Sedimentation of Lakes and Reservoirs with Special Reference to the Kulekhani Reservoir

K. M. Sthapit
Department of Soil Conservation, Kathmandu, Nepal

1. INTRODUCTION

Nepal is endowed with numerous glacial, tectonic and ox-bow lakes and some of the best examples are the well known Phewa, Begnas and Rupa lakes located at the Kaski District of Nepal. Future development in Nepal is dependent on capturing the hydropower potential, and the construction of reservoirs is a major dilemma. The Kulekhani reservoir (also known as Indra Sarobar reservoir) was developed in the early 1980's and is one of the major sources of electricity for Kathmandu. The construction of a 114 metre high rock filled dam created a reservoir of about 2 square kilometres in size, has a capacity to generate 92 megawatts of hydro-power (Phases I and II) and cost about a billion rupees.

The watershed area is in a fragile physiographic region which experience intense monsoon rainfall events. The land use is very intensive and with the high population pressure it is difficult to meet production demands. As a result conservation measures are inadequate and the erosion problem in the watersheds causes severe problems with sedimentation of lakes and reservoirs. To develop a soil conservation strategy and to arrive at a watershed management plan for the reservoir and hydropower generation it was essential to initiate a sediment monitoring program for the reservoir.

The Department of Soil Conservation initiated a sedimentation survey program in 1990 and considerable monitoring has taken place since that time. Sedimentation surveys have been carried out in Phewa, Begnas and Rupa Lakes and the Kulekhani reservoir. However, Begnas and Rupa lakes require additional monitoring for analyzing the sedimentation rates. This paper summarizes the efforts carried out by the Department of Soil Conservation (1993a, 1994a) in the monitoring of the sedimentation of Phewa Lake and the Kulekhani reservoir.

2. WATERSHED DESCRIPTION OF KULEKHANI RESERVOIR AND PHEWA LAKE

2.1. Phewa Watershed

The Phewa watershed is situated in the western part of the Pokhara Valley in the Kaski District (Western Development Region of Nepal), covers an area of approximately 123 square kilometres and has a mean annual rainfall rate of more than 3,500 mm/year.

The lowest part of the watershed is the outlet of Phewa Lake with the elevation of 793 metres, and the highest area in the watershed is the Panchase ridge in the west, at 2,589 metres elevation. Harpan and Andheri Khola are the major tributaries draining into the lake.

In the Phewa Tal watershed, agriculture constitutes about 39 % of the land use whereas forestry covers about 44 %, shrubland about 3 % and grazing lands another 3 %. The reservoir covers about 435 hectares and the remaining uses include barren lands, orchards, gullies and landslides. Of the 39 % of agricultural land (4,728 hectares) only 38 hectares consist of sloping terraces and about 84 % are level terraces with 8 % classified as valley cultivation and 7 % as cultivated fans (Table 1).

Nine percent of the watershed area has slopes steeper than 60 % and about 55 % of the watershed area is in the 30-60 % slope category. Of the remaining land, 18 % has slopes between 16-30 % and 11 percent has slopes less than 15 % (Table 2).

Table 1. Present land use status of Kulekhani and Phewa Watersheds.

Land Use Category	Phewa Tal Watershed		Kulekhani Watershed	
	Area (hectares)	Percent	Area (hectares)	Percent
Sloping Agriculture	38	0.3	4254	34.0
Level Terrace	3988	32.5	237	1.9
Valley Terrace/ Fans/ Tars	701	5.7	713	5.7
Forest	5431	44.3	5455	43.6
Shrubs	345	2.8	1147	9.2
Grazing and Grass lands	371	3.0	200	1.6
Barren / Rock Field	42	0.3	50	0.4
Lake	435	3.5	216	1.7
Gullies / Landslides	83	0.7	18	0.2
Others	829	6.8	210	1.3
Total	12263	100	12500	100

Table 2. Slope status of Kulekhani and Phewa Watersheds.

Slope Category	Slope in Percent	Phewa Tal (Percent)	Kulekhani (Percent)
I	< 15	11	9
II	16 - 30	18	28
III	31 - 60	55	52
IV	> 61	9	9
Lake/Wetlands		7	2

2.2. Kulekhani Watershed

Kulekhani watershed area, which covers 125 square kilometres and lies south west of the Kathmandu valley, is situated in the Central Development Region of Nepal. The watershed is subject to a monsoon climate, which brings rainfalls of about 1500 mm annually.

