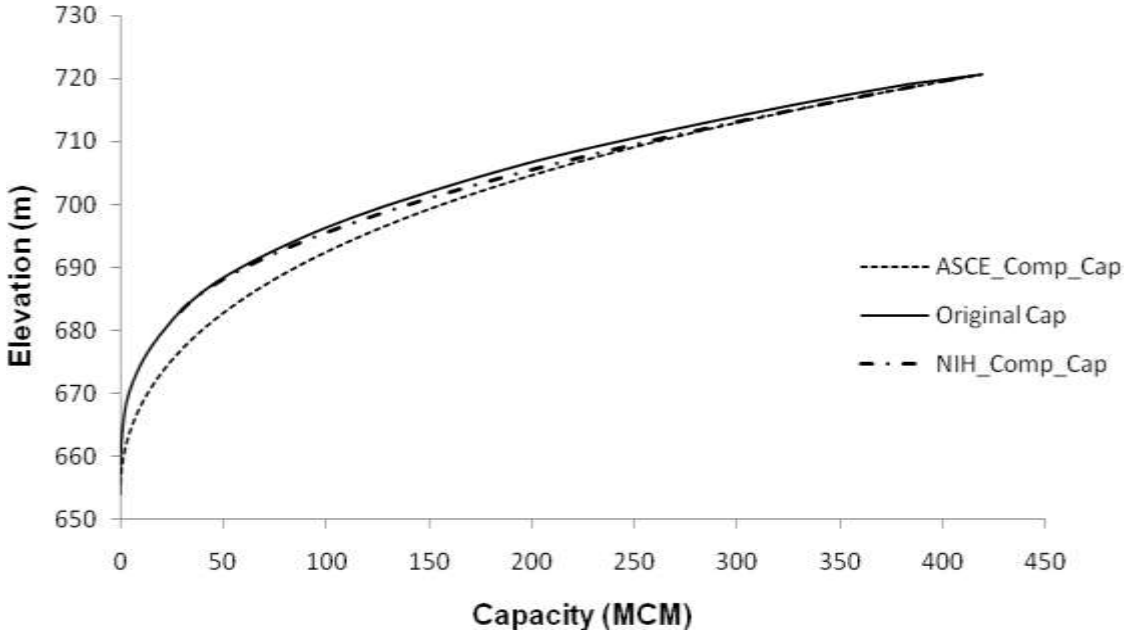


Figure – 4.46: Plot of observed and computed elevation – capacity curves for Dimbhe reservoir

