International Congress
INTERPRAEVENT 2002 in the Pacific Rim – MATSUMOTO/JAPAN
Congress publication, volume 1, pp.155-163

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CATCHMENT EROSION AND RESERVOIR SEDIMENTATION
-PREDICTION FOR KHWAE NOI RESERVOIR LIFESPAN PROJECT IN THAILAND-

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ABSTRACT
To predict the lifespan of the reservoir, which capacity was reduced by sedimentation, both sediment volumes generated from the entire catchment and that stored in the reservoir of the Khwae Noi River were calculated. Using Universal Soil Loss Equation the annual sediment volumes generated from the entire catchment amounted to 91.25 ton/ha/year. The annual sediment volume of the entire catchment was totally amount to 30.601149 mcm(=10^6m). Most of the sediment generated was trapped by the meandering riverbed in both upstream and downstream of Khwae Noi Catchment. Therefore, the sediment delivery rate from the entire catchment to the reservoir was calculated at totally 1.57 % Annual sediment volume accumulated in the reservoir was calculated at 0.11 mm/km^2/year, which reduced the water storage capacity of the reservoir. Distribution of the sediment deposition in the reservoir was estimated by using the Empirical Area Reduction method. As the results, the annual sediment inflow was totally amounted at 0.480392 mcm. The result suggests that the lifespan of reservoir was predicted at 437 years since its completion.
KEYWORDS:Reservoir lifespan, sediment generation, sediment storage, Khwae Noi River

INTRODUCTION

Sediment accumulations in reservoirs of the northern regions of Thailand become intensified among of the entire country. Decreasing in storage capacity of reservoir by sediment accumulation causes that the water operations in the irrigation area can not run completely. Thus the design for water resource management is successfully developed with assessing sedimentation and erosion. However the control factors affecting to sedimentation and erosion in an entire watershed are unknown in Thailand today.

The study of the Khwae Noi Catchment, which is conducted by Royal Irrigation Department linking with National Research Institute for Earth Science and Disaster Prevention, is one of the core researches for hydrological cycle. The goal of this research is to develop how the hydrological data set obtained are employed for calculating the volume of sediment generation from the entire catchment and sediment storage in the reservoir. The parameters for the model, such as magnitude of on-site erosion, were provided from Department of Land Development. Sediment volume yielded from bank erosion and channel incision were calculated partly using by Royal Irrigation Department Model, and the lifespan of the reservoir was calculated using USBR method (1974). Universal Soil Loss Equation (USLE) was employed for calculating the volume of sediment generation from entire catchment Furthermore, field survey for identifying the erosion rates, which are indicators of erosion hazard in different areas of the catchment has been conducted.

At last the researchers and technicians concerning about the water resource management can therefore understand that the hydrological process of both sediment generation and storage make an enrolment for the catchment-scale decision making. Such a case study of sedimentation, which are represented by the observed data, can be applied to the planning of the water resources development.

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This study focused (1) to calculate the sediment volume generated from the entire catchment area, (2) to calculate the sediment volume stored in the reservoir, and (3) to predict the lifespan of the Khwae Noi Reservoir.

STUDY AREA AND DATA

This study was conducted by the Khwae Noi dam project. The study site is located in a part of Khwae Noi River basin at latitude 17°11' N and longitude 100°25' E in Phitsanulok province, northern region of Thailand (Fig.1). The catchment area is approximately 4,254 km^2 and the annual inflow averaged at 1,513 mcm. The climate of the study area is typically tropical savannah affected by the monsoon, and the annual rainfall was ranged from 1,048mm to 1,733mm. The 80% of rainfall was accumulated during May and September. Mainly soil texture is dominated by sandy loam with gently undulating and Loam soil.

The predominant land use, such as upland crop and secondary forest, covered approximately 55% of the catchment area. Some species of indigenous forest survive at the highest points of the mountain range. However, some of the forested area are protected, a gradual encroachment of upland agriculture into the forested area has been seen. Most of water supplied from the upland catchment areas in Nakhonthai and Chartakarn District is intaken into the paddy field systems, which results to increase in evaporation and infiltration of water at the beginning of the wet season. While the intake cause the reduction in flow velocity of river water and increase sediment deposition on the riverbed. At last the upland area make an enrolment of an effective sink zone for eroded material generated from the entire catchment.