The outlet of the Kulekhani Reservoir is at about 1500 metres elevation and the south western ridge of Palung Khola marks the summit at 2,621 metres. Tasar, Chitlang and Bisingkhel Kholas are the major tributaries feeding the Kulekhani reservoir.

Agriculture constitutes about 42 % of the watershed area, forestry makes up 44 % of the land use, shrubland covers 9 % and grazing, about 2 % of the watershed. The reservoir, rock fields, landslides and residential areas cover about 3 %. Out of the 42 percent of agriculture land, about 81% are sloping (bari land) terraces and about 18 % are level and valley terraces (khet land) (Table 1).

Nine percent of the watershed area is steeper than 60 % and about 52 % of the watershed area falls into the slope category between 30-60 %. Of the remaining area, 28 % have slopes of 16-30 % and only 9 % have slopes less than 15 % (Table 2).

3. METHODOLOGY

The sedimentation survey is a part of a long-term monitoring effort of the lakes and reservoirs. Water depth of the reservoir is measured with respect to a reference water level and the differences in depth are used to estimate the sediment deposited at the bottom.

The instrument used for the depth measurement is a microprocessor controlled ROYAL RF-350A depth recorder (echo-sounding device). The deposited sediments are measured at several cross-sections along the lakes or reservoirs and the results are related to the original reservoir capacity. The positioning of the survey line is fixed by stretching a rope between the bench marks so that measurement can be made along the same fixed line year after year. The rope is marked at 25 metre intervals and these positions are recorded during the echo-sounding survey. This ensures that an accurate record of the locations of the boat with reference to the bench marks is maintained. The sounding is carried out during calm (windless) weather to assure easy boat handling and accurate measurements along the straight line of the rope.

The echo-sounder is a very precise instrument for water depth measurements. However, some errors may occur due to differences in site conditions. Calibration of the instrument is carried out by comparing manual readings with the depth measured by the echo-sounder and this gives results with accuracies in the plus/minus 10 cm range.

4. SEDIMENTATION SURVEY

4.1. Phewa Tal

Sedimentation surveys of Phewa lake were carried out in March 1990, May 1991, April 1992, December 1992 and January 1994 using 12, 11, 12, 15 and 18 fixed lines of measurements respectively. The base map of the reservoir was prepared using enlarged aerial photographs, and the distance of echo-sounding lines were measured using tachometric surveys in 1990 and 1992 by the staff of Nokia Cables Ltd.

4.2. Kulekhani

Sedimentation surveys of Kulekhani reservoir were carried out in March 1993, December 1993 and September 1994 using 18, 30 and 32 fixed lines of measurements respectively (Department of Soil Conservation and Watershed Management 1993, 1994). The base map of the reservoir was prepared from enlarged aerial photographs taken in 1986 and the distance of echo-sounding lines was measured by theodolite surveys.

5. RESULTS AND DISCUSSION

5.1. Phewa Tal

5.1.1. BATHYMETRIC MAP AND RESERVOIR CAPACITY

A bathymetric map of the lake was prepared at a scale of 1:10,000 based on the January 1994 sediment survey. During the highest water level, the area of the lake was 435 hectares in size and the gross capacity of the lake was 37.76 million m^3 (January 1994). With the reference water level at 794.15 the maximum depth of the lake is 23.4 m and the average depth is 8.70 m.

5.1.2. SEDIMENT DEPOSITED

The results indicate that the estimated annual sediment deposits in the whole Phewa lake area vary from 175,000 to 225,000 m^3. In the silt trap, the sedimentation rate varied between 90,000 and 120,000 m^3. The total estimated average sediment delivery rate from the watershed was calculated to be 17.37 m^3 per hectare for the period from 1990 to 1994.

Based on the five years of data and under the assumption that the lake loses its hydropower capacity when 80 % of the water volume is lost, then the lake has a 135 - 175 year lifespan. Annual deposition of about 90,000 to 120,000 m^3, as measured in the 68 ha silt trap area, would mean that the area would be filled up within the next 20 - 25 years. A more detailed record is needed to better understand the sedimentation process in the main lake area and the data needs to be analyzed statistically.