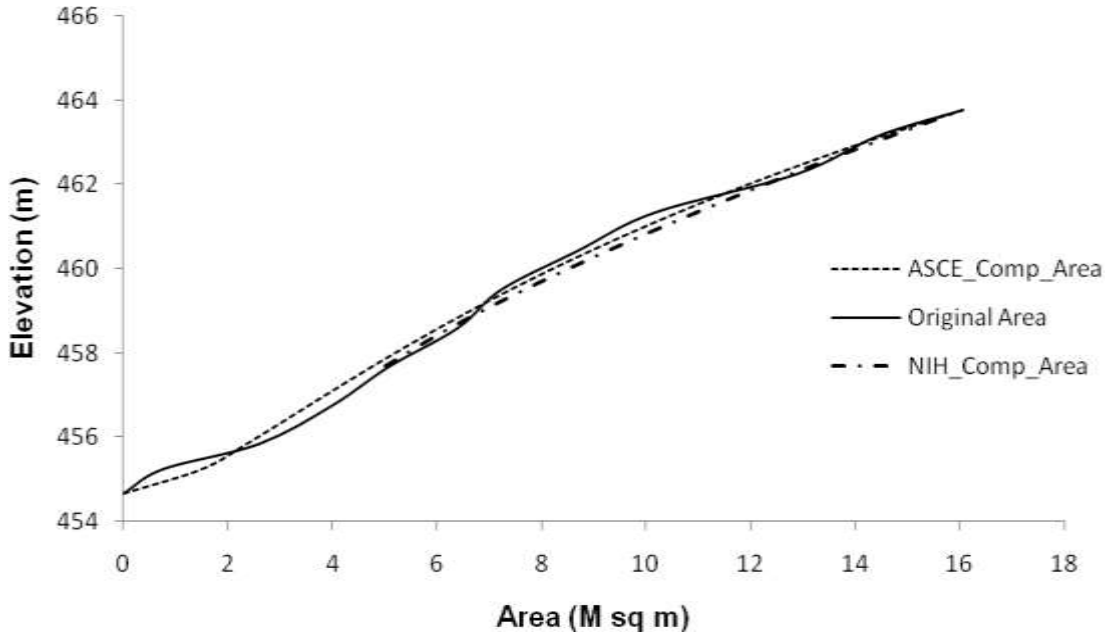


Figure – 4.47: Plot of observed and computed elevation - area curves for Ekrukh reservoir

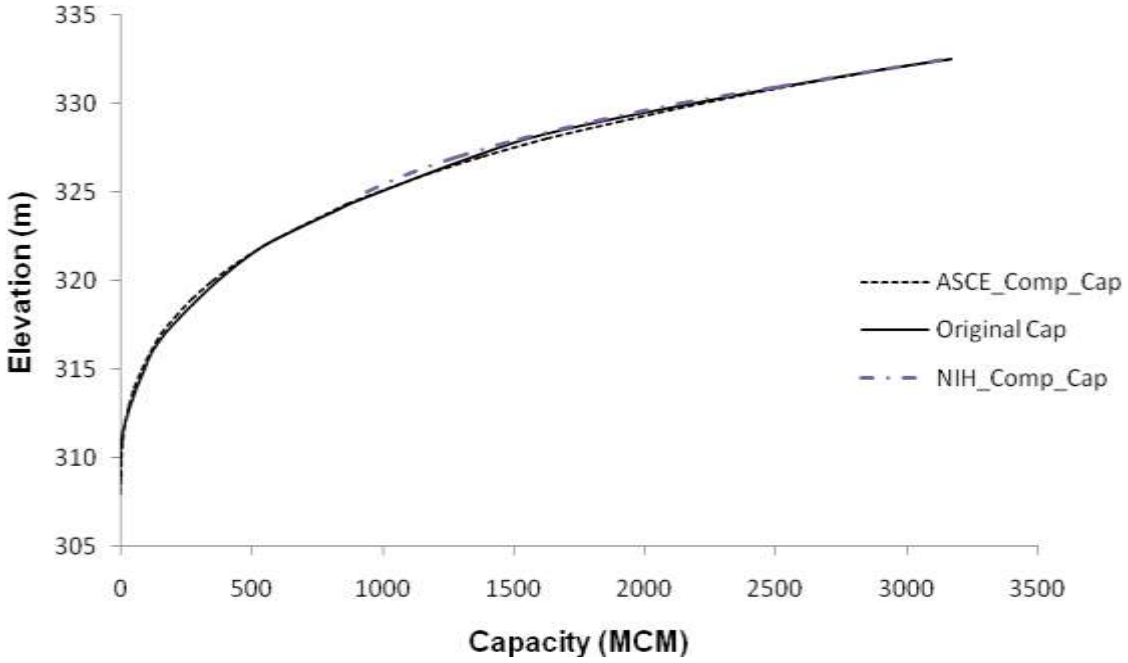


Figure – 4.48: Plot of observed and computed elevation – capacity curves for Ekrukh reservoir

