A Review on Status of Sediment Studies in Nepal

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ABSTRACT

Hydrological data on sediments and water discharge are needed for monitoring, planning and managing water resources projects. In this context, different government departments, and other non-government and international organizations and academic institutions have carried out several sediment studies of many water resources projects in Nepal. Most of those projects have developed sediment data sets on a river channel/ basin scale. These works on sediment yield studies are widely scattered. The present article attempts to briefly present those studies during various periods in the context of Nepal.

Key Words : Review, Sediment, Nepal

1. INTRODUCTION

For the purposes of monitoring, planning and management of water resources projects, what is of fundamental importance is the data and information on river sediment and discharge. In this context, different governmental departments, and other non-government and international organizations and academic institutions have carried out sediment studies of several water resources projects in Nepal. These works on sediment yield studies in Nepal are widely scattered. With a view to compiling and preparing a report on such sediment studies undertaken in various projects, a study work entitled "Preparing Report on Sediment Studies Carried out in Major Projects" was completed by GIS & Integrated Development Center under the sponsorship of the Department of Hydrology and Meteorology (DHM, 2007).

2. THE ROLE OF THE DEPARTMENT OF HYDROLOGY AND METEOROLOGY

The Department of Hydrology and Meteorology has been collecting suspended sediment samples by depth integrating method using USGS samplers and methodology. Sediment sampling was mainly started on demand basis in the past, resulting in about 27 sediment sampling sites as shown in the Table 1. But due to remoteness, and budgetary constraints, DHM could not continue samplings at all these 27 sites. Sediment data records are of the short duration. Available data are also reported to be inconsistent with time and space.

In recent years, due to increasing importance and demand of river sediment data, the role of the department in collecting and monitoring of such data has been increased. To enable users to assess the annual load by providing reliable and long term data series on sediment concentration, DHM introduced improved method of sampling and also redefined the frequency of sampling during monsoon, pre and post monsoon, and winter seasons. Evaporation technique is replaced by filtration technique. Presently, 22 river monitoring sites (Table 2) exist for regularly monitoring suspended sediment.

Only these twenty-two sediment sampling locations are still not enough to fulfill the data gaps for regional studies. More physical locations have yet to be covered by establishing additional networks. The large basins like Koshi, Karnali and Gandaki can not be regionalized as the individual units because

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Table - 1: Sediment Sampling Stations

S. No.	River and locations		S. No.	River and locations
1	Arun River at Uwagaun		15	Marsyangdi at Bimal Nagar
2	Bagmati River at Chobhar		16	Narayani River at Devghat
3	Bagmati River at Pandheradobhan		17	Rapti River at Bagaswoti
4	Bagmati River at Samphkhel		18	Rapti River at Jalkundi
5	Bheri River at Jamu		19	Sapta Koshi at Chatara
6	Burhi Gandaki at Arughat		20	Sarada Khola at Daredhunga
7	Kali Gandaki at Setibeni		21	Seti River at Belgaun
8	Kankaimai River at Mainachuli		22	Seti River at Chainpur
9	Karnali River at Asaraghat		23	Seti River at Phulbari
10	Karnali River at Chisapani		24	Sunkoshi at Kampughat
11	Kulekhani Khola at Kulekhani		25	Tamur River at Mulghat
12	Lothar Khola at Lothar		26	Trijuga River at Fatehpur
13	Mahakali at Pancheshwar		27	Trishuli River at Betrawati
14	Mai Khola at Rajdwari			

the rock hardness factor varies widely from high Himalayas to Siwaliks. It is, therefore, necessary to carry out sediment study by dividing large catchments into several relatively homogeneous units.

Debris flows in gullies are the significant carriers of the huge amount of mass waste into the rivers. Hardly field measured data on bed loads are available in Nepal. Hence, it is high time to start bed load sediment data collection for the selected rivers in Nepal.

DHM has to extend its cooperation with other institutions in sediment monitoring and assessment on Nepalese streams/rivers/watersheds by starting collaborative research with recognized universities.

3. MAJOR SEDIMENT STUDIES IN NEPAL

The present article is based on the data and information from various sources and the aforementioned document "Preparing Report on Sediment Studies Carried out in Major Projects". The following paragraphs briefly outline the methodologies used and findings from the various sediment studies during various periods.

3.1 KARNALI (CHISAPANI) MULTIPURPOSE PROJECT, 1987

Galay (1998) reviewed of the past records, some preliminary sediment computations, and regional data from India and Pakistan. A wide range of data scatter for the suspended concentrations for the Karnali River at Chisapani was observed. The report summarizes the previous estimates of total sediment load to be 93.5 Mt/yr by Nippon Koei (1987), 150 Mt (suspended load of 137 Mt and its 10% as the bed load) by Snowy Mountains Hydroelectric Authority, 1966 (DHM, 2007), and 126 Mt (with 20% for bed load) by Norconsult-Electrowatt, 1976 (DHM, 2007). Estimates by Nippon Koei and SMHA are based on the surface measurements taken in 1963 and 1964. From the preliminary computation, the total sediment load equal to the summation of wash load, bed-material load, and bed load, amounted to 74.2 M m3/yr. This load amounts to a sediment yield of 1730 m3/km2/year or 2422 tons/km2/year.