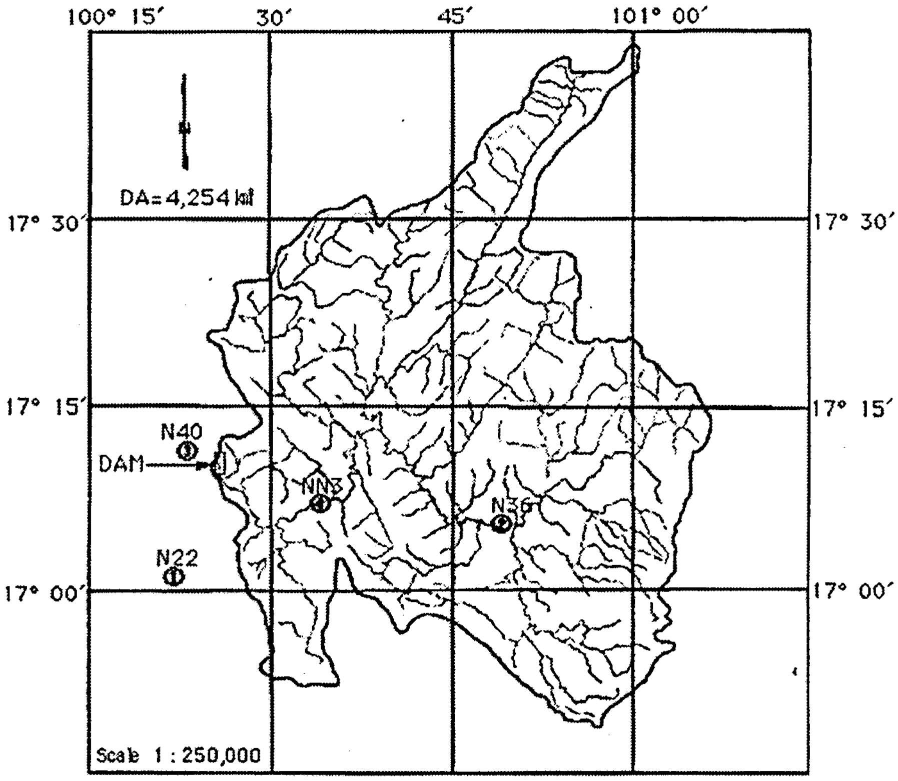

Fig. 1 Study area in Kwae Noi River basin located in P.Pitsanulok,Thailand.

The data required for this study, which are available for a series of USLE calculation adopted to all soil type within a catchment area, can be derived from topographic map, soil map, the land use/cover classification map, and the forest map managed by the Department of Land Development (DLD) and the Royal Forestry Department (RFD). The hydrological data, such as rainfall, runoff and sediment inflow combined with the reservoir survey for the detail of contour map, was provided from Royal Irrigation Department (RID).

METHODS

To determine the on-site erosion volume, the Universal Soil Loss Equation (USLE) was employed. Although the USLE needs many factors(parameters), the required parameters are successfully gained under the humid tropics condition. In this study, we use the parameter values determined by the DLD. The equation is generally shown as

Ea = R x K x LS x C x P

where Ea. = estimated average annual soil loss;
R = rainfall erosivity factor;
K = soil erodibility factor;
LS = slope length and steepness factor;
C = cropping and management factor;
P = conservation practice factor

The source erosion can be derived from combining the R-factor (Rainfall erosivity), K-factor (Soil erodibility), LS-factor (Slope length and steepness) and CP-factor (Cropping, management, and conservation practice). For each area of soil type, the mean level of erosion is presented in t/ha/yr.

Determination of USLE factors

R-factor (Rainfall erosivity) : Because northern region of Thailand was classified as a savannah climate group by using Koppen, S.Daja *et al.*(1997) suggested to use the following equation for R-factor of savannah area by Wischmeier and Smith (1978). R-factor can be derived from the simple linear function developed by the DLD. Based on the Northern Thailand climatic conditions, R-factor used for this equation was determined at R = 0.143 * (X-0.0375).

K-factor (Soil erodibility): This factor was determined from mainly soil texture, soil structure and permeability. The general description of soil texture is provided from the provincial soils map. In this study area 68 soil types comparing with monograph of Wischmeier and Smith (1978) were classified (S. Daja *et al.*, 1997). The full list of K-factor values classified into 12 classes was shown in Table 1.