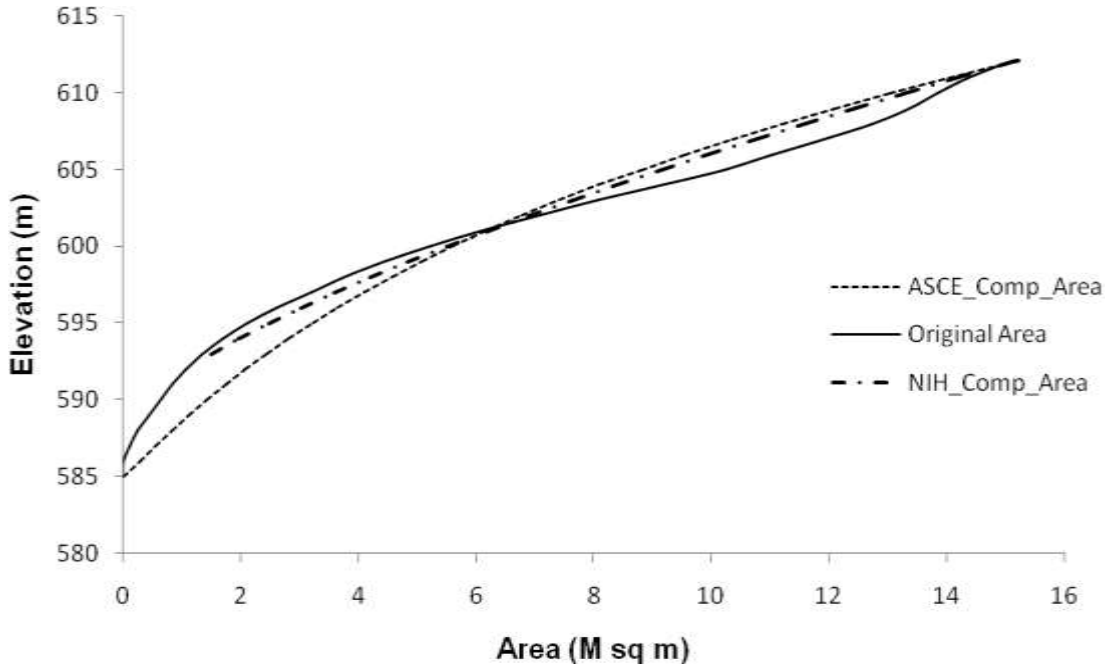


Figure – 4.49: Plot of observed and computed elevation - area curves for Gangapur reservoir

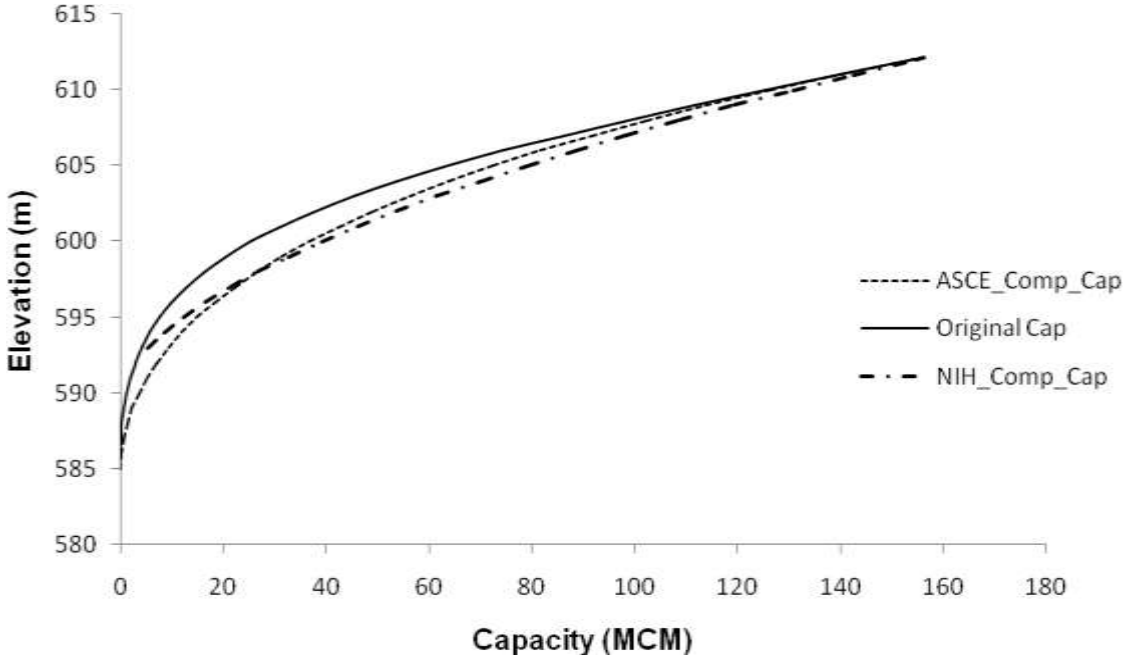


Figure – 4.50: Plot of observed and computed elevation – capacity curves for Gangapur reservoir