Table 2: Lists of the Station and Their Location under DHM

SN	Station Number	River	Name of Site	Basin	Area, km2	Elev. m	Latitude °N			Longitude °E		
							deg	min	sec	deg	min	sec
1	120	Chamelia	Karkale Gaon	Mahakali	1150	685	29	40	20	80	33	30
2	240	Karnali River	Asara Ghat	Karnali	19260	629	28	57	10	81	26	30
3	256.5	Budhi Ganga	Chitre, Mangalsen	Karnali	1576	506	29	9	24	81	12	30
4	260	Seti River	Banga	Karnali	7460	328	28	58	40	81	8	40
5	270	Bheri River	Jamu	Karnali	12290	246	28	45	20	81	21	0
6	280	Karnali River	Chisapani	Karnali	42890	191	28	38	40	81	17	30
7	286	Sarada Khola	Daredhunga	Babai	816	579	28	17	58	82	1	30
8	339.3	Jhimruk Khola	Cherneta	W. Rapti	653	738	28	3	24	82	48	59
9	350	Rapti River	Bagasoti	W. Rapti	3380	381	27	54	0	82	51	0
10	360	Rapti River	Jalkundi	W. Rapti	5150	218	27	56	50	82	13	30
11	406	Kali Gandaki	Kusma	Narayani	NA	667	28	12	0	83	42	0
12	420	Kali Gandaki	Kota Gaon	Narayani	11400	198	27	45	84	84	20	50
13	430.5	Seti River	Damauli	Narayani	1388	305	27	56	0	84	15	0
14	439.6	Marsyangdi	Japhate	Narayani	2950	610	28	122	13	84	24	11
15	445	Burhi Gandaki	Arughat	Narayani	4270	485	28	2	37	84	48	59
16	448	Tadi Khola	Belkot	Narayani	653	475	27	51	35	85	8	18
17	450	Narayani	Devghat	Narayani	31100	180	27	25	30	84	25	50
18	625	Sunkoshi River	Dolalghat	Koshi	NA	NA	28	38	30	85	43	0
19	647	Tamakoshi	Busti	Koshi	2753	849	27	38	5	86	5	12
20	690	Tamur River	Mulghat	Koshi	5640	276	26	55	50	87	19	45
21	695	Koshi River	Chatara	Koshi	54100	140	26	52	00	87	09	30
22	795	Kankai	Mainachuli	Kankai	1148	125	26	41	12	87	52	44

3.2 SEDIMENTATION PROGRAM 1989 MONSOON SEASON, KARNALI RIVER AT CHISAPANI, 1989

The Himalayan Power Consultants (HPC), with the help of a combined team of DHM permanent staff at site and Project site staff, carried out the sedimentation program during 1989 monsoon season in the Karnali River at Chisapani for the purposes of the Karnali (Chisapani) Multipurpose Project under the supervision and assistance provided by an HPC Sedimentologist. A total of about 750 samples were collected during the period from June to September, inclusive. Based on the intensive field works, a provisional correction factor of 1.3 to convert information from the partial to full depth, and a bed load as 15% of suspended load, the sediment load was calculated to be 147,971 Kt.

3.3 PANCHESHWAR MULTIPURPOSE PROJECT

Adopted from: Field Investigations Within Nepal Territory: 1) Vol. II/10 Sedimentation Investigations, Draft Final Report, 1990, 2) Vol. VII /Appendix E Sediment Data, Draft Final Report, 1990, and 3) Summary of Field Activities, Final Report, 1991.

A total of 467 suspended sediment samples within Nepal Territory in 1991 were taken at the dam site from cableway during the period from July 1989 and 1990 monsoon by the Pancheshwar Consortium. Based on catchment area (12,300 km2), the long term annual suspended sediment discharge was estimated at 90 Mt with the bed load entering the reservoir to be 31.69 Mt/year, thus the total sediment load being about 122 Mt/year. Based on mean annual discharge, and using the annual sediment deposition rates in Indian sub-continental reservoirs and selecting the upper envelope line for design, the annual sediment was found to be 100 Mt. The average of these two amounted to 111 Mt as the long-term annual sediment load at the Pancheshwar dam site. But the 1990 suspended sediment measurement results show the value to be 50 Mt, and considering bed load to be 20%, the total load seems to be 60 Mt. But the final recommended value was taken to be 66 Mt/year or 47 M m3/year by increasing further 10%.

3.4 BUDHI GANGA (BG-0) HYDROPOWER PROJECT, FEASIBILITY STUDY, MAIN VOLUME, 1998

METCON Consultants presented estimates of sediment yield based on some regionalization procedures one of which was based on the DHM sediment data (1974-1982) from Seti River. Other methods consisted of Himalayan Sediment Yield Technique (HSY), Khosla Procedure, Varshney Formula, and Sediment yield estimation model for Nepalese watershed. Finally the estimate given by HSY technique was adopted to be about 3,237,450 tonnes/yr and 3,390 tonnes/km2/yr. Budhi Ganga River at the headwork site drains an area of 955 km2.

3.5 SIKTA IRRIGATION PROJECT: INTERIM FEASIBILITY STUDY REPORT, 2003

The study team used the four year sediment data of the Rapti River at Jalkundi, the gauging site being operated by the Karnali West Rapt River Basin Office in Surkhet under DHM. The desilting basin was designed to settle suspended particle size up to 0.2 mm. Based upon the mean monthly concentration of silt available for the period from 1997 to 2001 from DHM; the average silt concentration was obtained to be equal to 5874.5 ppm. The desilting basin is designed to drop D50 up to 5521 ppm.

3.6 FEASIBILITY STUDY ON RAJKUDWA IRRIGATION PROJECT, 1993

Nippon Koei Co. Ltd. in association with Hokkaido Engineering Consultants co. Ltd. under JICA for the Ministry of Water Resources in 1993 carried out suspended sediment load sampling during the study period in the proposed headwork of the Gudrung River, the Kondre River 500 m downstream of its confluence with the Rajkudwa River, also at its (Kondre's) crossing with the East West Highway, and the Belwagurdwa River at the crossing of the same highway. Based upon field observations involving bed materials sampling, river characteristics, and conditions, the sediment load by discharge was estimated. From the sediment sampling, it was observed that the suspended load content of the Kondre River varies from 16 mg/l to 7,480 mg/l, and that of the Gudrung River ranges from 4 mg/l to 96 mg/l. Several bed load collections were carried out during the study period, using bed load collectors, and were analyzed in the laboratory, regarding particle size and specific gravity.

The sediment load was estimated by discharge varying from 1 to 20 m3/sec for the Gudrung headworks site as shown in the Figure-1. The total sediment load at 20 m3/sec amounted to 14.316 kg/s, the bed load being 9.600 kg/s. The formula developed by Kalinske and Brown had been used for estimating bed load with a particle size not over 40 mm due to the limitations of the intake screen spaces. Suspended load was estimated based on field observations and the Lane-Kalinske formula.