5.2. Kulekhani

5.2.1. BATHYMETRIC MAP AND RESERVOIR CAPACITY

Based on the sedimentation survey of September - October 1994, a bathymetric map of the reservoir was produced at the 1:7,400 scale, using 10 metre contour intervals (Figure 1). With reference to the highest water level (+1530.2 m), the area of the reservoir is about 216 hectares in size and the gross capacity of the reservoir is 72.41 million m^3 (October 1994).

5.2.2. SEDIMENTATION

A tremendous sedimentation rate was observed in the Kulekhani reservoir during and after the monsoon seasons of 1993 (between March to December) and 1994 (December 1993 to October 1994). With respect to the reference water level (+1530.2 m), the maximum decrease in the maximum water depth during the 1993 monsoon is 18.17 m, whereas the maximum decrease in the average cross-sectional water depth is 6.56 m. Similarly, during the 1994 monsoon season the maximum water depth in the main reservoir sections decreased to 3.29 m, and the maximum decrease in the average cross-sectional water depth was 1.83 m.

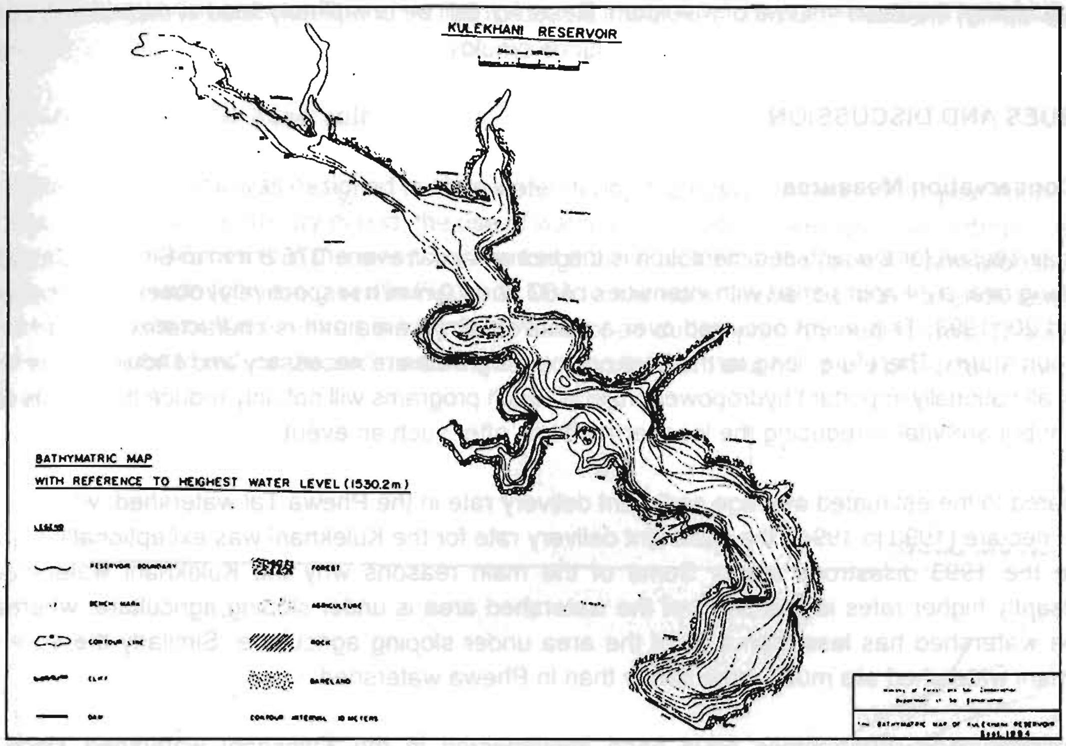

Figure 1. Bathymetric map of Kulekhani Reservoir.

The reservoir capacity is computed by multiplying the mean of the average depths of two cross sections by the area of the reservoir surface between those two sections. The gross capacity of the reservoir was reduced by 12.89 million m^3 of which 5.12 million m^3 were added during the 1993 disastrous monsoon storm and about 1.07 million m^3 were added during the 1994 monsoon season. If the sediment is distributed evenly throughout the watershed areas of 125 square kilometres, the annual sediment contribution rate accounts for about 45 m^3 per hectare before March 1993. During the 1993 monsoon season this rate increased to 410 m^3/ha and for the 1994 monsoon season we calculated the rate to be about 85 m^3/ha. The sediment contribution rate for the 1993 monsoon season was 10 times higher than during normal years, and for the 1994 monsoon, the sediment contribution rate was about twice the normal rate.