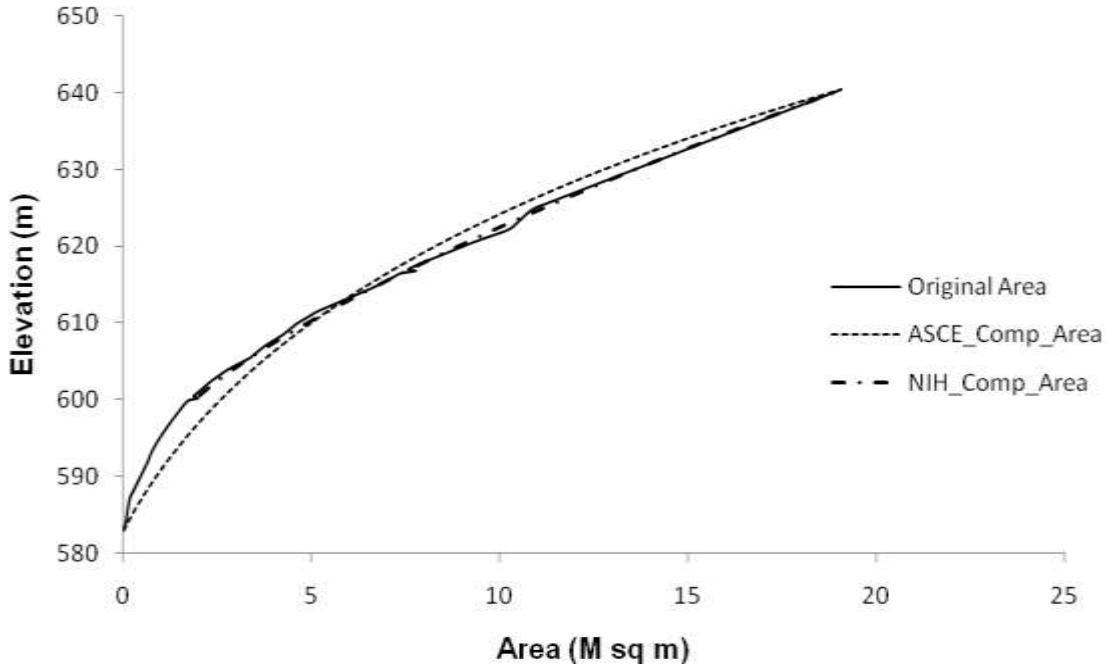


Figure – 4.51: Plot of observed and computed elevation - area curves for Warasgaon reservoir