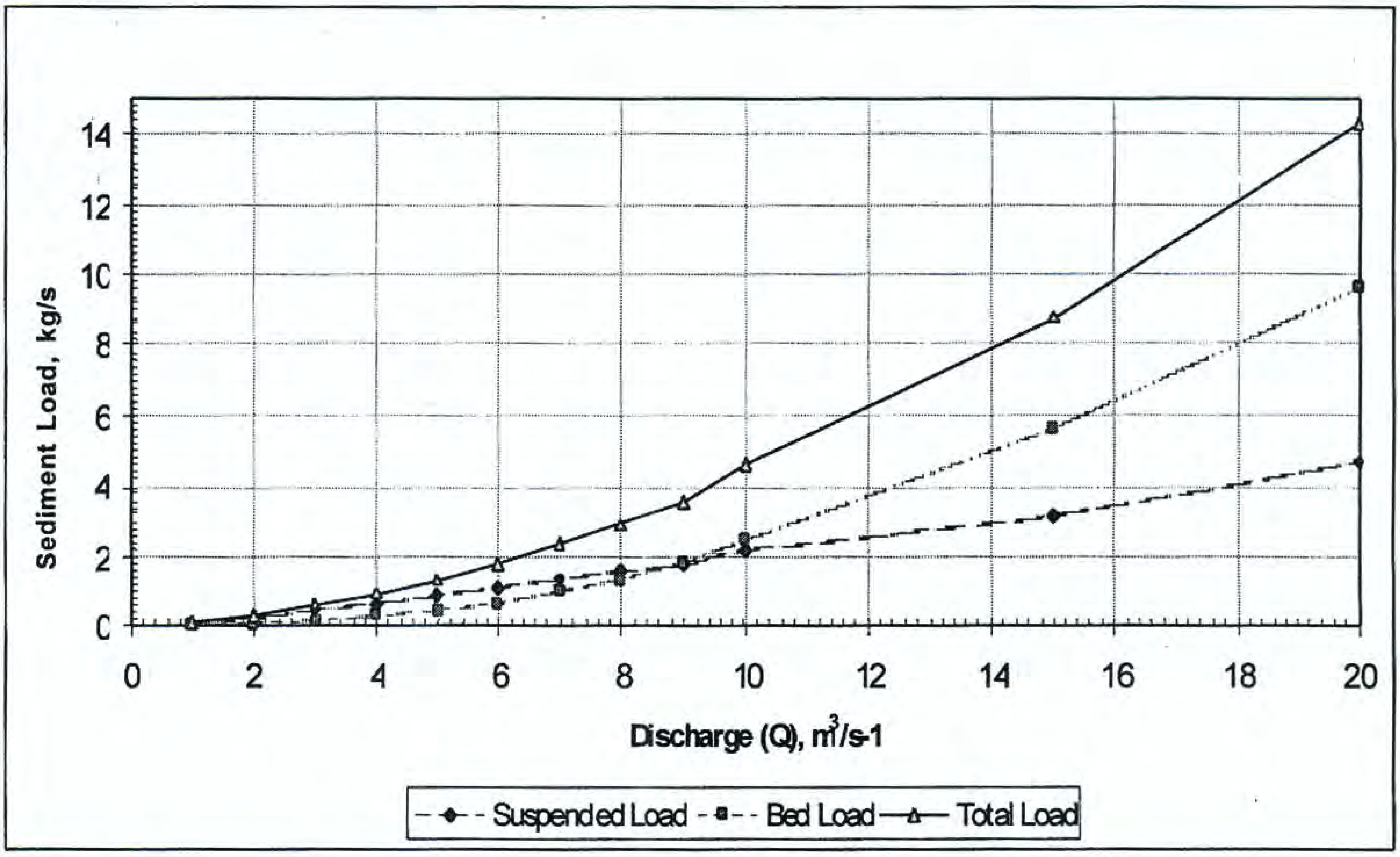

Figure 1: Rajkudwa Irrigation Project: The Resulting Sediment Load Estimated by Discharge up to 20 m^3s^{-1} for the Gudrung Headworks Site (Drawn based on the resulting data given in the study report)

3.7 SIMPLIFIED METHOD OF SEDIMENT MONITORING AND ESTIMATION: A CASE STUDY OF THE NARAYANI RIVER 2007

Sharma and Kharbuja (2007) carried out a research experiment in Narayani River near Narayanghat with a view to finding out whether a simplified method of sediment monitoring and estimation could be made available to be used in difficult conditions where the standard sediment sampling method would not be possible due to unavailability of standard equipment and skilled human resources.

In Nepal, the standard method consists of using the Depth Integrated sampling technique to monitor the sediment transport by a river. In this method, lowering and then lifting a sampler at uniform speed collect one sediment sample from each vertical section of a river. Thus, few numbers of samples from several (seven equally spaced) vertical sections are taken to obtain a mean sectional sediment concentration. The simplified method that was used during this research experiment consisted of the simple procedures of sediment sampling at 8:00 A.M. with a 500 ml sampling glass-bottle from free water surface at a convenient distance of 30 cm from the river bank for consistency in regular sampling. The local gauge reader was trained to do the sampling work. The samples were analyzed by filtration method at the site; and the dried samples were sent to the sediment laboratory in DHM in Kathmandu. This experimental study was carried out during monsoon season in 2002 and 2003.

A sediment rating curve was obtained by establishing a relationship between bank sediment concentration (simplified sampling) and mean sectional sediment concentration (standard sampling) sampled at different water level stages.

The simplified method of sampling was found satisfactory. Therefore, this method could be used for long-term monitoring and estimation of sediment in difficult conditions. A sediment rating curve for the Narayani River shows a good correlation over a range of values obtained during the monitoring period. For this, a regression analysis had been carried out, resulting into the following model for the best-fit curve with Scm as the mean sectional sediment concentration of river cross section (mg/l) and Scb as the sediment concentration on the bank (mg/l), the coefficient of determination (R2 being 0.85):

$$Scm = 7.2\ Scb0.81$$

This can be used to transform sediment concentration values obtained from simplified samples to mean sectional sediment concentration. The daily sediment transport rates, Sy (tons/day) at the gauging site can then be obtained from the computed mean sectional sediment concentrations, Scm (mg/l), using the mean daily flow rate (m3 s-1) obtained from discharge rating curve, by using the following equation:

$$Sy = 0.086\ Scm\ Q$$

For the periods from July 1 to September 30 in 2002 and 2003, the averages of computed daily mean sectional sediment concentrations were respectively 2,809 and 4,987 mg/l with the corresponding cumulative sediment flux being 88 Mt and 191 Mt, and corresponding specific annual sediment yield being 2,835 and 6,153 t/km2. Although the simplified method can be beneficially be used in the remote areas with difficult conditions, the research paper recommends the regular updating of the calibration curve.