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 m^3 less than the gross capacity of the reservoir before the storm (85.30 million m^3). The capacity of the reservoir in October 1994 was further reduced to 72.41 million ^{3}, which is 12.89 million m^3 less than the original gross capacity of the reservoir (85.30 million m^3).

Considering the lower part of the intake (i.e. +1471 m) as the dead level, then the dead volume was reduced by 8.45 million m^3 by October 1994 out of total 11.2 million m^3. This translates into 75.4 % of the dead volume. If the trend remains the same and if no major conservation effort is made, the dead volume of Kulekhani Reservoir will be completely filled in less than 5 years.

Similarly, if the upper part of the intake (i.e. +1476 m) is considered as the dead level, the dead volume was reduced by 6.33 million m^3 by October 1994 out of total 11.2 million m^3 which translates into 56.5 %

of the dead volume. If the trend remains same and if no major conservation effort is made, then based on this calculation the dead volume of Kulekhani Reservoir will be completely filled in the next 10 years.

6. ISSUES AND DISCUSSION

6.1. Conservation Measures

The main reason for the high sedimentation is the heavy rainfall event (376.8 mm in Simlang and 535 mm in Tistung over a 24 hour period with intensities of 67 and 70 mm/h respectively) observed between July 19 and 20, 1993. This event occurred over a relatively small area and is characterized as an unusual monsoon storm. Therefore, long term conservation programs are necessary and should be the integral part of all nationally important hydropower projects. Such programs will not only reduce the effects of such a storm but are vital in reducing the long term effects after such an event.

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 the Kulekhani was exceptionally high even before the 1993 disastrous storm. Some of the main reasons why the Kulekhani watershed has significantly higher rates is that 34 % of the watershed area is under sloping agriculture, whereas the Phewa watershed has less than 1 % of the area under sloping agriculture. Similarly the soils in the Kulekhani watershed are much more sandy than in Phewa watershed.

Soil conservation programmes have been implemented in the Kulekhani watershed since 1978 (Department of Soil Conservation and Watershed Management, 1992). The main conservation measures were: planting of trees and grasses on degraded lands, introducing fruit trees, 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 the soil conservation programme in the watershed is insignificant compared to the needs. Slope failures and stream bank cutting contribute tremendously to the sediments in the reservoir. It is very important to stabilize these activities particularly when it involves infrastructure like the dam, bridges and settlement areas. Since implementation through people's participation is the main strategy, and productivity conservation is the main theme of the soil conservation programme, local people are not keen to participate in stabilizing landslide and stream bank protection as these activities are less oriented towards productivity conservation considering the effort it requres.

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 the projects (such as hydro-power) which are directly affected by the sedimentation.

6.2. Sediment Management within the Reservoir

About 1.5 million m^3 of sediment were deposited in the reservoir above the dead volume area. Due to hydro-power generation, the water level before the monsoon is well below and most parts of the reservoir surface above the dead level are exposed. Therefore, flushes of sediments to the front and mid parts of the reservoir are likely to occur at the beginning of each monsoon season. The October 1994 survey showed that during the 1994 monsoon, up to 1.13 million m^3 of sediments entered the dead volume area, whereas in the area upstream of the dead volume area, erosion rates of 68 thousand m^3 were measured. Therefore, management of the sediment within the reservoir is also equally important for the reservoir protection. More than 66 % of dead volume and about 15 % of live volume has been reduced since its construction in 1982. Reduction in live volume produces less electricity whereas filling of dead volume will stop hydro-power generation. Therefore, all probable measures to stop sediment (either from the watershed or reservoir) reaching the dead volume should be made.

6.3. Water Levels in the Reservoir

The Kulekhani Reservoir was designed to store water during the monsoon season for year-round hydro-power generation. During the dry period, the use of water for the hydro-power generation drops the water level by more than 40 metres in the reservoir. The longitudinal profiles of the reservoir and probable water levels before the monsoon are given in Figure 2. Due to low water levels, the flush of sediments to the front and mid parts of the reservoir is very likely to happen during premonsoon storms. Therefore, all probable measures to reduce the sediments from reaching the front and mid parts of the reservoir should be taken.