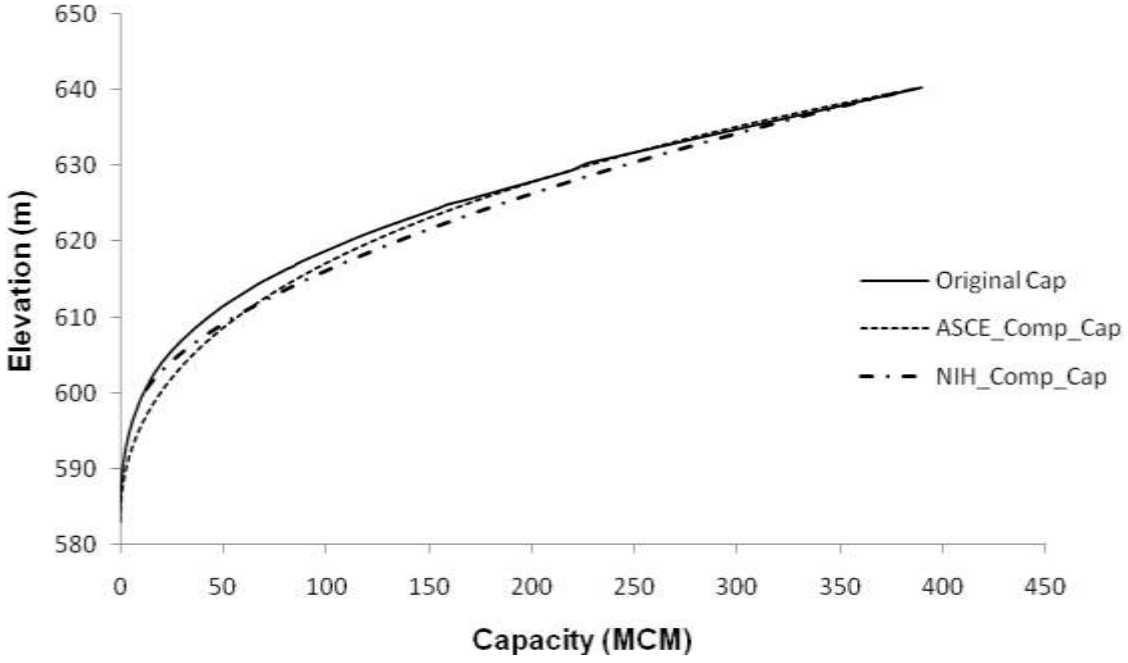


Figure – 4.52: Plot of observed and computed elevation – capacity curves for Warasgaon reservoir

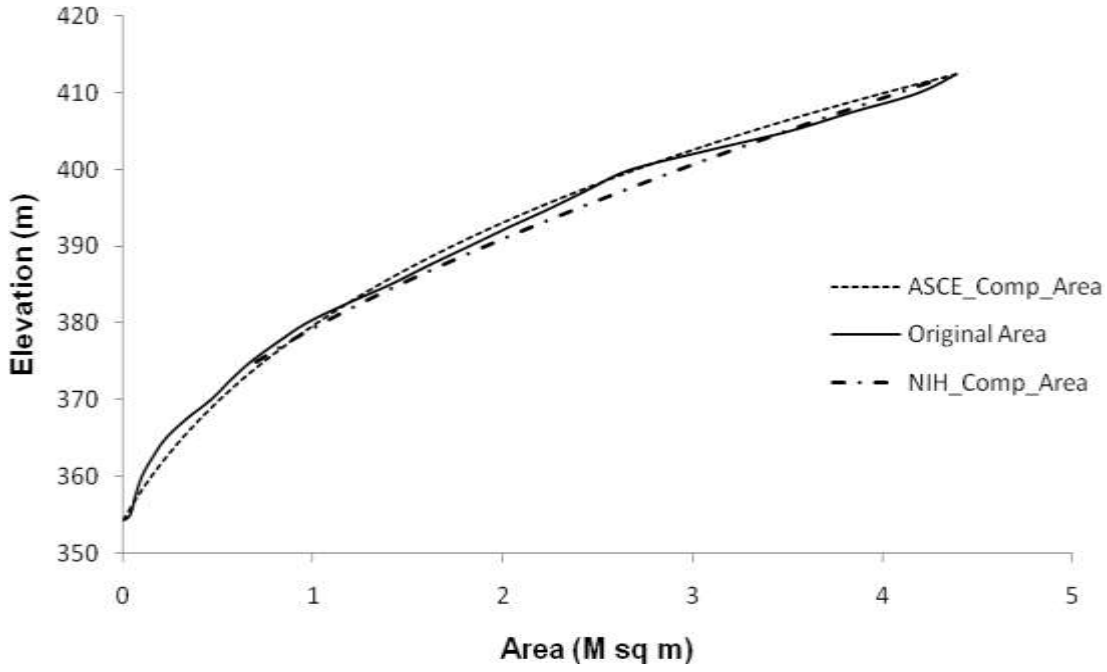


Figure – 4.53: Plot of observed and computed elevation - area curves for Wan Akola reservoir

