1. INTRODUCTION

Nepal is endowed with enormous potential for hydro-power. Harnessing this potential is of the utmost importance for the country's development. The Kulekhani reservoir (also known as Indra Sarowar) is 216 hectares and resulted from the construction in the early 1980s of a 114 meters-high rock-filled dam. Hydro-power generation from the Kulekhani Project was developed in two phases. Kulekhani I (60 MW) costing US$ 68.0 million was completed in December 1982 and the Kulekhani II (32 MW) costing Yen 12.150 billion was completed in December 1986. The total installed capacity of 92 megawatts hydro-power of Kulekhani I and II accounts for about 45 % of country's hydro-power generation. (Nippon Koei Co., LTD., 1994).

The original gross capacity of the reservoir was 85.3 million m^3, of which 73.3 million m^3 is live and 11.2 million m^3 is dead volume. The reservoir, designed for a life-span of 50 years, is expected to last 100 years.

The watershed area lies in a fragile physiographic region which experiences intense monsoon rainfall events. The watershed area has been intensively used in response to meeting people's basic needs for food, fodder, fuelwood, fiber and shelter. As a result, the erosion processes in the watershed transport an enormous amount of sediment to the reservoir. Sedimentation monitoring plays an important role in developing strategy for watershed management and hydropower generation.

2. OBJECTIVE

The objective of long-term sedimentation monitoring is to create a database on sedimentation in the Kulekhani reservoir which could then inform predictions of how the sedimentation rate might affect the reservoir capacity and expected life-span of the reservoir. Corresponding strategies for managing the watershed and sediment could then be formulated in the interests of long-term generation of hydropower.

3. THE KULEKHANI WATERSHED

The Kulekhani watershed area covers 125 sq km of Makwanpur District, in Nepal's Central Development Region, about 30 km south-west of Kathmandu (see Fig 1). The watershed area has a monsoon climate with an annual rainfall of about 1400 mm. About 80 % of the total rainfall occurs between June to September each year (see Annex I).

The outlet of the Kulekhani Reservoir is at about 1500 meters elevation and the south-western ridge of Palung Khola marks the summit at 2621 m. Tasar, Bisingkhel and Chitlang Kholas are the major tributaries of the reservoir. The average slope of the tributaries range from 1.2 % to 21.3 %.

Agriculture constitutes about 42 % of the watershed area, forestry constitutes about 44 %, shrub-land covers about 9 % and grazing about 2 %. The reservoir, rock field, landslides and residential area cover about 3 %. Out of 42 % agricultural land, about 82 % is sloping (Bari land) terrace and about 18 % is level and valley terraces (Khet land) (see Table 1. IWMP, 1992.)

Some 9 % of the watershed area is steeper than 60 % slope and about 52 % of the watershed area falls into the slope category 31-60 %. Of the remaining area, 28 % has slopes of 16-30 %, 9 % has slopes of 3-15 % and 2 % is lake and wetland.(see Table 2. IWMP, 1992).

Figure 1. Location Map of Kulekhani Reservoir and Watershed Areas.

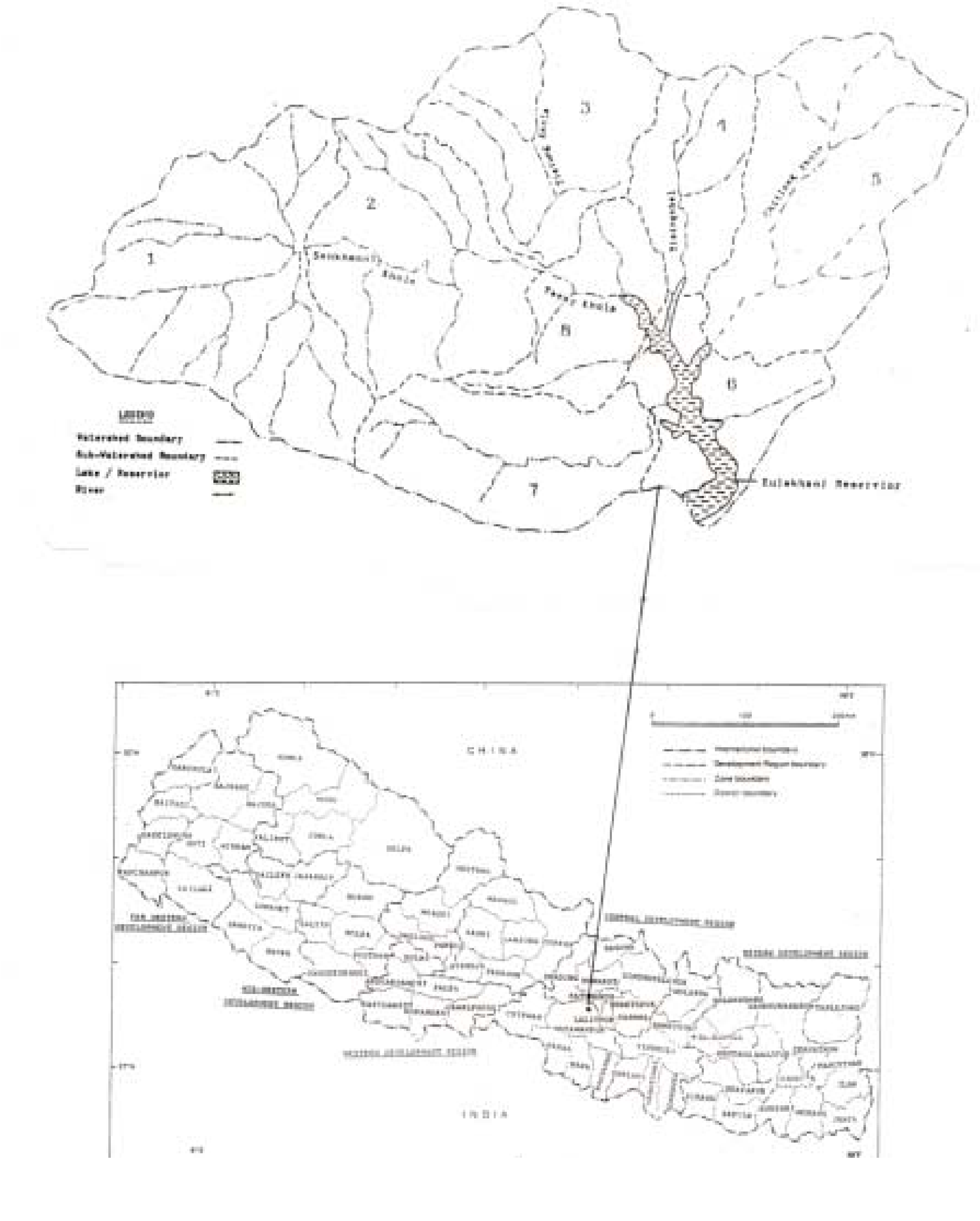


Table 1. Land-use in the Kulekhani Watershed (1991).

Land-use Category	Area in ha.	%
Sloping Terrace	4254	34.0
Level Terrace	237	1.9
Valley Terrace/Fans/Tars	713	5.7
Forest	5455	43.6
Shrub-land	1147	9.2
Grazing and grass lands	200	1.6
Barren / Rock Field	50	0.4
Lake	216	1.7
Gullies / Landslides	18	0.1
Others	210	1.7
Total	12500	100

Source : IWMP, 1992.

Table 2. Slope Status of Kulekhani Watershed Areas.

Slope Category	Slope in percent	Percent
I	< 15	9
II	16 - 30	28
III	31 - 60	52
IV	> 60	9
Lake / wetlands		2
Total		100