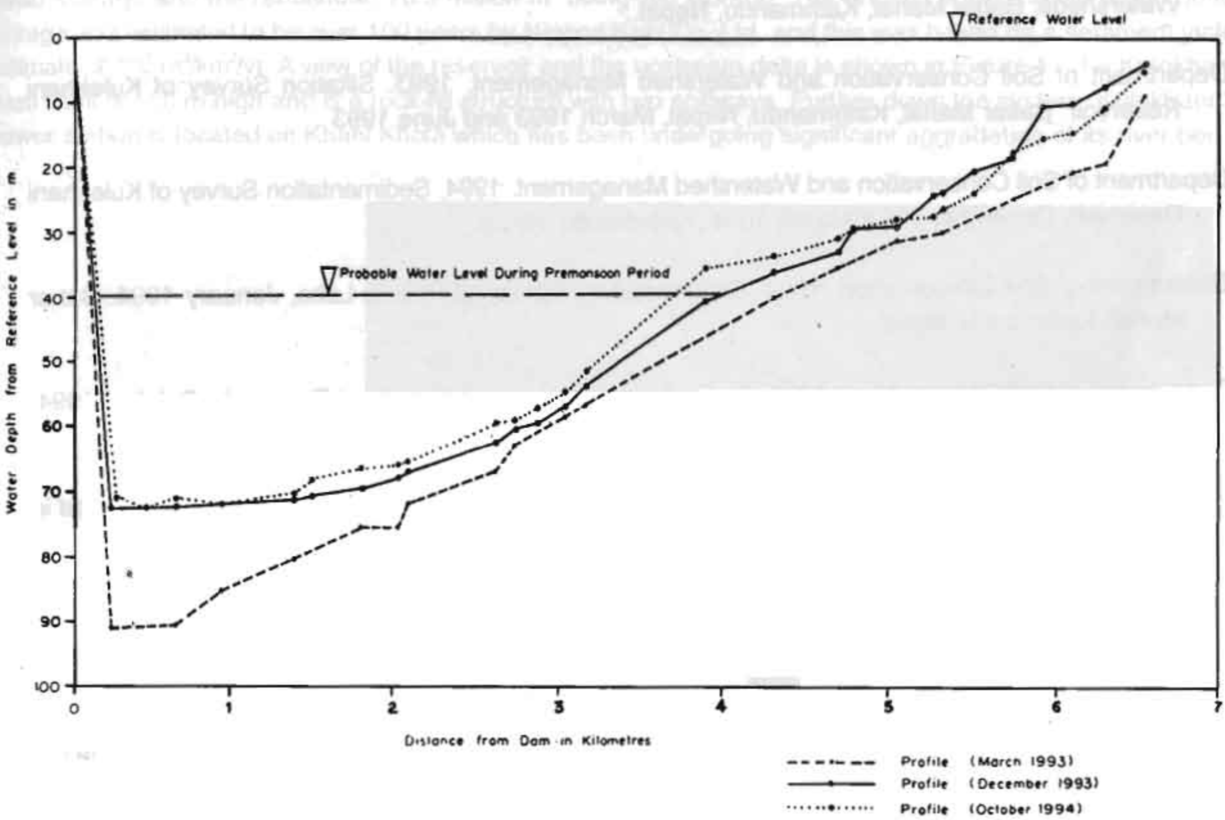

Figure 2. Longitudinal profile of Kulekhani Reservoir.

6.4. Discussion

It is nature's law that reservoirs will fill up with sediments one day. The issue is how the life span of the reservoir could be lengthened. Huge amounts of sediments are still in transit from the source to the reservoir. Monitoring of the sediment transport to the reservoir is essential for the necessary countermeasures 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 above the dead volume area.

The observed annual sediment delivery rate from the Kulekhani watershed is much more than the designed rate of about 18 m^3 per hectare. The current rates drop 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 (Sthapit 1994). Therefore, realizing the risk and the dramatic effects of monsoon storms, future hydro-power generation projects need to be designed to account for unusual events and very high sedimentation rates. Only then can we hope to materialize the great hydro-power potential available in Nepal. Otherwise the blessing will turn into a curse!

7. REFERENCES

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