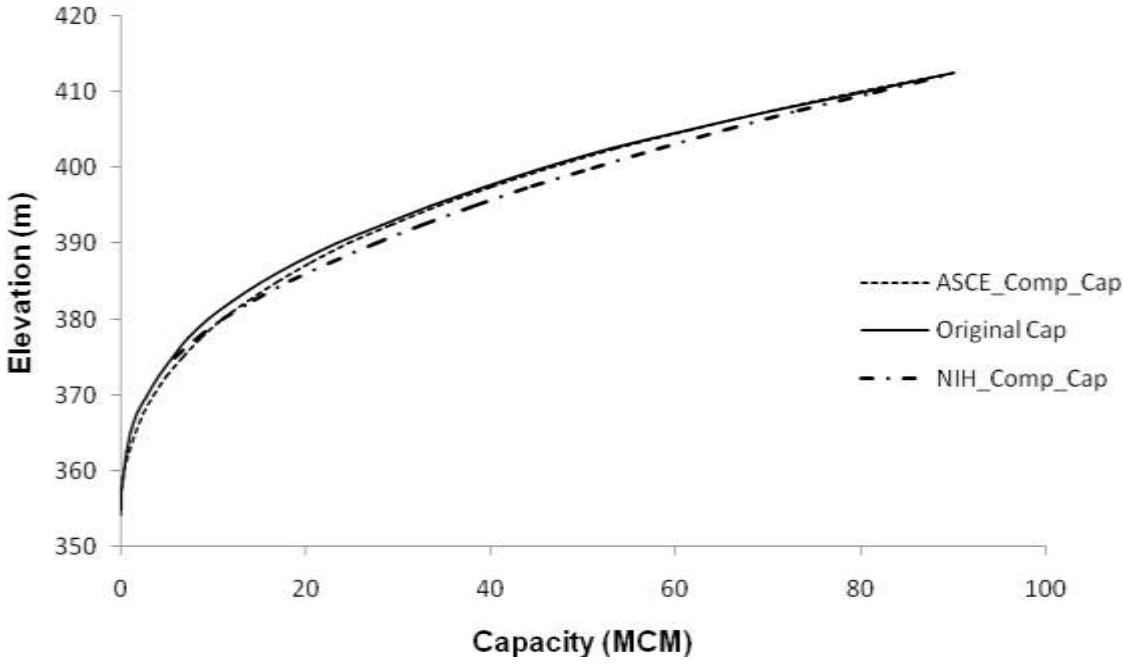


Figure – 4.54: Plot of observed and computed elevation – capacity curves for Wan Akola reservoir

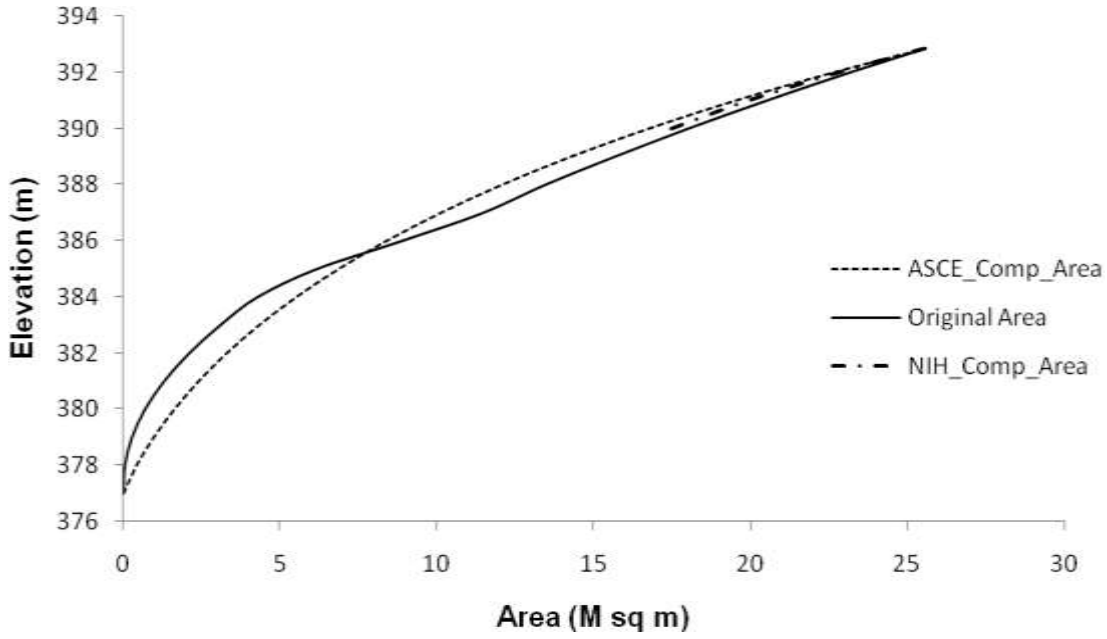


Figure – 4.55: Plot of observed and computed elevation - area curves for Manar reservoir