4. SEDIMENTATION SURVEY

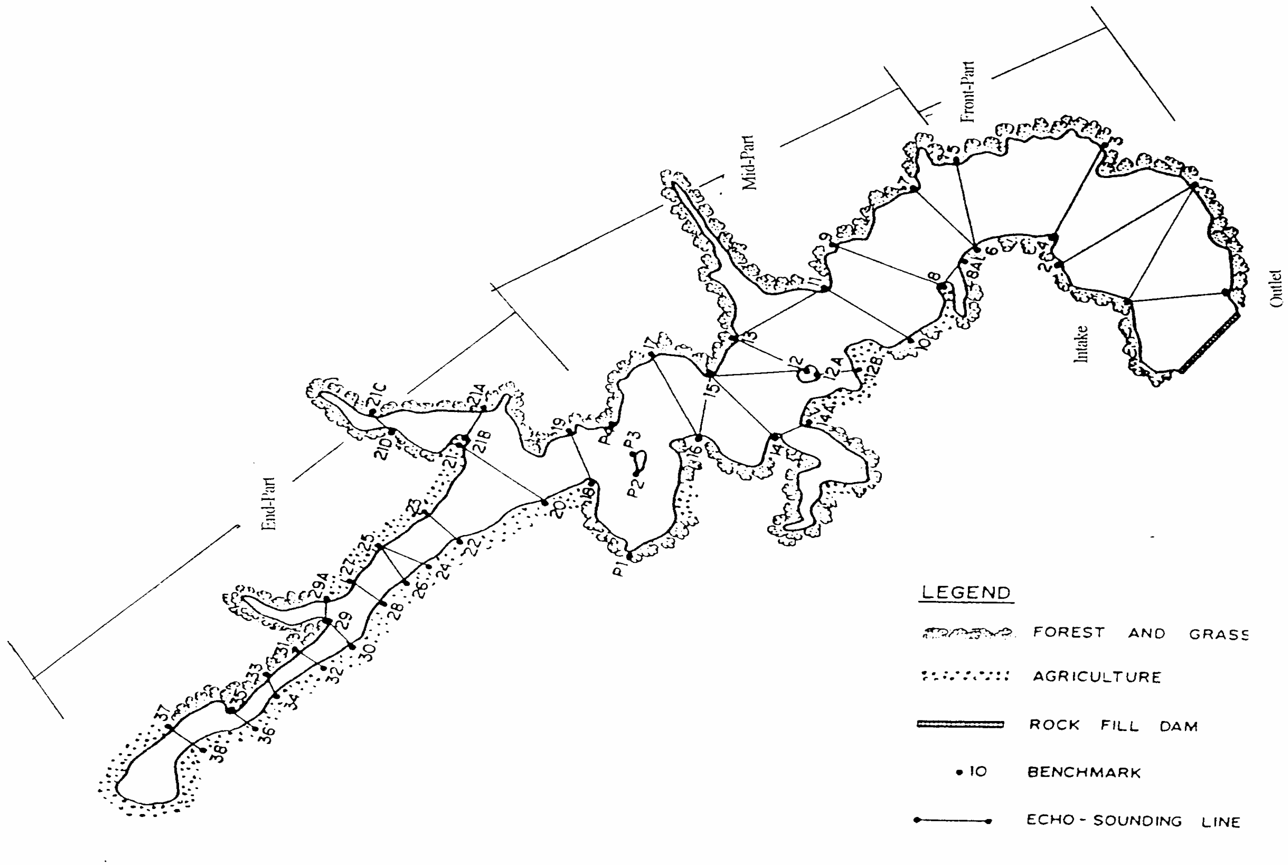
The Department of Soil Conservation carried out sedimentation surveys in March and December 1993, October 1994 and November 1995 using 18, 30, 32 and 39 line of measurements. The base map of the reservoir was prepared from enlarged aerial photographs taken in 1986. The distances of survey lines were measured using electronic total stations (ETS) instrument. The benchmarks and survey lines are shown in Figure 2.

A similar survey was carried out in 1989 by the Nepal Electricity Authority (NEA) which measured 19 cross sections. However, the inability to locate most of the benchmarks has not permitted comparisons to be made with subsequent surveys. NEA carried out a further survey in November 1995.

4.1. METHODS

The depth of water in the reservoir is measured from a row-boat with an echo-sounding instrument. The measured water depth is related to the reference water level (i.e. 1530.20 m). Water levels during the surveys are given in Annex II. Average water depth is computed for each cross-sectional profile, shore to shore, using the reference water level (1530.20 m, which is also the designed highest water level). Any decrease in water depth indicates deposition (siltation of the reservoir) whereas any increase in water depth indicates erosion. The sediment deposition or erosion is computed by multiplying the mean of the average water depths of two cross-sections by the area of the reservoir surface between those two cross-sections (Method I). A bathymetric map was prepared. The gross capacity of the reservoir is also computed by multiplying the mean of the average water depths of two contour lines by the area of the reservoir surface between those two contour lines using the bathymetric map (Method II).

Figure 2. Position of Benchmarks and Survey Lines, Kulekhani Reservoir, November 1995.



It is believed that the method I is more realistic for estimating the sediment deposition as this will minimize the errors resulted other than average water depth and reservoir surface areas. Whereas method II is considered to be more realistic for computing the gross capacity of the reservoir, since there is a significant difference in gross capacity of the reservoir whenever the number of survey line changes.

The instrument used was a micro-processor-controlled depth recorder (Echo-sounding) of the type ROYAL RF-350A. The manufacturer is Fuji Royal Co., Japan. The recorder works at a high frequency of 200 kHz.

The positioning of the survey line is fixed by stretching a rope between bench marks so that measurement can be made along the same fixed line year after year. The rope is marked at 25 meters interval and these positions are recorded during the echo-sounding survey. This ensures the location of the measurements with reference to the bench marks. The sounding is carried out during calm (windless) weather to assure easy boat handling and accurate measurements along the straight line of the rope.

4.2 LIMITATIONS AND ERRORS

The echo-sounder is a very precise instrument for measuring water depth. However, some errors may occur due to differences in site conditions. The instrument was calibrated by comparing manual readings with the depth measured by the echo-sounder. Calibration of the instrument in another lake (Phewa Lake) gave an accuracy within the range of plus / minus 10 cm. The instrument was calibrated at about 40 m depth in Kulekhani Reservoir. Results in one case were 3 % higher, and in two cases about 1 % lower, than manual readings (see Annex III). However, manual depth measurement in the absence of proper equipment and stagnant positioning of the boat are major difficulties of calibration.

The calibration of the instrument should be carried out frequently, if possible for each section. However, in the lack of proper equipment this was not done. Also, holding of the boat while calibration has been the major practical difficulties. Considering the field situation while calibrating the instrument, it is believed that the error will be only plus / minus 1 percent. This instrument error was not considered in stating the results.

The reservoir bed is steep and rugged, thus 39 cross-sectional profile measurements are insufficient for producing a bathymetric map, estimating the volume and, thereby, the degree of sedimentation. Also, any error in the positioning of the boat, even by a few meters, may cause a significant error in the measurement of water depth. This error is more prominent close to the shore.

The clarity of the graph produced by echo-sounding depends on nature of the material at the surface of the reservoir bed. Rock and other hard surfaces produce a fine graph line whereas loose or soft sediment produces a thick graph line. The upper line of the graph gives a more accurate representation and is therefore considered for the analysis.

The distance between benchmarks were initially measured by the theodolite. When the distance exceeded 400 meters, measurement became difficult. In November 1995, the distance was re-measured by the Electronic Total Station (ETS) instrument and used for the analysis.

The surveys were carried out at different water levels (see Annex II). Some errors in measuring the depth are associated with the water level during the survey. Therefore, it is recommended that surveys are carried out in periods of highest water level in order to minimize such errors.

5. RESULTS AND DISCUSSION

5.1. BATHYMETRIC MAP

The sedimentation survey of March 1993 was used as the base line, whereas data from the surveys of December 1993, October 1994 and November 1995 were used to estimate the sediment deposition in the reservoir. Bathymetric maps of the reservoir were prepared at the scale of 1:7,400, using 10-meter contour intervals. The bathymetric map prepared based with data from November 1995 is shown in Figure 3. With reference to the highest water level (1530.20 m), the area of the reservoir is about 216 ha.

5.2. WATER DEPTH

With respect to the reference water level (1530.20 m), the maximum decrease in the maximum water depth during 1993 monsoon (March-December 1993) was 18.2 m, whereas the maximum decrease in average water depth is 6.5 m. Similarly, during 1994 monsoon (December 1993 - October 1994) the maximum water depth in the main reservoir sections decreased by 3.3 m, and the maximum decrease in the average cross-sectional depth was 2.7 m. During the 1995 monsoon (October 1994 - November 1995), the maximum water depth in mid-reservoir sections decreased by 4.5 m, and maximum decrease in the average cross-sectional depth was 2.5 m (see Table 3).

The November 1995 survey does not show a uniform trend in the decrease of water depth. Sediment distribution in the reservoir depends on many factors, such as the topography of the area, the presence of tributaries, land-use, geomorphology, erosion process, rainfall in the tributaries, length of reservoir, size of the sediments and, most important, the water level in the reservoir. In certain sections such as Intake to Outlet, BM 1 to Intake and BM 1 to BM 2, where erosion is unlikely to occur, the average water depth and highest water depth have been increased. This suggests that, with time, the loose sediment became compacted and the depth increased. This is more so in the front part of the reservoir where fine clay sediments were deposited. However, no information is available on the rate of compaction. If this is the case, the volume of sediment deposited will be more than that estimated. Comparing the results of December 1993 and October 1994, this effect was not observed. The reason might be that the rate of compaction was greatly superseded by the rate of deposition, thereby masking any effect of compaction.

In the 1995 monsoon, the water level in the reservoir rose high by June. Most of the decrease in water depth and deposition of sediment therefore occurred in the mid-part of the reservoir as the velocity of inflow was reduced. The reservoir was full when the survey was carried out in November 1995.

Due to hydro-power generation, the water level in the reservoir before the start of the monsoon is low. Therefore, the pre-monsoon rain eroded the deposition from the end part to the mid and front part of the reservoir increasing water depth in the end part. This is observed in Sections 29_30, 31_32, 33_34 and 35_ and 36 of the reservoir (see Table 3).