3.8 DETAILED SEDIMENT STUDY OF SUNKOSHI AND MARSYANGDI RIVERS OF NEPAL, 2001

Hydro-Engineering Services (P) Ltd. under the sponsorship of the Water and Energy Commission Secretariat carried out field works in Sun Koshi River at Hampachuwar and Marsyangdi River at Bimal Nagar. The samples were collected once a week plus during the rainy days of 2000. Data analysis showed that the annual sediment load of Sun Koshi River at Hampachuwar based on resulting sediment data for the year 2000 amounts to about 190.39 Mt. Based on the area proportional method, the yearly sediment load for the Sun Koshi River at Kampu Ghat was estimated to be about 184.88 Mt for the year 2000. Similarly, for Marsyangdi River at Bimal Nagar, the annual sediment load had been computed to be about 18.1 Mt.

3.9 THE FEASIBILITY STUDY ON TRISHULI IRRIGATION PROJECT, FINAL REPORT VOLUME I, MAIN REPORT, 1997

The balancing reservoir constructed under the Trishuli Hydropower Project in 1970 had suffered progressive sedimentation. NEA commenced dredging of the reservoir in 1976 up to 1986. Cross section survey in 1986 showed the sedimentation amount to be at 430,000 m3. Chuo Kaihatsu Corporation had carried out the Feasibility Study on Trishuli Irrigation Project in 1997. Sediment data on Trishuli River from 1977 to 1979 were used to assess the monthly sediment concentration and annual sediment inflow into the reservoir. Recommended monthly sediment concentration as per the F/S Report on Trishuli-Devighat Hydropower Upgrading Project (August 1990) is shown in Figure 2.

3.10 SEDIMENT STUDY OF BAGMATI RIVER, 1995

Yogacharya and Bhusal (1995) made assessment on the suspended sediment load in Bagmati River, and also analyzed the seasonal variation, the relation with river flows, and daily rainfall over the basin for the period from 1973 to 1977.

Data used consisted of suspended sediment concentration and discharge measurements of Bagmati river at Pandheradobhan and at Gaur for the monsoon period of 1994, suspended sediment concentration and computed river flows of Bagmati

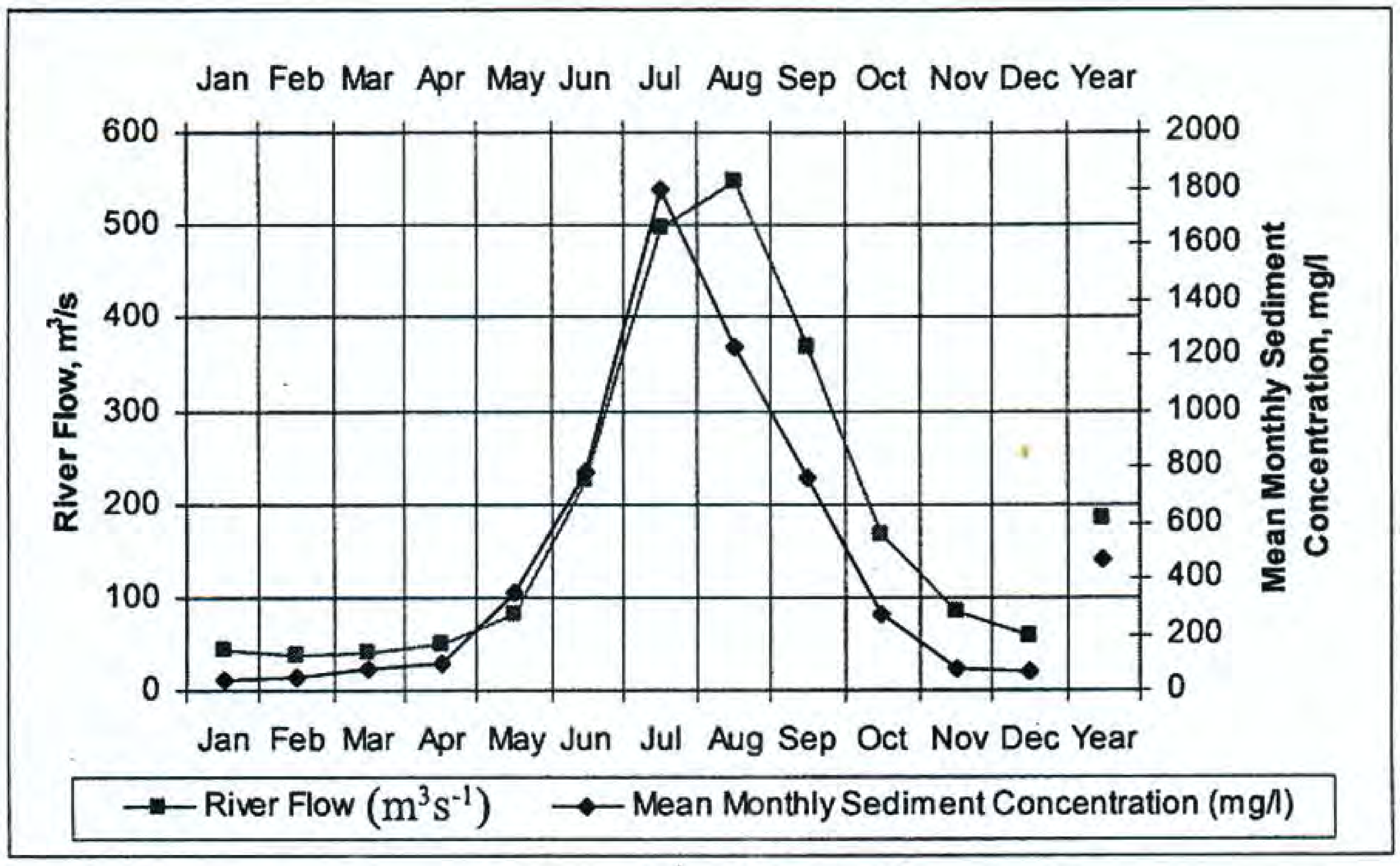

Figure 2: Recommended monthly sediment concentration for Trishuli-Devighat Hydropower Upgrading Project, F/S Report Aug 1997 (drawn based on the results from the report).

river at Chobhar, and daily rainfall data of Kathmandu Valley for the period of 1973-1977 including information from nine rainfall stations within the Bagmati basin. Based on the observed rainfall data, a year was divided into four periods as winter, Pre-Monsoon, Monsoon, and Post-Monsoon. The relationships of daily total sediment transport (Cs kg/day/km2) with daily total river flow (Q = river flow in m3/day/km2), and daily total basin rainfall (P = Rainfall depth in m3/day/km2) for Bagmati River at Chobhar were derived by regression analysis as below:

- Winter: log Cs = 1.528 * log Q +1.3547 * log P – 5.904 ; r = 82%
- Pre-Monsoon: log Cs = - 1.303 * log Q + 12.83 * log P – 40.7 ; r = 83%
- Monsoon: log Cs = - 1.1546 * log Q + 5.3753 * log P – 13.45 ; r = 98%
- Post-Monsoon: log Cs = - 3.665 * log Q + 0.075 * log P – 9.3 ; r = 94%

A good equation having correlation (90 %) between suspended sediment (Cs kg/day/ km2), river discharge (Q m3/ day/ km2), and precipitation (P m3/ day/ km2) was found on data of Bagmati River at Chobhar gauging station, and is given below:

$$C_s = \frac{1}{325} Q^{1.28} \; P^{0.39}$$

Bagmati river in Terai: With 40 day data, average suspended concentration for Bagmati River amounted to 1522 ppm at Pandheradobhan, and to 813 ppm at Gaur. Maximum suspended concentration at Gaur amounted to 6372 ppm on 15 August 1994. With data from 15 June to 26 September 1994, the average suspended sediment discharge was 57.52 x 106 kg/day. The relationship of suspended sediment concentration with discharges based on data of 13 July – 15 August 1994 gives:

log Cs = 0.4442 * log Q – 1.2976 r = 78%

The result on full range of data series are given below:

Cs = 1.7349 * Q – 924; r = 82%

$Cs = 1.0932 * P - 1642;$ $r = 81\%$
$Cs = 0.6967 * Q + 0.705 * P - 1570;$ $r = 84\%$
$\log Cs = 0.6489 * P + 0.511;$ $r = 64\%$
$\log Cs = 1.5114 * \log Q + 2.0199;$ $r = 88\%$
$\log Cs = 1.276 * \log Q + 0.3899 * \log P - 2.512;$ $r = 95\%$

3.11 SEDIMENT LOAD DATA MANAGEMENT AND SEDIMENT STUDY OF SUNKOSHI RIVER, BAGMATI RIVER AND OTHER RIVERS, 2000

Nepal Consult (P) Ltd., and GOEC Nepal under the sponsorship of the Water and Energy Commission Secretariat compiled and checked data on sediment and sediment study of all the rivers of Nepal which have sediment data in general, and Sun Koshi River and Bagmati River in particular in order to assist in reasonable future forecast of the sediment load vital for reservoirs and decanters.

A rating curve was constructed by log-transforming all data and using a linear least square regression to mathematically determine the line of best fit. Suspended load-rating curves were derived in order to determine total sediment loads for corresponding years. Long-term annual sediment loads and the specific sediment yields were derived for all the stations as shown in the following Figures 3 and 4 respectively.

As a part of regionalization, a simple non-linear regression relationship has been established between the long-term annual suspended load in million tons (Y) and the drainage area in km2 (X), resulting in the following formula as given in the report, with the coefficient of correlation being about 0.85:

$$Y = 0.0011X1.1337$$

The following Figure 3 shows the refined version of the formula with the corresponding coefficient of determination.

Using the regional simple non-linear regression relationship between the long-term annual suspended load in million tons and the drainage area in sq km, the long-term annual suspended sediment load and specific sediment yield from Nepalese territory (147,181 sq km) as given in the report, amount respectively to 795 million tons and 5400 tons/km2. With the refined formula as of the present article, these figures amount to 816 million tons and 5542 tons/km2 respectively.