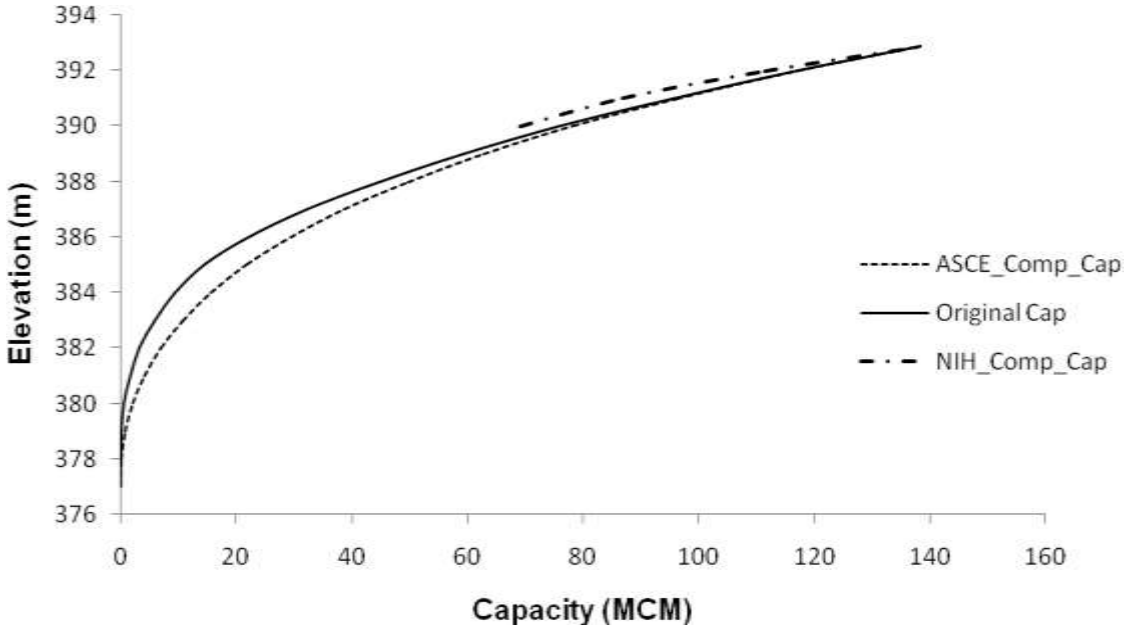


Figure – 4.56: Plot of observed and computed elevation – capacity curves for Manar reservoir

The results of the analysis show that both the methods estimate the reservoir areas and capacities at different elevations quite close to the observed values. Therefore, these methods can be used to approximate the elevation-area-capacity relationships for various kind of reservoir analysis, such as reservoir flood routing, reservoir operation, reservoir classification, and reservoir sediment distribution. Such methods can also be used in large scale river basin models having a number of reservoirs in the basin, thus avoiding the necessity of specifying EAC table for the reservoirs.

4.8 Limitations of the Developed Relationships

The limitation of the mathematical relationships developed in this study is that they are applicable only in the live storage zone of a reservoir. Another limitation of the mathematical relationships is that they do not take in to account the type of reservoir under consideration. Since average relationships have been worked out based on the analysis of large number of Indian reservoirs, the mathematical relationships may over or under-estimate the area and capacity values for some reservoirs depending on the location of their dimensionless area and capacity curves with respect to the average curve. Further refinement in the relationships is needed to take into account the type of valley also behind a reservoir.

On the other hand, ASCE method [J. Mohammadzadeh-Habili et. al (2009)] provides area and capacity estimates in the full range of the reservoir. It also accounts for the characteristics of a reservoir in terms of reservoir coefficient. However, this method is quite sensitive to the accurate specification of the river bed level at the dam site as it affects the reservoir coefficient and the natural logarithmic function curve, based on which the area and capacity equations have been established.

Finally, it needs to be mentioned that the developed equations only approximates the area and capacity curves. For those analyses which are highly sensitive to the accurate specification of areas and capacities at intermediate elevations, observed elevation-area-capacity tables may be used.