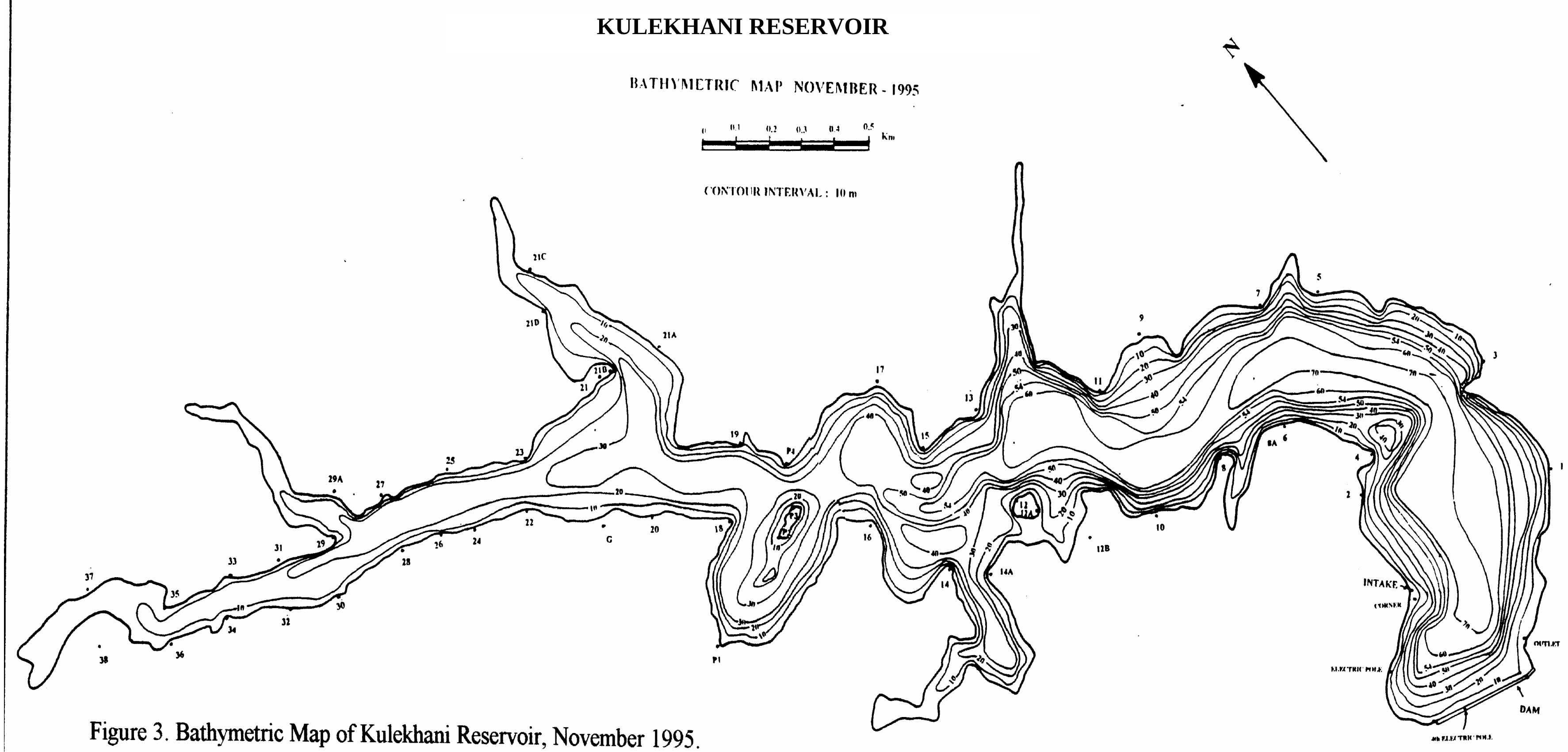


Figure 3. Bathymetric Map of Kulekhani Reservoir, November 1995.

Table 3. Average and Maximum Depths of Echo-Sounding Survey Lines, Kulekhani Reservoir

Cross Section	Actual Length in m.	Shore to Shore Length in m	Average Water Depth in meters with Reference level to water level 1530.20					Change in Average water depth in meters			Highest Water Depth recorded with Reference level to water level 1530.20					Change in Highest Water Depth in m.			Remarks
			1989	Mar. ‘93	Dec. ‘93	Oct.- ‘94	Nov. ‘95	Mar.'93 Dec.'93	Dec.'93 Oct.'94	Sept.'9 Nov.'95	1989	Mar. ‘93	Dec. ‘93	Oct. ‘94	Nov. ‘95	March- Dec.'93	Dec.'93 Oct.'94	Oct.'94 Nov.'95	
1 To Intake	549.68					47.9	48.2			0.3				72.3	72.7			-0.5	Front Part
Intake To Outlet	408.62					45.0	46.5			1.5				70.9	72.3			-1.4	Front Part
Intake to Outlet-Gate							40.1								40.1				New Line
4th Lamp to Gabion Wall							39.1								62.4				New Line
Outlet-Gate to Electric Pole							27.7								58.2				New Line
1 To 2	626.90	622.19		58.8	54.0	53.7	54.2	-4.8	-0.3	0.4		90.4	72.3	70.9	71.9	**-18.2**	-1.4	-1.0	Front Part
3 To 4	453.52	540.67		47.0	45.0	44.9	45.1	-2.0	-0.1	0.2		85.1	72.0	71.7	71.8	-13.1	-0.2	-0.1	Front Part
5 To 6	375.26	369.56		53.9	51.3	51.0	50.5	-2.6	-0.3	-0.6		80.2	71.4	70.4	70.2	-8.8	-1.1	0.2	Front Part
7 To 6	337.24	331.35	52.7		51.4	48.6	49.2		**-2.7**	0.6	79.0		70.7	68.2	70.1		-2.5	**-1.9**	Front Part
8A To 8	144.92	136.77			24.0	21.2	22.8		-2.8	1.6			40.4	34.7	38.2		-5.7	-3.5	Front Part
9 To 8	426.87	412.47		43.5	41.7	40.3	37.9	-1.8	-1.3	-2.4		75.7	69.5	66.4	68.1	-6.2	-3.1	-1.7	Front Part
9 To R2	487.05		44.0		38.0						74.2		70.7						
9 To 10	499.08	480.95		44.1	42.2	41.4	41.8	-1.9	-0.8	0.4		75.4	67.9	65.9	67.0	-7.4	-2.1	-1.2	Mid Part
11 To 10	375.89	369.17		52.3	50.5	48.7	48.5	-1.8	-1.8	-0.2		71.9	67.0	65.2	65.8	-4.9	-1.7	-0.5	Mid Part
12B To 12A	172.90	141.41			11.9	11.9	9.4			-2.5			22.2	22.2	22.7		0.0	-0.5	Mid Part
13 To 11	396.26	387.46			51.6	50.2	50.2		-1.4	0.0			63.2	63.1	63.7		-0.0	-0.6	Mid Part
13 To 12	274.34	270.58		43.6	42.1	41.4	38.8	-1.5	-0.8	**-2.5**		66.8	62.7	59.4	59.6	-4.1	**-3.3**	-0.2	Mid Part
12 To 15	321.09	317.54		36.0	35.7	34.8	35.1	-0.3	-0.9	0.3		63.1	60.5	59.0	57.8	-2.5	-1.6	1.2	Mid Part
14 To 14A	113.72	96.29			25.0	22.7	18.3		-2.3	-4.4			39.5	33.6	34.4		-5.9	-0.8	Mid Part
15 To 14	352.32	345.01			39.7	39.3	38.2		-0.4	-1.1			59.6	57.1	54.8		-2.5	2.2	Mid Part
16 To 15	253.62	246.66		43.5	41.8	41.1	37.1	-1.7	-0.7	-4.0		58.6	56.9	54.5	51.0	-1.7	-2.4	3.6	Mid Part
17 To 16	386.65	376.84		40.8	40.2	39.5	32.8	-0.6	-0.7	-6.7		56.6	53.7	51.3	46.9	-2.9	-2.4	4.4	Mid Part
P1_P2					25.9	22.3	22.0		-3.5	-0.3			40.5	35.2	39.6		-5.3	-4.5	Mid Part
P3_P4					17.4	18.5	20.4		1.1	1.9			34.2	33.4	34.3		-0.8	-1.0	Mid Part
P5_P6						41.2								67.5					Mid Part
18 To 19	207.28	203.31		27.0	25.0	25.9	24.6	-2.0	0.9	-1.2		39.8	35.9	33.3	33.6	-3.9	-2.6	-0.3	End Part
20 To 21	422.72	413.27		22.9	21.6	21.7	21.6	-1.3	0.0	-0.0		35.2	33.0	30.5	30.6	-2.2	-2.5	-0.0	End Part
21B To 21A	182.85	161.88			16.4	16.1	16.7		-0.3	0.6			25.9	27.2	27.0		1.3	0.2	End Part
21D To 21C	120.91	106.28	11.2		12.0	11.0	10.8		-1.0	-0.2	15.2		16.3	15.4	17.4		-0.9	-2.0	End Part
21B To G	419.86		21.7			21.7					35.2		29.3						End Part
21 To G	395.94	387.84				19.3	19.1			-0.1				29.3	30.1			-0.8	End Part
22 To 23	151.27	170.74		21.0	20.0	20.1	20.1	-1.0	0.0	0.0		31.0	29.2	27.7	28.1	-1.8	-1.5	-0.4	End Part
24 To 25	157.27	147.72	23.6		19.5	21.4	17.5		2.0	-4.0	29.2		24.2	27.3	26.3		3.1	1.0	End Part
26 To 25	179.76	170.30		23.6	19.2	20.9	20.6	-4.4	1.7	-0.3		29.7	23.9	26.1	26.0	-5.8	2.2	0.2	End Part
28 To 27	160.12	151.07	20.3		17.0	19.3	18.6		2.3	-0.7	27.2		20.5	23.8	24.0		3.3	-0.2	End Part
29 To 29A	129.35	122.70			14.3		14.0						20.7	18.3	19.3		-2.4	-1.0	End Part
29A To P	275.52	271.25			12.7		14.4						18.6		21.2				End Part
30 To 29	170.73	161.74		17.1	12.5	13.2	14.2	-4.6	0.6	1.1		24.6	18.6	17.7	20.8	-6.0	-0.9	-3.2	End Part