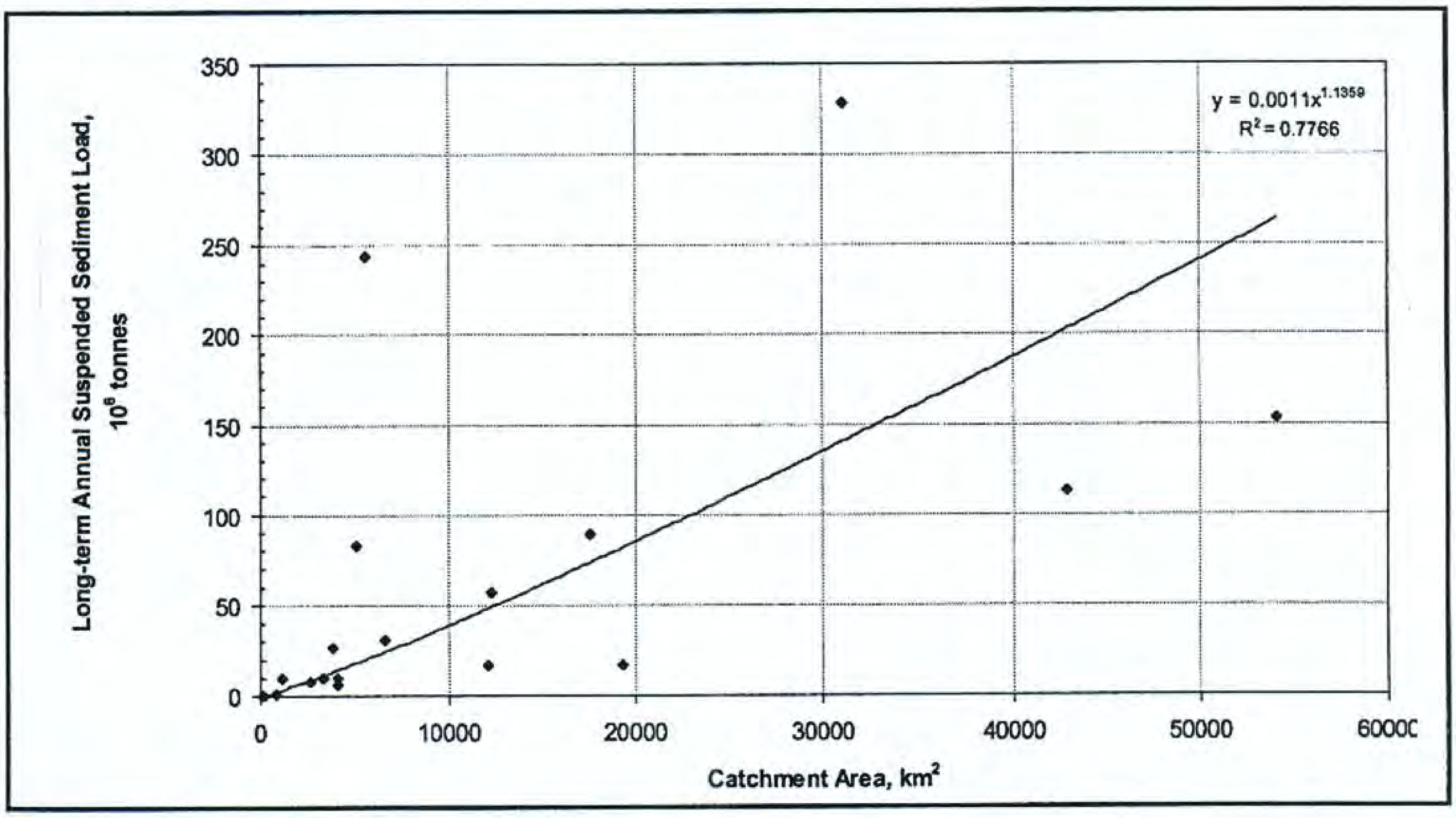

Figure 3: Regression relationship between the drainage area and the long term annual suspended load

3.12 LIKHU-IV HYDROPOWER PROJECT, FEASIBILITY STUDY, 1998

The sediment yield of Likhu Khola reported in the reconnaissance study by EDC, 1994 (DHM, 2007) is 2,030 tons per square kilometer per year. Considering sediment data for Sapta Koshi, Tamur, Sun Koshi and Arun rivers from 1948 to 1977 collected by the Indian Central Water Commission (CWC), and other field observations and various recently published reports, the specific sediment yield (Ys) for Likhu Khola has been estimated to be about 1,331 $tkm^{-2}yr^{-1}$ based on the following regression equation with the coefficient of determination as 0.98:

Specific Sediment Yield, Ys = 18A0.31 *EXP (60q)

Here, A represent the catchment area in km^2, and q is the specific flow in $m^3s^{-1}km^{-2}$.

3.13 DUDH KOSHI HYDRO-ELECTRIC PROJECT: FEASIBILITY STUDY, VOL. IV, 1998

Canadian International Water & Energy Consultants (CIWEC) had made estimates of sediment loads to be used in the feasibility level design of the project. The catchment area at the dam site is 4,100 km2. Because of lack of sediment data in the initial stages of the study, using Himalayan Sediment Yield (HSY) Technique, the total sediment yield was computed to be 7.1 million tones per year.

From the sediment sampling during the period from July to September in 1997 and considering 5% of the monsoon month as the unmeasured sediment load for the remaining period of the year, and also considering 15% allowance for the bed load, the annual sediment for 1997 comes out to be 9.14 Mt, which is higher than that estimated by HSY Technique. Using the 1987 data, the suspended sediment load was found to be 5.1 Mt for that year. Using the sediment rating curve based on 30 year data from DHM for Dudh Koshi River at Rabuwa Bazar, the average annual sediment load for the present study site amounted to 21 Mt/yr which is considerably higher than either the value derived from HSY (7.1 Mt/yr) or the value computed from the 1997 measurements (9.14 Mt/yr). From this following observations are made:

- 1997 measurements were taken in a drier than the normal year; and hence, the lower value.
- The rating curve values take into account the monsoon flows in the wetter years; and hence, the higher value.
- The HSY Technique is less reliable than the measured values as it relies on judgment to assess the effect of landslides and catchment conditions on the sediment yield.

The project study team also carried out the study on reservoir sedimentation during the projected useful life (40 years) of the hydroelectric scheme. The reservoir has a total storage of 687.4 M m^3 of which 442.1 M m^3 is the live storage.

3.14 FEASIBILITY STUDY OF KABELI HYDRO POWER PROJECT, VOL. III & VI, 1998

Nepal Consult (P) Ltd. in association with Hydro-Engineering Services (P) Ltd. had carried out the Feasibility and EIA Study of Kabeli-A Hydropower Project (KB-A) in 1998. Sediment sampling was carried out during the period from 28 July to 30 September 1997. For assessing the sediment yield at different stages of the discharge, a regression equation between the river discharge Q in m3/sec and sediment concentration Sc in ppm was developed as follows:

Sc = 0.00012 Q3.0745

Using this equation, the mean monthly sediment yield based on daily data had been assessed as shown in the Figure 4. This gives the annual sediment yield to be about 1.88 Mt (million tonnes), resulting in the recommended value of the specific yield in the Kabeli basin to be equal to 2.180 $tkm^{-2}yr^{-1}$.

The specific sediment yields of Kabeli River as reported by various investigators are as follows:

- Galay (1998) : 4.050 $tkm^{-2}yr^{-1}$ based on catchment characteristics of different physiographic zones.
- Canadian International Water & Energy Consultants (CIWEC): 3.668 t/km2/year based on sediment sampling in Tamur River from 16 July to 30 September 1997.
- CIWEC: 9.096 t/km2/year based on DHM sediment data of Tamur River for few months in 1978, 1979, 1981, & 1982.