* * *

CHAPTER - 5
CONCLUSIONS

Effective management of water and related environment in a river basin requires an integrated and co-ordinated planning and utilization within the basin. In this context, the operation analysis of existing and proposed reservoirs forms an important part of the planning and management of water resources system. Elevation-Area-Capacity (EAC) curves of a storage reservoir are among the primary requirements for various kind of reservoir analysis such as reservoir flood routing, reservoir operation analysis, reservoir classification, and reservoir sediment distribution. A river basin may contain a large number of reservoirs/hydraulic structures. Though some of the general details like MDDL, FRL, and storage capacity/reservoir area at FRL and MDDL may be available from various sources (say, web site of India WRIS), it may be difficult to gather EAC tables for various reservoirs.

In this study, an effort has been made to characterize the elevation-area and elevation-capacity curves for Indian reservoirs. The elevation-area-capacity table of 78 Indian reservoirs have been used to develop such relationships. Original and revised elevation-capacity data of 42 reservoirs in the State of Gujarat, Maharashtra, and Andhra Pradesh have been provided by CWC. The data for 16 reservoirs have been collected from various past studies carried out at NIH. From the weekly newsletter of real-time available water storage in some major Indian reservoirs (published by CWC regularly), elevation – capacity table for 20 reservoirs has been generated. For all the reservoirs under consideration, the general details such as MDDL, FRL, year of construction, the name of river on which located, and catchment area have been taken from the web site of India WRIS (http://india-wris.nrsc.gov.in/wrpinfo) under the section of water resources projects.

Depending on the availability of type and range of original and revised EAC tables for different reservoirs, the reservoirs have been classified into four types: [Gorge (Type-IV), Hill (Type-III), Flood plain – foothill (Type-II), and Lake (Type-I)]. Dimensionless plots (relative depth vs. relative area or relative capacity) in the live storage zone of reservoirs in normal and Log scales have been prepared for each reservoir. Such plots have been clubbed for different types of reservoir for deriving representative unique mathematical equations for the area and capacity curves. The methodology has been programmed in MS-EXCEL. From the plots of relative depth vs relative capacity for different types of reservoirs (depending on value of ‘m’), it is inferred that different types of reservoirs do not occupy specific zones in dimensionless plots. Therefore, dimensionless plots of all the reservoirs have been combined to work out the average mathematical relationships. Based on the original and revised capacity survey estimates, relative area and relative capacity curves have been prepared for the original and revised conditions separately. From the available plots, average dimensionless curves have been plotted and generalized mathematical equations have been derived which can be used to approximate the elevation-area and elevation-capacity curves within the live storage zone of a reservoir using the basic details of the reservoir (such as reservoir elevation at MDDL/FRL and storage capacity/reservoir area at FRL and MDDL).

J. Mohammadzadeh-Habili et. al (2009) have developed area capacity relationships for reservoirs using the similarity between the natural logarithmic function curve and the reservoir capacity curve. The obtained equations also consider a dimensionless parameter, named as the "reservoir coefficient". This method approximates the Elevation-Area and Elevation-Capacity curves within the full range of reservoir depth.

In the present study, the developed mathematical relationships (within the live storage zone) and the method proposed by J. Mohammadzadeh-Habili et. al (2009) have been used to investigate their applicability for Indian reservoirs. A number of reservoirs, for which the data requirements of the two methods could be met, have been selected and comparative plots of areas and capacities from the two methods have been prepared in conjunction with the original curves. It is seen that the two methods approximate the intermediate areas and capacities quite close to the observed values.

However, there are some limitations of the developed approach. The mathematical relationships developed in this study are applicable only in the live storage zone of a reservoir and do not take into account the type of reservoir under consideration. Since average relationships have been worked out, the mathematical relationships may over or under-estimate the intermediate area and capacity values for some reservoirs depending on the location of their dimensionless area and capacity curves with respect to the average curve. On the other hand, method proposed by J. Mohammadzadeh-Habili et. al (2009) provides area and capacity estimates in the full range of the reservoir and also accounts for the characteristics of a reservoir in terms of reservoir coefficient. However, this method is quite sensitive to the accurate specification of the river bed level at the dam site as it affects the reservoir coefficient and the natural logarithmic function curve, based on which the area and capacity equations have been established.

Finally, it needs to be mentioned that the developed equations only approximates the intermediate area and capacity curves of a reservoir. For those analyses which are highly sensitive to the accurate specification of reservoir areas and capacities at intermediate elevations, observed elevation-area-capacity tables may be used.

* * *

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