31 To 32	145.72	126.80	15.8		8.7	11.1	12.8		2.5	1.7	23.2		10.7	15.6	18.2		4.9	-2.6	End Part
34 To 33	118.92	116.52		14.7	8.2	11.2	12.7	**-6.5**	3.0	1.5		20.5	10.2	14.4	16.2	-10.3	4.2	-1.8	End Part
36 To 35	94.55	82.35		11.7	6.6	5.8	8.9	-5.1	-0.8	3.1		19.0	7.8	10.7	12.7	-11.3	3.0	-2.0	End Part
38 To 37	164.89	110.45		5.2	2.3	3.1	2.7	-2.9	0.7	-0.4		8.8	4.2	5.0	4.4	-4.6	0.8	0.6	End Part

5.3. SEDIMENTATION

The deposition or erosion of sediment is computed by multiplying the mean of the average water depths of two cross-sections by the area of the reservoir surface between those two cross-sections (Method I). The sedimentation of the reservoir in the 1993 monsoon (March-December 1993) is estimated to have been about 5.19 million m^3 (Table 4), whereas sedimentation in the 1994 monsoon (December 1993 - October 1994) is estimated to have been about 0.91 million m^3 (Table 5). Although total sedimentation is estimated to have been only 0.91 million m^3 during the 1994 monsoon, the total reduction in the dead volume capacity is estimated to be about 1.05 million m^3 and about 144,600 m^3 of sediment from the live volume area has been transported to dead volume area (see Table 5). Similarly, in the 1995 monsoon, total sedimentation of the reservoir was estimated to have been about 1.02 million m^3 (see Table 6). The total reduction in dead volume capacity is estimated to be about 1.07 million m^3 and about 54,000 m^3 of sediment has moved from the live volume area to the dead volume area (see Table 6).

Table 4. Sediment Calculation, Kulekhani Reservoir Echo-sounding Survey, March and December 1993. Method I

Cross Section	With Reference To The Highest Water Level (1530.2 m.)					Change in water	Remarks
	Surface Area	Average Water Depth in m		Volume of Water in ha-m		Volume in ha-m	
	of lake in ha-	March '93	Dec. '93	March '93	Dec. '93	Mar-Dec.'93	
1_2	30.0	58.78	54.00	1761.05	1617.84	-143.21	
1_2 & 3_4	10.4	52.91	49.50	551.85	516.29	-35.57	Sedimentation
3_4 & 5_6	19.0	50.48	48.16	960.54	916.48	-44.05	in 1993 monsoon
5_6 & 8_9	17.2	48.71	46.50	837.73	799.80	-37.93	is 519.36 ha.m.
8_9 & 9_10	6.5	43.82	41.96	283.92	271.87	-12.05	That is reservoir
9_10 & 10_11	3.34	48.19	46.37	160.95	154.86	-6.10	capacity is reduced
10_11 & 12_13	17.6	47.93	46.31	845.49	816.91	-28.58	by 5.19 million cu.m.
12A_12B	2.4	9.77	9.77	23.35	23.35	0.00	
12_13 & 12_15	3.2	39.80	38.90	128.55	125.63	-2.92	
12_15 & 15_16	21.6	39.76	38.74	859.50	837.56	-21.94	
15_16 & 16_17	4.2	42.17	41.01	174.98	170.19	-4.79	
16_17 & 18_19	22.8	33.90	32.58	771.45	741.52	-29.93	
18_19 & 20_21	20.7	24.93	23.27	514.80	480.53	-34.28	
20_21 & 22_23	9.6	21.96	20.80	211.26	200.10	-11.16	
22_23 & 25_26	4.4	21.60	19.60	94.59	85.85	-8.74	
25_26 & 29_30	10.6	19.63	15.87	208.47	168.49	-39.98	
29_30 & 33_34	4.8	15.88	10.36	75.43	49.19	-26.24	
33_34 & 35_36	2.0	13.17	7.38	26.59	14.90	-11.70	
35_36 & 37_38	3.2	8.45	4.46	27.38	14.45	-12.93	
37_38	2.5	5.22	2.34	13.15	5.90	-7.26	
	216.0			8531.04	8011.68	-519.36	

Note : Section 12A_12B is located at an elevation, where deposition is not likely.
Therefore, average depth of Dec. 1993 is taken for March 1993.

Table 5. Sediment Calculation, Kulekhani Reservoir Echo-sounding Survey, December 1993 - October 1994. Method I

Cross Section	Area (ha.)	Av. Water Depth (m.) Dec.'93	Av. Water Depth (m.) Oct.'94	Volume of water (ha-m.) Dec.'93	Volume of water (ha-m.) Oct.'94	Change in Volume in (ha-m.		Remarks
1_2	29.96	54.00	53.70	1617.75	1608.76	-8.99		
1_2 & 3_4	10.43	49.50	49.29	516.18	513.99	-2.19		Sedimentation
3_4 & 5_6	19.03	48.16	47.96	916.30	912.49	-3.81		in 1994 monsoon i.e.
5_6 & 6_7	4.65	51.34	49.83	238.69	231.67	-7.02		December 1993 to October
6_7 & 8_9	11.03	46.52	44.48	513.34	490.83	-22.51		1994 is estimated at 91.20 ha.m.
8_9 & 9_10	6.48	41.96	40.89	271.83	264.93	-6.90		That is, the reservoir
9_10, 10_11	3.34	48.11	46.78	160.79	156.34	-4.46		capacity is reduced by
& 11_13								0.91 million cu.m.
12_13 & 10_11	13.21	46.31	45.02	611.76	594.65	-17.11		
12_13 & 12_15	3.23	38.90	38.07	125.64	122.96	-2.68		From dam site section up to
12_15,12A_12B,	14.88	28.59	27.61	425.38	410.90	-14.47		P1_P2 and P3_P4 is
15_16 & 14_14A								considered as
15_16 & 16_17	4.15	41.01	40.30	170.37	167.42	-2.95		dead volume area.
16_17, 18_19,	22.77	27.11	26.56	617.23	604.65	-12.58		Then,
P1_P2 & P3_P4							-105.66	
18_19,20_21 &	10.83	20.97	21.22	227.09	229.80	2.71		During 1994 monsoon i.e.
21A_21B								December 1993 to
20_21 & 22_23	9.62	20.80	20.87	200.01	200.68	0.67		October 1994.
21A_21B &	6.98	14.19	13.57	99.06	94.76	-4.29		Dead volume is reduced by
21D_21C								1.05 million cu.m.
25_26 & 22_23	4.38	19.60	20.47	85.85	89.66	3.81		
25_26 & 27_28	2.92	18.10	20.10	52.84	58.68	5.84		The live volume of the
27_28,29_30 &								reservoir is increased by
29_29A	4.15	14.61	14.93	60.68	62.04	1.36		about 0.14 million cu.m.
29_30 & 31_32	2.53	10.61	12.16	26.83	30.75	3.92		
31_32 & 33_34	2.22	8.42	11.17	18.71	24.81	6.10		
33_34 & 35_36	2.02	7.38	8.48	14.87	17.09	2.22		
35_36 & 37_38	3.24	4.46	4.41	14.45	14.29	-0.16		
37_38	2.53	2.34	3.06	5.92	7.74	1.82		
Triangle								
8_8A	1.52	23.95	21.17	11.47	10.14	-1.33		
11_13	5.21	51.60	50.22	83.92	83.14	-0.78		
14_14A	8.30	24.96	22.69	58.47	53.15	-5.32		
21D_21C	2.84	12.00	11.02	9.98	9.16	-0.82		
29_29A	3.55	14.28	12.31	16.02	14.74	-1.28	14.46	
	216.00			7171.41	7080.21	-91.20		

Table 6. Gross Capacity Calculation, Kulekhani Reservoir Echo-sounding Survey, October 1994 November 1995. Method I.