Table 1 Soil texture and values of K-factor in Khwae Noi Catchment

No.	Soil texture	K-factor (hill slope)	K-factor (flat land)
1	Sand	-	-
2	Loamy sand	0.05	0.06
3	Sandy loam	0.27	0.26
4	Loam	0.33	0.35
5	Silt loam	0.49	0.34
6	Silt	-	-
7	Sand clay loam	0.21	0.22
8	Clay loam	0.24	0.27
9	Silty clay loam	0.35	0.42
10	Sandy clay	-	0.17
11	Silty clay	0.21	0.27
12	Clay	0.15	0.18

LS-factor (Slope length and steepness): This factor was determined from the combination of slope length and steepness, because all material eroded passes through the slope surface processing from the longitudinal profiles. LS-factor of this area based on the classification of S. Daja *et al.*(1997) and Wischmeier and Smith (1978) was represented as the following equation yielded from the relationship between L, S and the erosion rate of soil type in the study area. $LS = [L (0.0076 + 0.0053 S - 0.00076 S^2)]^{0.5}$

CP-factor (Cropping, management and conservation practice): The combined factor C with P is determined ambiguously from many qualitative differences. The factors approximately estimated from landuse classification and values provided for the northern region by the DLD (1983). The estimate values of C-factor and P-factor in this area were shown in the Table 2.

Table 2 Results of C-factor and P-factor

	Upland	Rice	Fruit tree	Grass land	Forest	Rock land
C-factor	0.47	0.28	0.034	0.13	0.048	0
P-factor	1	0.027	1	1	1	0

Determination of Hydrological data

Hydrological measurements have been carried out to establish the relationship between discharge and sediment yield from Khwae Noi Catchment area. The monthly runoff data of the station N40, located at 3 km downstream from the catchment, ware employed for estimating the discharge from the entire catchment. Mean annual runoff record at station N40 is shown in Table 3.

Table 3 Mean annual runoff at the station N40

Year	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual
1977	17.3	34.9	15.7	86.9	210.0	730.0	186.0	57.4	29.0	18.8	12.8	11.0	1409.8
1978	9.3	21.6	44.1	352.0	730.0	614.0	460.0	92.7	39.2	22.3	14.9	13.0	2413.1
1979	14.6	33.9	124.0	65.8	209.0	219.0	116.0	30.3	19.7	15.2	11.0	11.7	870.2
1980	14.8	58.5	155.0	320.0	511.0	999.0	214.0	79.8	41.1	24.6	16.1	14.2	2448.1
1981	19.4	69.5	90.8	426.0	483.0	328.0	200.0	88.8	41.9	26.8	17.8	14.8	1806.8
1982	21.3	55.0	68.4	57.4	133.0	580.0	312.0	88.3	43.9	30.7	17.7	15.4	1423.1
1983	12.7	24.3	46.3	65.0	221.0	476.0	360.0	121.0	42.6	28.3	21.1	15.8	1434.1
1984	19.7	26.0	205.0	141.0	239.0	426.0	409.0	94.8	40.8	26.2	18.4	16.4	1662.3
1985	16.3	32.7	65.8	255.0	396.0	400.0	555.0	218.0	74.0	36.3	23.1	19.2	2091.4
1986	15.4	122.0	177.0	166.0	299.0	373.0	108.0	48.3	27.8	16.9	11.2	12.2	1376.8
1987	11.9	24.4	59.0	17.1	245.0	305.0	181.0	63.6	25.6	14.8	10.1	6.2	963.7
1988	12.0	132.0	82.7	104.0	201.0	122.0	204.0	51.4	23.9	15.8	9.4	8.9	967.2
1989	13.7	66.8	125.0	86.5	83.8	149.0	138.0	44.9	24.0	15.2	9.1	17.1	773.2
1990	16.2	155.0	326.0	202.0	194.0	410.0	174.0	54.1	31.2	23.1	16.4	14.4	1616.4
1991	18.3	53.6	55.8	39.7	424.0	425.0	188.0	42.7	24.4	20.8	14.0	13.3	1319.6
1992	8.1	12.2	40.3	60.2	305.0	256.0	155.0	31.8	23.0	17.3	11.5	12.3	932.7
1999	94.9	206.7	183.3	118.3	321.8	736.8	312.4	113.8	54.5	35.9	22.2	20.4	2221.0
Mean	19.8	66.4	109.7	150.8	306.2	444.1	251.3	77.7	35.7	22.9	15.1	13.9	1513.5

The runoff yield in Khwae Noi River basin was estimated from the runoff records of 4 main stations. The results show that each values of runoff yield at the hydrological stations averaged at 11.51 l/sec/ km^2 as shown in Table 4.