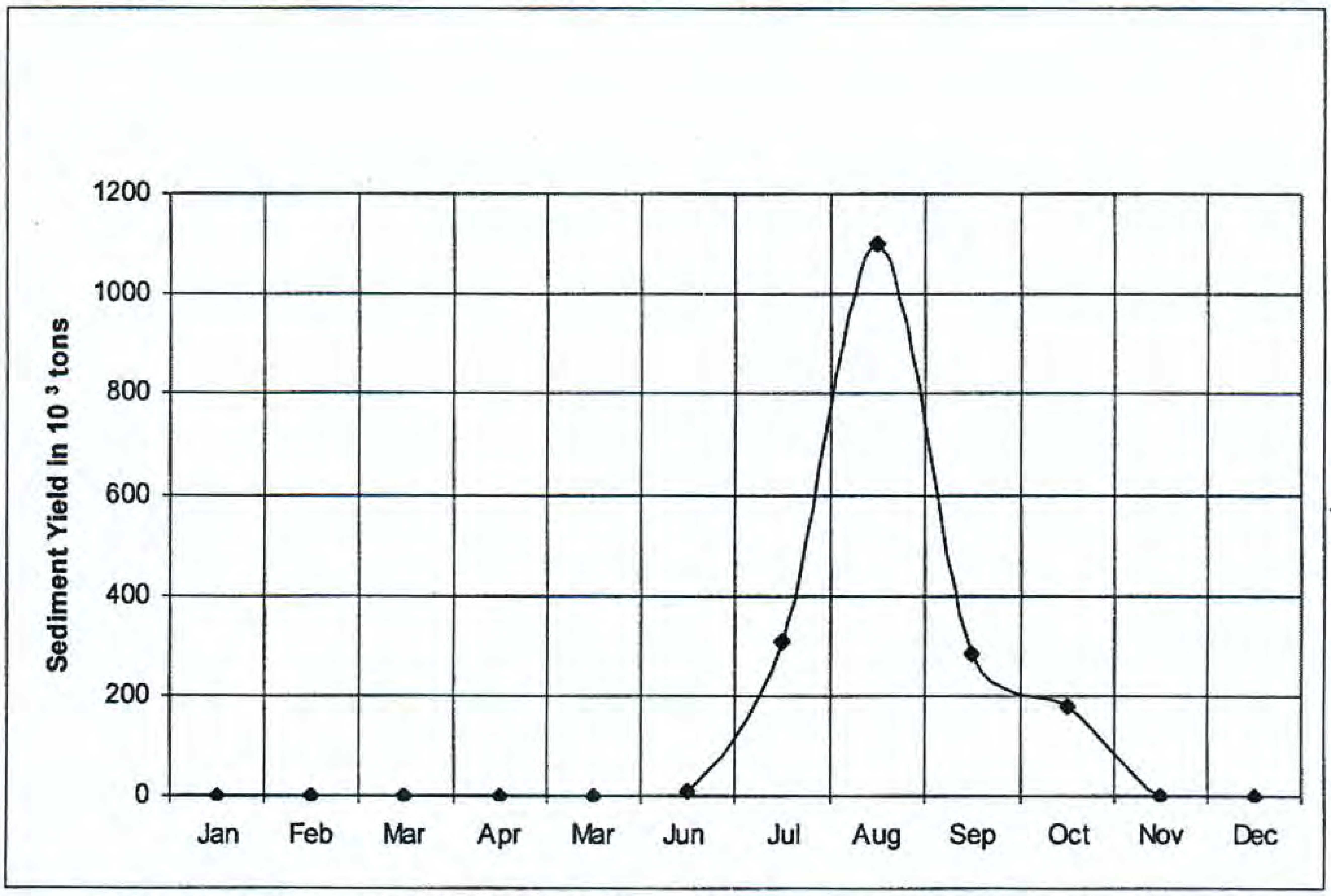

Figure 4: Monthly sediment yield for Kabeli river (Drawn based on the results from the report)

4. REGIONAL STUDIES

4.1 REGIONAL SEDIMENT STUDIES OF RIVERS OF NEPAL, 1989

Yogacharya (1989) assessed the annual sediment loads from the rivers of Nepal on the basis of the available records on the suspended sediments of 15 stream-gauging sites in Nepal, out of which eight are snow-fed and seven rain-fed stations.

Non-linear multiple regression analysis methodology was used to develop the relationship between annual sediment load and mean annual discharge and other watershed parameters like drainage area (km2), basin slope, precipitation (mm), forest cover (%), agricultural area (%), snow cover (%), and rocky and meadow area (%), and finally to estimate the mean annual sediment yield. When all the catchment areas are considered, the total mean annual sediment (suspended) load from Nepal amounts to 640 Mt. Considering 15% of the suspended load as the bed load, the total annual sediment load has been estimated to be about 736 Mt equivalent to about 5260 tons per km2.

4.2 SUSPENDED SEDIMENT YIELD ESTIMATION MODEL FOR NEPALESE WATERSHEDS, 1992

Sharma and Kansakar (1992) used the sediment data from 12 stations to develop the methodology based on regression analysis of the annual sediment yield against the basin descriptors. An exhaustive search multiple regression computer program was used to determine a series of best possible regression equations. Among them, the best regression equation is:

ASY0.5 = -2.20992 + 0.05439 Arock0.5 + 0.0748 A20.5 + 0.05097 MWI0.5

In this relationship, the parameters used are ASY (Annual Sediment Yield, Mt/year), Arock (Area of rock and meadow, km2), A2 (Drainage Area in km2 below 2000 m), and MWI (Monsoon Wetness Index at basin centroid, mm). The best-fit relationship with standard error of regression equation and goodness of fit respectively equal to 4.454 and 0.995 is basically applicable in the Middle Mountain region. Hence, care should be taken to use it for the Himalayan and Terai regions. The model should be updated regularly. The model is applicable to assess the suspended load only. The authors recommend improving the existing network and revising it to include Terai and High Himalayan regions as well, and to monitor the glacier lakes and GLOFS (glacier lake outburst floods).

5. QUANTIFICATION ON BED LOAD SEDIMENT TRANSPORT IN TADI RIVER OF NEPAL, 2007

Bhusal (2007) analyzed bed load sediment data of Tadi river collected by the NISP project and by DHM. The objective is to assess the bed load sediment transport from basin outlet. Three verticals at 1/4, 2/4 and 3/4 sections are chosen for sampling. Bed load sampling was carried out with Helly Smith sampler (weighing 62.5 kg and mouth opening of 0.0762 m). Bed load samplings were carried out in three verticals across the cross section during monsoon and post-monsoon periods only by the NISP project, 2001. In 2006, additional bed load samples were collected for further study. Sampling period included the lean flow period as well. The bed load samples collected in the field are transferred in plastic bags to the laboratory, dried, weighed and sizes distribution determined. Bed load transport through the each section is computed by multiplying the dry weight of sediment with the length of the cross sectional bed that the sample is representing. Summation of all partial sectional data is the total bed load amount through the gauging section. For simplicity, necessary gaps on data series are filled by establishing the following basic relationship (Bogardi, 1974). The dimensionless constants (a, b) of the following equation are estimated from observed data.

$$q^{2/3}S = ad + bq_B^{2/3}$$

where, q_B is the rate of bed load transport (kg/sec/m), and q is specific discharge (m3/s/m2), S is the slope, and d is the particle diameter (m).
The following relationships are established:

Left Bank	For Partial Section, LL:	$q_i^{2/3}S = 0.365\,d + 0.0012\,q_{B_i}^{2/3}$
Center	For Partial Section, LC:	$q_i^{2/3}S = 0.205\,d + 0.0028\,q_{B_i}^{2/3}$
Right	For Partial Section, LR:	$q_i^{2/3}S = 0.254\,d + 0.0013\,q_{B_i}^{2/3}$

Using these relations, bed load transport through the section can be determined satisfactorily for the monsoon and post-monsoon periods. These coefficients need to be verified/corrected for extreme conditions of high flows (high velocities) and low flows.