Cross Section	Area (ha.)	Average Water depth (m.)		Volume of water (ha - m)		Change in volume (ha-m)		Remarks
		Oct.'94	Nov.'95	Oct.'94	Nov.'95			
Intake To Outlet	10.90	44.97	46.46	489.95	506.18	16.23		
1 To Intake	9.73	46.44	47.35	451.67	460.57	8.90		
& Intake_Outlet								Sedimentation in 1995
1_2 & 1_Intake	9.34	50.80	51.20	474.37	478.06	3.69		monsoon i.e. Oct.'94 to
1_2 & 3_4	10.43	49.29	49.61	513.99	517.28	3.28		Nov.'95 is 102.03 ha-m.
3_4 & 5_6	19.03	47.96	47.77	912.49	908.78	-3.71		That is the reservoir capacity
5_6 & 6_7	4.65	49.83	49.86	231.67	231.78	0.12		is reduced by 1.02 million
6_7 & 8_9	11.03	44.48	43.57	490.83	480.79	-10.04		cu. m..
8_9 & 9_10	6.48	40.89	39.85	264.93	258.15	-6.77		
9_10, 10_11	3.34	46.78	46.83	156.34	156.53	0.19		From dam site
& 11_13								section up to P1_P2
12_13 & 10_11	13.21	45.02	43.66	594.65	576.68	-17.97		and P3_P4 is
12_13 & 12_15	3.23	38.07	36.97	122.96	119.40	-3.55		considered as
12_15,12A_12B,	14.88	27.61	24.96	410.90	371.40	-39.51		dead volume area.
15_16 & 14_14A								
15_16 & 16_17	4.15	40.30	34.94	167.42	145.15	-22.27		Then
16_17, 18_19,	22.77	26.56	24.97	604.65	568.56	-36.09	-107.50	
P1_P2 & P3_P4								During 1995 monsoon
								i.e. Sept. 94 to Nov. 95
18_19,20_21 &	10.83	21.22	20.79	229.80	225.18	-4.62		Dead volume is reduced
21A_21B								by 107.5 ha-m., that is
20_21 & 22_23	9.62	20.87	20.85	200.68	200.49	-0.19		1.07 million cu.m.
21A_21B &	6.98	13.57	13.77	94.76	96.12	1.36		
21D_21C								
22_23 & 25_26	4.38	20.47	20.32	89.66	89.00	-0.66		
25_26 & 27_28	2.92	20.10	19.58	58.68	57.16	-1.52		Live volume
27_28,29_30 &								of the reservoir is
29_29A 4.15	14.93	15.60	62.04	64.82	2.78			increased by about
29_30 & 31_32	2.53	12.16	13.51	30.75	34.18	3.43		54,700 cu.m.
31_32 & 33_34	2.22	11.17	12.74	24.81	28.30	3.49		
33_34 & 35_36	2.02	8.48	10.77	17.09	21.71	4.62		
35_36 & 37_38	3.24	4.41	5.76	14.29	18.64	4.36		
37_38	2.53	3.06	2.65	7.74	6.70	-1.04	5.47	
Triangle								
8_8A	1.52	21.17	22.79	10.14	10.91	0.77		
11_13	5.21	50.22	50.23	83.14	85.30	2.16		
14_14A	8.30	22.69	18.29	53.15	42.84	-10.31		
21D_21C	2.84	11.02	10.84	9.16	9.01	-0.15		
29_29A	3.55	12.31	14.01	14.74	15.72	0.98		
	216.00			6887.44	6785.42	-102.03		

The Project Completion Report anticipated an annual sedimentation rate of 7 m^3 per hectare (as cited by NEA, 1995). If the estimated sediment is distributed evenly throughout the 125-sq. km. watershed, the annual rate of sediment contribution from the watershed would account for about 42 m^3 per hectare up to March 1993. During the 1993 monsoon, this rate increased to 415 m^3 per ha, and for the 1994 monsoon, the rate was estimated to have been 73 m^3 per ha. Similarly, the rate for the 1995 monsoon is estimated to have been about 82 m^3 per ha. Therefore, the average sediment contribution rate, up to the disastrous rainfall event of 1993, was about six times higher than the anticipated rate. The sediment contribution rate for the 1993 monsoon was 59 times higher than the anticipated rate and about 10 times higher than the normal rate. Sediment contribution rates in the 1994 and 1995 monsoons were 10 and 12 times higher than the anticipated rates and about twice the normal rate (see Table 6). The total sediment contribution rate must be higher than the mentioned rates, as sediment lost through the spillway, gate and intake for hydro-power generation is not considered in the estimation. This is more significant for the disastrous rainfall event of 19 and 20 July 1993, when one of the two gates was open for maintenance and millions of m^3 of water, heavily laden with sediment drained through it.

Table 7. Sediment Contribution Rate From Watershed Area

Period	Total Sedimentation in m^3	Sediment Contribution Rate m^3 per ha
1982 to 1993	7344100	42
1993 Monsoon	5193600	415
1994 Monsoon	912000	73
1995 Monsoon	1020300	82

For the sediment calculation for the next survey it is suggested to measure the minimum of the cross-sections measured in November 1995 and compute the sediment deposition using Table 8.

The main reason for high sedimentation in the 1993 monsoon was unusually heavy rainfall (376.8 mm in Simlang, 419 mm in Sarbang and 535 mm in Tistung over a 24 hour period with intensities of 67 and 70 mm/h in Simlang and Tistung respectively) observed between 8:00 a.m. 19 and 20 July 1993. The peak flood inflow into the reservoir was estimated at 1,340 m^3 per second, during the 1993 flood. It was the recorded maximum flood for the Kulekhani Watershed with a estimated flood frequency period of 100 years. Nippon Koei, 1994. This disastrous rainfall also augmented the landslide area (see Figure 4).

5.4. RESERVOIR CAPACITY

The gross capacity of the reservoir is computed by multiplying the average depth of two contour lines and the area between the contour lines using the bathymetric map. The capacity of the reservoir in December 1993 amounted to 75.11 million m^3, which is 10.19 million cu. m less than the original gross capacity of the reservoir (see Table 9). Similarly, the capacity of the reservoir in October 1994 was further reduced to 72.41 million cu. m, which is 12.89 million cu. m less than the original gross capacity of the reservoir (see Table 10). The capacity of the reservoir in November 1995 is estimated to have been 70.83 million m^3 (see Table 11). Therefore the gross capacity of the reservoir was reduced by 14.47 million m^3, of which 5.19 million m^3 was contributed by the disastrous monsoon of 1993, about 0.91 million m^3 from the 1994 monsoon and 1.02 million m^3 from the 1995 monsoon. Therefore, the sediment deposition up to 1993 was 7.34 million cu. m since the first damming of the river in 1979.

Table 8. Gross Capacity Calculation, Kulekhani Reservoir Echo-sounding Survey, November 1995. Method I.

Cross Section	Area in ha. Nov.'95	Average Water depth (m) Nov.'95	Volume of water (ha-m)	Remarks
4th Electric Pole_Intake	4.93	39.05	192.44	The reservoir capacity is 6699.65 ha .m.
4th Electric Pole_Intake & Intake_Outlet-gate	4.02	39.58	159.19	That is the reservoir capacity is about 66.99 million cu.m.
Intake_outlet-gate & Intake_Outlet	1.95	43.29	84.19	
Intake_outlet & 1_Intake	9.73	47.35	460.57	
1_2 & 1_Intake	9.34	51.20	478.06	
1_2 & 3_4	10.43	48.13	501.87	
3_4 & 5_6	19.03	47.77	908.78	
5_6 & 6_7	4.65	49.86	231.78	
6_7 & 8_9	11.03	43.57	480.79	
8_9 & 9_10	6.48	39.85	258.15	
9_10, 10_11 & 11_13	3.34	46.83	156.53	
12_13 & 10_11	13.21	43.66	576.68	
12_13 & 12_15	3.23	36.97	119.40	
12_15,12A_12B, 15_16 & 14_14A	14.88	24.96	371.40	
15_16 & 16_17	4.15	34.94	145.15	
16_17, 18_19, P1_P2 & P3_P4	22.77	24.97	568.56	
18_19,20_21 & 21A_21B	10.83	20.79	225.18	
20_21 & 22_23	9.62	20.85	200.49	
21A_21B & 21D_21C	6.98	13.77	96.12	
25_26 & 22_23	4.38	20.32	89.00	
25_26 & 27_28	2.92	19.58	57.16	
27_28,29_30 & 29_29A	4.15	15.60	64.82	
29_30 & 31_32	2.53	13.51	34.18	
31_32 & 33_34	2.22	12.74	28.30	
33_34 & 35_36	2.02	10.77	21.71	
35_36 & 37_38	3.24	5.76	18.64	
37_38	2.53	2.65	6.70	
Triangle				
8_8A	1.52	22.79	10.91	
11_13	5.21	50.23	85.30	
14_14A	8.30	18.29	42.84	
21D_21C	2.84	10.84	9.01	
29_29A	3.55	14.01	15.72	
Total	216.00		6699.65	

Figure 4. Location Map of Slope Failure in Kulekhani Watershed (As of Sept. 1994).