Table 4 Runoff yield at N22 , N36, N40 and NN3

Station	Period (year)	Catchment area (km^2)	Discharge (mcm)	Runoff yield (l/sec/ km^2)
N22	1963-1985	4,841	1,583	10.4
N36	1969-1987	1,651	655	12.6
N40	1977-1992, 1999	4,340	1,513	11.0
NN3	1967-1992	3,320	1,259	12.0
			Average	11.51

Annual discharge at the station N40 is averaged at 1,513 mcm in the period of 17 years, and this value can be proportion to the ratio, representing as the annual discharge in the study area, at 1,468.9 mcm or 46.6 m^3/s. Although the discharge data at the station N40 was provided during 1977-1992, the actual sampling data of sediment was submitted only for 9 months from April 1999-January 2000. To understand the relationship between discharge and sediment during 1977-1992, the calibration of those for the 9 months was extended. The results of water level, sediment and discharge were detailed in Table 5. Water level and sediment yielded were plotted against discharge in Fig. 2 and Fig. 3 respectively.

Table 5 Monthly discharge and sediment volume in the water year 1999 at N40

Water level (m)	Instantaneous discharge (m^3/s)	Month	Monthly discharge (mcm:10^6m^3/month)	Sediment (ton/day)
9.0	417	April	1.76	4.6
7.8	333	May	3.05	12.9
6.0	216	June	2.95	10.9
4.8	150	July	2.07	5.6
4.4	130	August	3.99	25.2
3.8	103	September	7.03	82.2
2.8	63	October	3.99	23.6
2.4	51	November	2.10	5.4
0.8	11	December	1.17	1.7
0.4	3	January	0.90	0.9
0.3	0	February	-	-
0	0	March	-	-