6. STUDIES IN THE KULEKHANI RESERVOIR

The sedimentation survey of Kulekhani reservoir started by the Nepal Electricity Authority, Engineering Services in 1989, followed in 1993 by the Department of Soil Conservation, while establishing the benchmarks to carry out the survey, with more surveys during 1994. NEA / Nippon Koei made similar survey in 1995 with more benchmarks established, while using Electronic Total Station (ETS). Later in the same year, NEA and Department of Soil Conservation also simultaneously carried out the sediment survey. As a part of annual program, NEA had been carrying out the sediment surveys in various years. All benchmarks had been fixed with geodetic co-ordinates, and all range line lengths checked by ETS. Echo-sounding has also been used during the surveys since 1999.

6.1 SEDIMENTATION STUDY OF KULEKHANI RESERVOIR 1993-1994

The Storage capacity of the Kulekhani Reservoir is 85.3 Mm^3, the dead storage and live storage being respectively 12 and 73.3 Mm^3. Originally, the operating life of the dead storage was estimated to be over 100 years based on the sediment yield of 700 $m^3/km^2/yr$.

The result from the sedimentation survey from 29 December 1993 to 2 January 1994 was used to calculate the sediment deposited in the reservoir. It is stated that the decrease in water depth with reference to bench mark level is related with the sedimentation of the lake. The sedimentation survey of March 1993 was used as the base line information on the reservoir bed with reference to the highest water level (+ 1530.2 m).

The maximum depth during March 1993 and that during December were respectively found to be 90.44 and 72.27 m. This gives the maximum decrease in the maximum water depth to be equal to 18.17 m, resulting in the decrease in the reservoir capacity (sediment deposited) to be 771.12 meters. The gross capacity had been reduced by 10.19 M m3 since its construction, of which 7.71 M m^3 had been contributed from the last disastrous sedimentation. Dead volume was also reduced by 66% in last 13 years.

The CD-ROM (Galay, 1998) prepared by the Institute for Resources and Environment, University of British Columbia, Vancouver BC, Canada for WECS addresses the key issues relating to sediments in Nepalese Himalayas, including sediment sources, dynamics, measuring techniques, yields and transportation, with special reference to hydropower development, forming a chapter on sedimentation in the Kulekhani Reservoir.

6.2 THE REPORT ON THE STUDY OF KULEKHANI RESERVOIR SEDIMENTATION LOADS, 1999

The report submitted by the Mountain Risk Engineering Unit, Tribhuvan University to the WECS in 1999 concluded that the gross storage capacity of the reservoir was reduced to 72.41 Mm^3 between 1981 and 1994. The high intensity of rain of 1993 mainly contributed to this loss. Thus, the gross capacity of the reservoir was reduced by 12.89 Mm^3 (15%) of which 4.8 Mm^3 was contributed by the 19 July 1993 disastrous monsoon, and about 1.07 Mm^3 from the 1994 monsoon. The annual sediment contribution rate accounts for about 45 m^3 per hectare before March 1993 whereas about 410 m^3 for the 1993 monsoon that is 10 times higher than the normal year.

The total sediment volume in the Kulekhani watershed amounts to 5.67 Mm^3 that consists of 2 Mm^3 from landslides, 3 Mm^3 from gouging of river and streambed, 0.24 Mm^3 from river and stream bank undercutting, 0.3 Mm^3 from rill and gully erosion, and 0.13 Mm^3 from surface erosion.

6.3 REPORT ON KULEKHANI RESERVOIR SEDIMENTATION STUDY, 2000

The Project Preparation and Studies by the Department of Soil Conservation in association with Soil, Rock and Concrete Laboratory, NEA, assessed the situation of sediment deposition in the reservoir. Sedimentation survey had also been carried out. This study shows that the rate of sediment accumulation into the reservoir is decreasing since 1995. The total sediment load into the reservoir was found out to be 22.66 Mm^3 that was accumulated during the past 18 years since 1982, the siltation rate being 9991 $m^3/km^2/year$ (= 22.66 Mm^3/ (18 years * 126 km^2)). Total sediment volume in 1998 was 22 Mm^3 and that in 1999 was 22.66 Mm^3, thus the difference of 0.66 Mm^3 gives the sediment volume deposited in 1999, out of which 0.44 Mm^3 is in dead storage and the remaining 0.22 Mm^3 in live storage. The sediment incoming into the reservoir during 1999 monsoon is thus more than in 1998. But the overall trend of sediment deposition in the reservoir is decreasing.

6.4 REPORT ON KULEKHANI RESERVOIR SEDIMENTATION STUDY, 2004

Nepal Electricity Authority, Engineering Services prepared the sedimentation survey report of Kulekhani reservoir in 2004. The annual siltation rate has been calculated by dividing the volume of sediment by the number of years; and this rate divided by the catchment area gives the annual siltation rate per unit catchment area. It was found that in comparison with the previous years, there has been significant sediment deposition in the Kulekhani reservoir in the year 1993. The estimated deposit amounted to about 0.03 Mm^3 of the sediment. It was 0.06 Mm^3 of sediment inflow in to the reservoir during 2002. Out of 0.03 Mm^3 sediment deposited, the dead storage was 0.02 Mm^3, 0.01 Mm^3 being in the live storage space. Originally, as stated elsewhere, the reservoir capacity was 85.3 Mm^3, and got reduced to 62.271 Mm^3 during the period of 22 years. Thus, the average annual siltation rate over this period of 22 years was about 8308 m^3/km^2; and the siltation rate of 2003 was 238 m^3/km^2/year.

7. CONCLUSION & RECOMMENDATION

There is a need for further developing the sediment sampling network along with increasing the frequency of sediment sampling and discharge measurements in order to improve the assessment of sediments. Because of the large variation of sediment concentration in the rivers from year to year, it is of utmost necessity to consider the length of the sediment sampling records, type of equipment used and methodology adopted. Large catchments have to be divided into several relatively homogeneous units and start sediment monitoring.

Apart from regular sediment sampling activities, the DHM needs to take care of the sedimentation survey and study of important lakes and reservoirs as well. Since the cross section lines of the reservoir play a vital role in assessing the sediment deposition, future projection and also help the estimation in future projects.

DHM also needs to extend its cooperation with other institutions in sediment monitoring and assessment on Nepalese streams/rivers/watersheds by starting collaborative research with recognized universities.

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