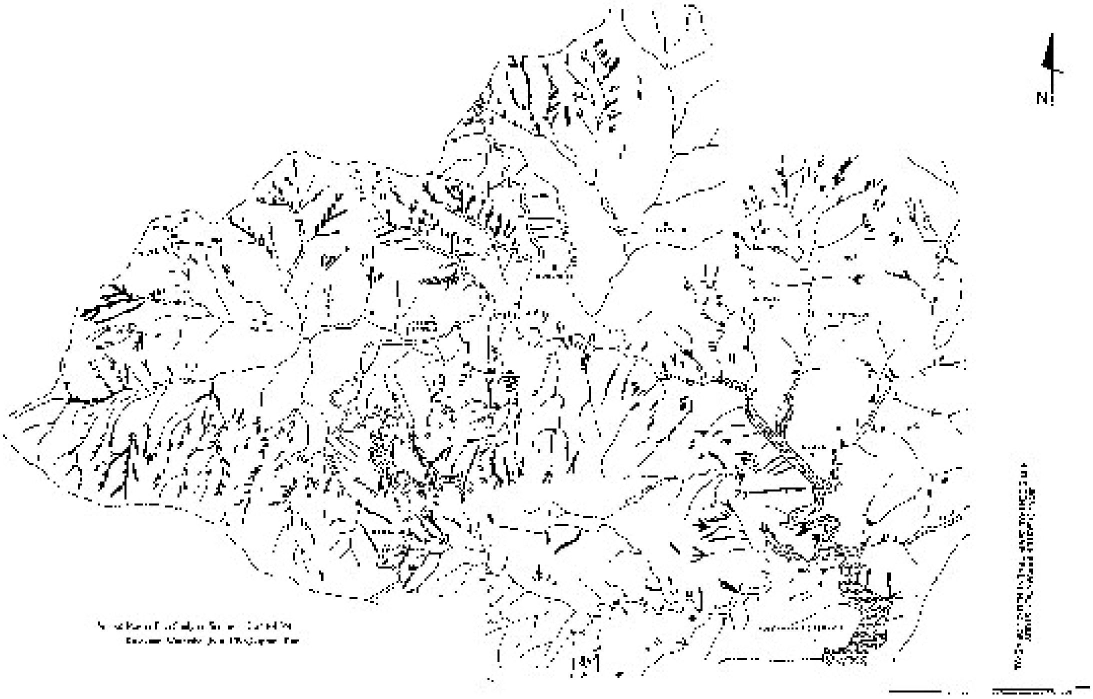


Table 9. Area and Capacity of the Reservoir, December 1993. Method II

Contour Interval in m.	Area in ha.	Volume of Water in Million Cu.m.	Dead Load in million cu.m.		Reduction in Dead Volume in million cu.m.	Total Capacity in million cu.m.		Area in ha.
			Design	Dec.'93		Design	Dec. '93	
> 70	19.22	13.65	11.20	6.11	5.09	85.30	75.11	20.71
60-70	22.19	14.42						23.91
54-60	13.38	7.63						14.42
50-54	14.44	7.51						15.56
40-50	17.95	8.08						19.34
30-40	23.79	8.33						25.63
20-30	35.03	8.76						37.75
10-20	32.39	4.86						34.90
< 10	37.71	1.89						40.63
	216.10	75.11						

Table 10. Gross Capacity Calculation of the Kulekhani Reservoir, October 1994. Method II.

Contour Interval in m.	Area in ha.	Volume of Water in Million Cu.m.	Dead Load in million cu.m.		Reduction in Dead Volume in million cu.m.	Total Capacity in million cu.m.		Total Reduction in the Reservoir Capacity in million cu.m.	Remarks
			Design	Oct.' 94		Design	Oct.' 94		
> 70	10.22	7.26				85.30	72.41	12.89	Lower and upper level of Intake are 1471 and 1476 meters
60-70	24.07	15.65							
54-60	16.08	9.17							
50-54	14.38	7.48							
40-50	15.80	7.11							Considering 1471 meters as Dead Volume Level
30-40	29.38	10.28	11.20	2.75	8.45				
20-30	33.66	8.42							
10-20	34.39	5.16							Considering 1476 meters as Dead Volume Level
< 10	38.03	1.90	11.20	4.87	6.33				
	216.01	72.41							

Table 11. Gross Capacity Calculation of the Kulekhani Reservoir, November 1995. Method II.

Contour Interval in m.	Area in ha.	Volume of Water in Million Cu.m.	Dead Load in million cu.m.		Reduction in Dead Volume in million cu.m.	Total Capacity in million cu.m.		Total Reduction in the Reservoir Capacity in million cu.m.	Remarks
			Design	Nov.'95		Design	Nov.'95		
> 70	12.91	9.17				85.30	70.83	14.47	Lower and upper level of Intake are 1471 and 1476 meters
60-70	23.81	15.48							
54-60	13.44	7.66							
50-54	9.51	4.95							
40-50	15.84	7.13							Considering 1471 meters as Dead Volume Level
30-40	31.21	10.92	11.20	3.05	8.16				
20-30	32.68	8.17							
10-20	35.34	5.30							Considering 1476 meters as Dead Volume Level
< 10	41.27	2.06	11.20	5.22	5.98				
	216.01	70.83							

The gross capacity of the reservoir is also computed by multiplying the average depth of two cross-sections and the area between the two cross-sections. The capacity of the reservoir in December 1993 is estimated to have been 71.71 million m^3 (see Table 5), 68.87 million m^3 in October 1994 (see Table 6) and 66.99 million m^3 in November (see Table 8). The difference between the capacity computed by methods I and II is given in Table 12. The figure computed by method II is about 3 million m^3 more than that by method I. However use of method I is recommended for sediment estimation and method II for capacity estimation, as method I will minimize the errors resulted other than average water depth and reservoir surface area.

Table 12. Comparison of the Reservoir Capacity

Year	Reservoir Capacity in Million cu.m.		Difference in million cu.m.
	Method I	Method II	
December 1993	71.71	75.11	3.40
October 1993	68.87	72.41	3.54
November 1995	66.99	70.83	3.84

Note : Method I : Surface area and Average water depth of cross sectional profiles. Table 4, 5, 6, and 8.
Method II : Contour area and Average water depth of contour lines. Table 9, 10 and 11.

6. ISSUES

6.1. CONSERVATION ISSUES

Record of 24 hours rainfall events (June to October) with different rainfall amounts exceeding 100 mm (see Table 13) reveals that disastrous rainfall events such as the one observed in 19 - 20 July 1993 at Kulekhani watershed is characteristic of the Nepali monsoon. These events are characterized by intense rainfall over a relatively small area. The only uncertainty is where it will happen next. With this in mind, in a mountainous country like Nepal, with extensive overuse of the land, how far the conservation measures can help to conserve soil and water, thereby reduce the reservoir sedimentation has been a major issue.

Table 13. Record of 24 hours Rainfall Events (June - October) with different rainfall amounts between 1971 - 1990.

	24 hours Rainfall categories in mm			
	100 - 199	200 - 299	300 - 399	More than 400
No of Events	1604	340	51	12

(Source : Modified after Chalise et.al., 1995)

Tremendous damage was caused to the watershed in 19-20 July 1993 monsoon. There were numerous slope failures in the forested area as well. The damage therefore seems to be unavoidable. The slope failure in the forest mainly occurred where the forests have been extensively over-used in fulfilling local needs such as fodder and fuel wood. However, the dense well-protected forest areas in the north - east of the watershed were less affected. Similarly, the Sarbang Burrow-Pit covering about 18 hectares, the clay quarrying site for the construction of the dam which was reclaimed and conserved by the Department of Soil Conservation with the bio-engineering measures, was also least affected by the rainfall event of 19 - 20 July 1993. This indicates that proper conservation measures can reduce the damage considerably.

Soil conservation programs have been implemented in the Kulekhani watershed since 1978. The main conservation measures were: planting of trees and grasses on degraded lands, introducing fruit trees on marginal lands, on-farm conservation, construction of conservation ponds, road-slope stabilization, protection of irrigation canals, trail improvement, gully and landslide stabilization, torrent control, and stream bank protection The scale of conservation intervention so far carried out by the government in the watershed compared to the need has been negligible (see Table 14). Therefore, it neither covers an extensive area nor creates significant reduction in reservoir sedimentation. Therefore, there is a great need for extensive conservation intervention to significantly reduce reservoir sedimentation. And to-day the challenge is to develop the package of conservation measures that would be socially acceptable and economically regenerative such that the measures will be adopted by the peoples themselves.

Table 14. Major Achievement during Fiscal Year 1978/79 to 1991/92 (DSC, 1996).

Major Activities	Unit	Achievement
PREVENTIVE MEASURES		
Rehabilitation of Degraded Lands	ha.	455
Terrace Improvement	ha.	95
Fruit Tree Planting	ha.	34
Fruit Tree Distribution	no.	27,000
Pasture (Grass Planting)	ha.	51.5
Conservation Pond	no.	15
Water Source Protection	no.	14
REHABILITATIVE MEASURES		
Gully Treatment	no.	17
Landslide Treatment	no.	31
Trail Improvement	km.	4
Irrigation Channel Improvement	no.	5
Torrent Control	no.	2
Embankment	m	94
Extension and Income Generation Activities		

Compared to the estimated average sediment delivery rate in the Phewa Tal watershed, which is 17.37 m^3 per hectare (1990 to 1994), the sediment delivery rate for Kulekhani was exceptionally high even before the disastrous rainfall event of 19 - 20 July 1993. One reason why the Kulekhani watershed has significantly higher rates is that 34 % of the watershed area is under sloping agriculture, compared to just 0.3 % in the Phewa watershed. Similarly, the soils in the Kulekhani watershed are much more sandy than in Phewa watershed.

Slope failures and stream-bank cutting contribute tremendously to the sediments in the reservoir. It is very important to stabilize these activities particularly where there are dams. Implementation through people's participation is the main strategy, and productivity conservation is the main theme, of the soil conservation program. However, local people are not keen to participate in stabilizing landslide and stream-bank erosion as these activities are very expensive and less oriented towards productivity conservation. The benefits, they feel, do not justify the efforts required.

Special emphasis should be given to the prevention and reclamation of landslides and gullies. Stream-bank protection and the construction of sediment traps are needed to protect the hydro-power capacity of the reservoir. Implementation of such activities needs to be borne by projects (such as hydro-power) which are directly affected by the sedimentation.

Sediment-trapping dams alone may not be economical. Maintenance of buffer strips such as level terraces across the slope can play an effective role in trapping sediment. Level terraces are typical of the traditional Nepali farming landscape and has proved important in trapping sediment. Therefore, based on the topography and sediment source, construction of level terraces across the slopes in appropriate areas might prove fruitful in trapping sediment as well as permitting appropriate land-use. For the significant impact of conservation on reservoir sedimentation, long term conservation programs should also be an integral part of all the nationally important hydro-power programs.

6.2. SEDIMENT MANAGEMENT

The longitudinal profiles of the reservoir and probable water level before the monsoon are given in Figure 5. During the dry period, the use of water for the hydro-power generation reduces the water level in the reservoir by more than 40 meters. This exposes the sediment to erosion agents. Therefore, the pre-monsoon storms flush the sediments from the end part of the reservoir to the front and mid parts of the reservoir (see Figure 2). Also, when hydro-power is generated in the dry period, the sediment from the end part of the reservoir is transported to the front and mid parts of the reservoir due to the reduced water level. During the monsoon, the water level in the reservoir will rise and the sediment begin to be deposited once more in the end part.

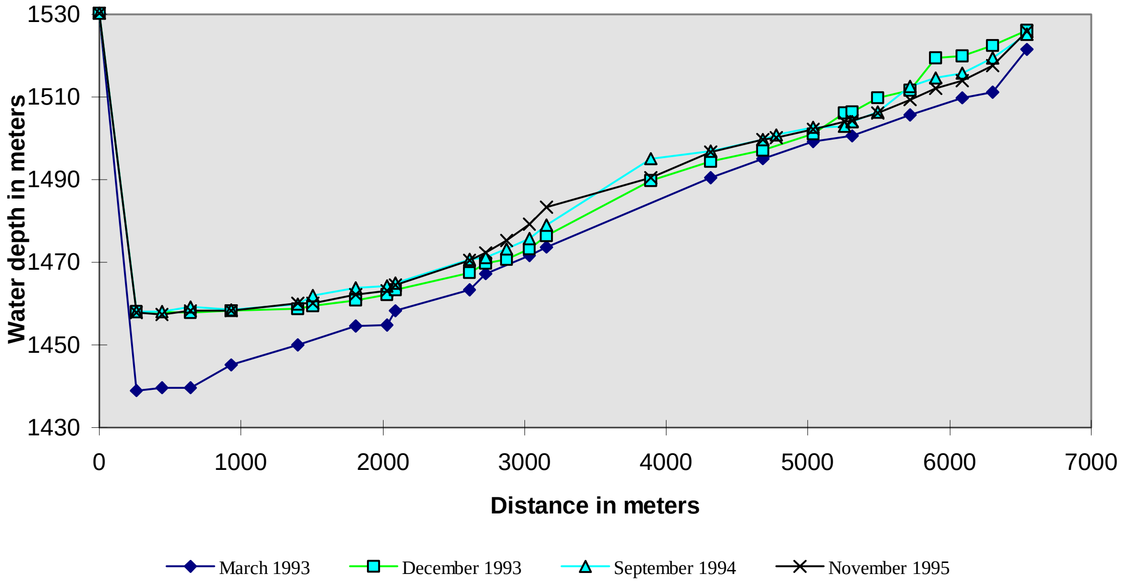
In December 1993, about 1.5 million m^3 of sediment were deposited in the reservoir above the dead volume area. The survey indicated that during the 1994 monsoon, about 1.05 million m^3 of sediments entered the dead volume area, of which 144 thousands m^3 of sediment was flushed from the end part of the reservoir (see Table 5). Similarly, the November 1995 survey showed that about 1.07 million m^3 of sediments were deposited in the dead volume area, of which about 54 000 m^3 of sediment eroded from the area upstream of the dead volume area. (see Table 5). Therefore, management of sediment within the reservoirs is also equally essential for the reservoir protection. About 14.47 million m^3 of total capacity of the reservoir has been reduced since its construction. Similarly, 8.16 million m^3 and 5.98 million m^3 of dead volume, which amounts to 73 % and 53 % of the designed dead volume respectively, have reduced with the corresponding lower level of intake (1471 m) and upper level of intake (1476 m) as dead level respectively. Reduction in live volume produces less electricity whereas filling of dead volume will stop hydro-power generation. Therefore, all feasible measures to stop sediment (either from the watershed or reservoir) reaching the dead volume area should be made.

6.3. LIFE SPAN OF RESERVOIR

The Kulekhani reservoir was designed for a 50-year life span but is expected to serve for 100 years. However, the observed sedimentation is much higher than 7 cu.m. per hectare, the annual rate of sedimentation originally anticipated. The concern now , therefore is how long reservoir can serve the country.

There are different ways of predicting the life span of the reservoir based on the survey results. One can consider the pattern of distribution of sediment; loss of dead volume and finally, annual rate of sedimentation of the dead volume. Each produces a slight different pictures.

Figure 5. Longitudinal Profile of Kulekhani Reservoir



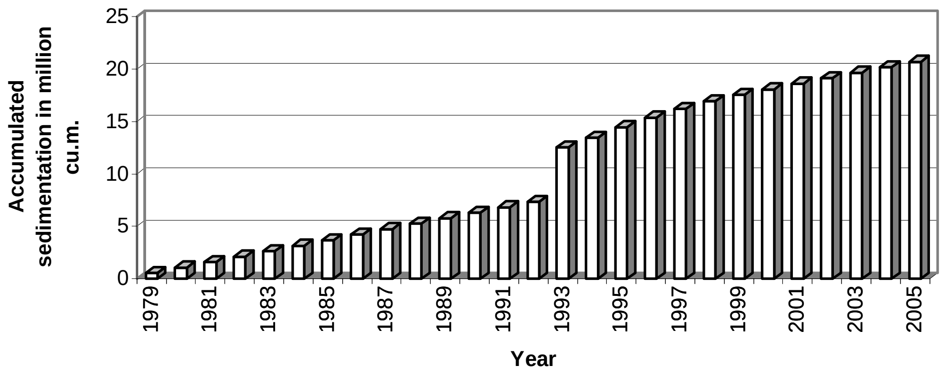
If the lower intake level (1471 m) is taken as the dead level, Table 11 indicates that the designed dead and live volume have been reduced by 8.16 million m^3 (56 % of the total sediment deposited) and 6.31 million m^3 (44 percent of the total sediment deposited) respectively. Assuming that sedimentation rate revert to the normal (1979 to 1982) rates 5 years after disastrous rainfall event, the projected sedimentation of the reservoir by the year 2004 will be about 20 million m^3 , 56 % of which i.e. 11.3 million m^3 will be deposited in the dead volume area (see Figure 5). If this should happens, hydro-power generation will be ceased by the year 2004 (after 9 years from 1995).

Again, taking the lower level of the intake (1471 m)as the dead level, Table 11 shows that 73 % percent of the dead volume has been lost in the 17 years since the first damming of the river in 1979. If sedimentation in dead area continues at the average rate, the dead volume will be fully filled in 5 years and hydro-power generation will be ceased by the year 2000.

Similarly, Table 5 and 6 shows that sedimentation of the dead volume occurs at about 1 million cu.m. annually. Taking lower level of the intake (1471 m) as dead level the remaining dead volume of about 3 million m^3 will be filled in 3 years, that is by the monsoon of 1998, thereby hydro-power generation will be ceased.

The results predict that the remaining life-span of hydro-power generation ranges from 3 to 9 years (1998 - 2004 monsoon). The predicted life-span of the reservoir is therefore reduced to 20 - 26 years, which is almost half of the designed and quarter of the expected life span. Keeping this in view, the Government of Nepal in cooperation with the Government of Japan has begun to build an inclined intake and some sediment trapping dams.

Figure 6. Sedimentation of Kulekhani Reservoir



☐ Note : Year 1996 to 2005 is projected figure

7. DISCUSSION

Sedimentation is a natural phenomenon that is impossible to prevent. The issue is how the life- span of the reservoir could be lengthened. Huge amounts of sediment are in transit from the source to the reservoir. Sediment monitoring is essential for the necessary counter-measures to be taken in time to protect the reservoir from sedimentation. Every effort should be made to lengthen the life of the reservoir, and this includes watershed management, construction of sediment traps, structures, and management of the sediment within the reservoir and watershed.

The observed annual sediment delivery rate from the Kulekhani watershed is much more than the anticipated rate of about 7 m^3 per hectare. The current rates diminish the economic benefit of the Kulekhani Hydro-power Project dramatically. Also, if the dead volume is silted up as quickly as projected from the survey, this will affect the whole country's energy scenario and hydro-power economy. Therefore, realizing the risk and dramatic effects of monsoon storms, future hydro-power generation projects need to be designed to account for unusual events and very high sedimentation rates. Lack of sufficient long term information on rainfall and sedimentation rates have been the bottleneck for designing such hydro-power projects in Nepal.

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Annex I. Rainfall Records, Sarbang Burrow Pit- Kulekhani Watershed.

Month	**Monthly Rainfall in mm**						**Rainfall During** June-September	**% of** Annual
	1991	**1992**	**1993**	**1994**	**1995**	**Average**		
January	19	10	16	47	7.4	20		
February	3	19	2	17	40.8	16		
March	62	0	62	6	28.3	32		
April	117	39	108	21	11.4	59		
May	82	158	175	158	76.8	130		
June	240	131	256	220	609.5	291	1099	79
July	228	260	683	156	306	327		
August	383	170	481	261	248.9	309		
September	145	92	191	279	155.9	173		
October	0	64	13	0	4.4	16		
November	3	21	0	10	N.A.	7		
December	34	10	0	0	N.A.	9		
Total	1316	974	1987	1175	1489	1388		
Largest Storm in 24 hours	102 1 April	44 20 July	419 20 July	72 15 Sept.	147 12-Jun			
Largest Rainfall in a month	383 August	260 July	684 July	279 Sept.	610 June			
Number of Rainy days	120	97	117	110	106	110		

Annex II. Date and Water level, Kulekhani Reservoir.

March 1993		December 1993		October 1994		November 1995	
Date	W.L. in m	Date	W.L. in m	Date	W.L. in m	Date	W.L. in m
21 Mar.'93	1481.38	29 Dec.'93	1529.93	28 Sept.'94	1519.34	1-Nov-'95	1530.17
22 Mar.'93	1481.14	30 Dec.'93	1529.92	29 Sept.'94	1519.40	2-Nov-'95	1530.18
23 Mar.'93	1480.94	31 Dec.'93	1529.86	30 Sept.'94	1519.47	3-Nov-'95	1530.2
24 Mar.'93	1480.54	1 Jan.'94	1529.77	30 Sept.'94	1519.48	4-Nov-'95	1530.2
		2 Jan.' 94	1529.63	1 Oct.'94	1519.51	5-Nov-'95	1530.23
				1 Oct.'94	1519.50	6-Nov-'95	1530.24
				2 Oct.'94	1519.46		
				2 Oct.'94	1519.45		
				3 Oct.'94	1519.49		

Annex III. Calibration of Echo-sounding equipment.

Date	Measurement	Manual Reading	ROYAL RF-350A	Difference in %
6-Nov. 95	1	42.7	44.1	3.17
	2	42.5	42.1	-0.95
	3	42.5	42.1	-0.95
		127.7	128	
			Average	1.70

Steadying the boat while calibration of the echo-sounding equipment was taking place was a major practical difficulty. The field situations while calibrating the instrument reveals that the error will be only plus / minus 1 percent.

PREFACE

The sedimentation survey of Kulekhani reservoir was carried out from 1 to 6 November, 1995 under the Watershed Management Project. The survey team consist of Messrs. : K. M. Sthapit (Team Leader), B. K. Rimal, J. N. Joshi, H. R. Shrestha, K. Dangol, R. N. Bhattarai and B. Paudel. Graph reading were carried out by all members of the team. Author carried out analysis, report writing and bathymetric map preparation.

The comments and suggestions by Mr. John Howell (Bio-engineering Advisor, Road maintenance Project) and supports provided by the Organizer and Forest Research Project supported by the Overseas Development Agency - United Kingdom to attend the conference are highly appreciated. The editorial effort by Mr. Omar Sattaur, from Forest Research Project has been highly appreciated.

Keshar Man Sthapit

ABSTRACT

Nepal is blessed with enormous capacity for the hydro-power. Capturing of the country's potential of the hydro-power became utmost for the country's development. The construction of a 114-meter high rock-filled dam to make a 2 sq. km. reservoir is an important step to tap 92 megawatts (Kulekhani Phase I & II) of hydro-power. The reservoir was designed with a gross capacity of 85.3 million m^3 of which 73.3 million m^3 is live and 11.2 million m^3 is dead volume. The designed life span of the reservoir is 50 years, however the expected life period is 100 years, with an anticipated annual sedimentation rate of 7 m^3 per hectare.

Erosion processes in the rugged terrain of the watershed transport a tremendous amount of sediment reducing its life-span. Therefore, sedimentation monitoring of the reservoir is essential if appropriate strategies for the management of the watershed and sediment are to be formulated.

The siltation survey program was carried out first in March 1993, secondly in December 1993, thirdly in September 1994 and finally in November 1995. The survey indicates that, since the construction of the reservoir, gross capacity has reduced by more than 14.47 million m^3 of which about 5.19 million m^3 was contributed by the freak rainfall of 1993 which resulted in disastrous floods. If the sediment is distributed equally to the 125-sq km watershed area, the annual sediment contribution rate would have amounted to about 42 m^3 per hectare up to March 1993. In reality it was 415 m^3 per ha for 1993, 59 times higher than the anticipated rate and about 10 times higher than normal years i.e. years before the disastrous monsoon rains of 1993.

Since the construction of the reservoir, the gross capacity has been reduced by about 14.47 million m^3 out of designed total capacity of 85.3 million cubic metres i.e. about 17 % of gross volume. Similarly, the dead volume is 3.04 million m^3 if the lower part of the intake i.e. + 1471 metres is considered as dead level and it is 5.98 million m^3 if the upper part of intake i.e. 1476 metres is considered as dead level in November 1995.

The water level in the reservoir will be low before the monsoon, due to hydro-power generation. Sedimentation of the dead volume area (front and mid parts) of the reservoir is therefore very much likely for most of the beginning part of the monsoon. Therefore, all feasible measures to stop sediment reaching the front part, which reduces the dead volume, should be made.

The survey also reveals that sediment is transported from the end part of the reservoir to the front and mid parts. Therefore, management of the sediment within the reservoir is also equally important for the protection of the reservoir.
The main reason for high sedimentation of the reservoir during the monsoon of 1993 was the extraordinary 24 hours of rainfall of more than 500 mm. and the intense rainfall of about 70 mm/hr

on 19-20 July 1993. Tremendous damage was caused to the watershed in 19-20 July 1993 monsoon. However, the dense well-protected forest areas and well conserved degraded areas such as the Sarbang Burrow-Pit were also least affected by the rainfall event of 19 - 20 July 1993. This indicates that proper conservation measures can reduce the damage considerably. Therefore, there is a great need for extensive conservation intervention to significantly reduce reservoir sedimentation. And to-day the challenge is to develop the package of conservation measures that would be socially acceptable and economically regenerative such that the measures will be adopted by the peoples themselves.

Slope failures and stream-bank cutting contribute tremendously to the sediments in the reservoir. However, local people are not keen to participate in stabilizing landslide and stream-bank erosion as these activities are very expensive and less oriented towards productivity conservation. Therefore, implementation of such activities needs to be borne by projects (such as hydro-power) which are directly affected by the sedimentation.

Record of 24 hours rainfall events (June - October) reveals that such intensive events are the characteristics of monsoon climate of Nepal. Therefore, it is essential that the necessary long-term conservation programmes are devised, especially for nationally important projects such as hydropower generation. Such conservation programmes need to be implemented long before and after the completion of such projects.

The life-span of the reservoir is reduced to 20 - 26 years, which is almost half of the designed and quarter of the expected life span. The observed annual sediment delivery rate from the Kulekhani watershed is much more than the anticipated rate of about 7 m^3 per hectare. The current rates diminish the economic benefit of the Kulekhani Hydro-power Project dramatically. Therefore, realizing the risk and dramatic effects of monsoon storms, future hydro-power generation projects need to be designed to account for unusual events and very high sedimentation rates. Lack of sufficient long term information on rainfall and sedimentation rates have been the bottleneck for designing such hydro-power projects in Nepal.

SEDIMENTATION MONITORING

OF

KULEKHANI RESERVOIR

BY

KESHAR MAN STHAPIT

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