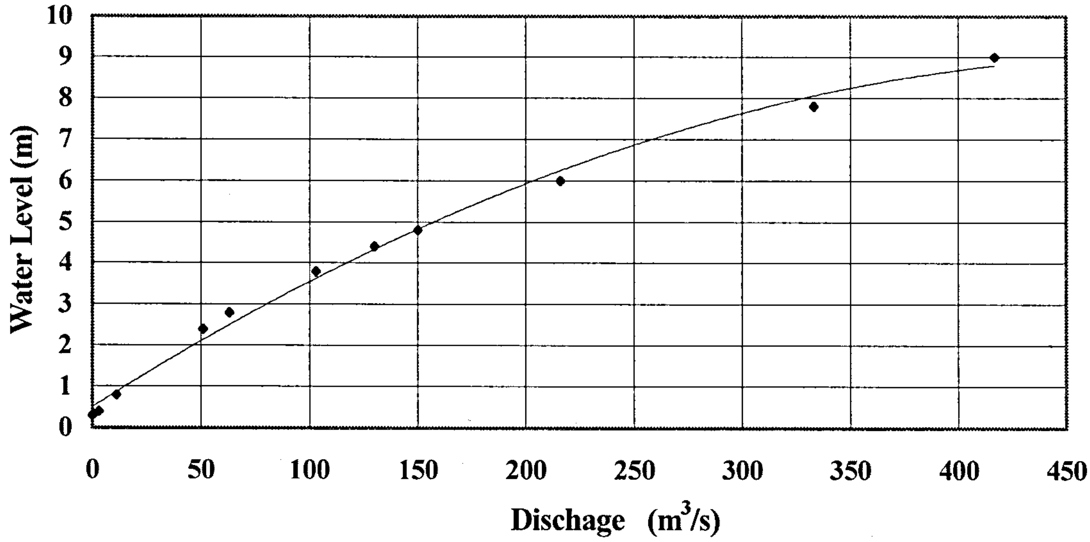

Fig. 2 Water level plotted against discharge at the station N40

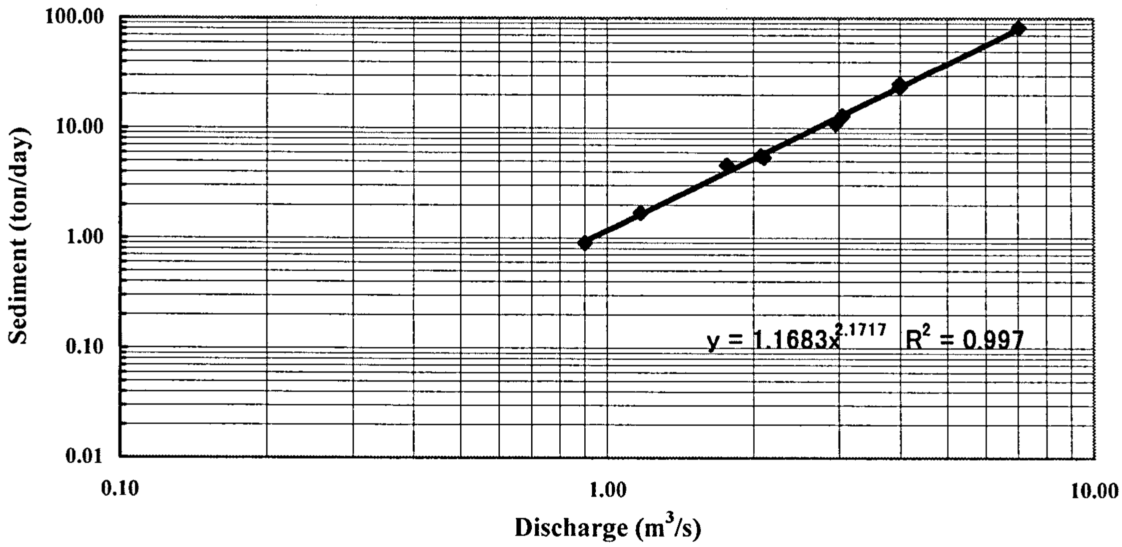

Fig. 3 Sediment volume plotted against discharge in 1999 at the station N40

Two methods are employed for comparing the sediment inflow to the reservoirs. The first is to estimate the sediment generation volume from the sediment volume deposited in the reservoirs. The records from three stations along the same stream are used for the calculation, the upstream station NN3, the study station N40 and the downstream station N22. The result of sediment analysis is shown in Table 6.

Table 6 Sediment Yield at Station N22, N40 and NN3

Station	Period (year)	Catchment area (km^2)	Suspended sediment (ton/yr)	Total sediment (ton/yr)	Sediment ($ton/yr/km^2$)
N22	1963-	4,841	350,800	456,040	94.20
N40	1999	4,340	393,395	511,413	117.84
NN3	1969-1987	3,320	310,856	404,113	121.72
				Average	111.25

The result from Table 6 indicated that sediment yield is varying from 94.20 to 121.72 $ton/yr/km^2$ and the average sediment yield is about 111.25 $ton/yr/km^2$. The volume of sediment yielded from the effective catchment area, 4,213.5 km^2, can be represented as sediment volume deposit in the reservoir. The effective catchment area was calculated by subtracting the reservoir area, 40.5 km^2, from the entire catchment area. The gross sediment volume calculated from sediment concentration, 468,752 ton/yr, plus additional 30% of the bedload is resulted at 609,378 ton/yr. Using unit weight of sediment as 1.2685 ton/m^3, gross annual sediment can be transformed into 0.480392 mcm and into 0.11 $mm/yr/km^2$ in erosion rate.

The second, we analyzed the relationship between sediment and discharge using program RQS proposed by RID (1991). As they provided rating curve of relationships between discharge(Q_w) and sediment concentration(Q_{sed}), which is yielded from the observed hydrological data, so we could use them to integrate the total sediment weight in the period of 17 years. All coefficients determined by the non-linear regression were substituted in following equation.

$$Q_{sed} = 2.129(Q_w)^{1.4589} \quad (r^2 = 0.6978)$$

The sediment concentration, 210,952 ton/yr plus additional 30% of bedload were amounted at 174,238 ton/yr as annual sediment inflow. Using unit weight of sediment, 1.2685 ton/m^3 sediment weight can be transformed into 0.216191 mcm and into 0.05 $mm/yr/km^2$ in erosion rate. Calculating of sediment concentration for nine months in 1999 (water year), the following equation was derived.

$$Q_{sed} = 1.1683(Q_w)^{2.1717} \quad (r^2 = 0.9970)$$

The sediment concentration, 1.789271 ton/yr plus additional 30% of bedload were amounted at 2.326052 ton/yr as annual sediment inflow. Using unit weight of sediment, 1.2685 ton/m^3 sediment weight can be transformed into 1.833703 mcm and into 0.43 $mm/yr/km^2$ in erosion rate.

To determine the method used in this study, both equations above were compared. Because the second method showed that the erosion rate varied from 0.05 to 0.43 $mm/yr/km^2$, and also only 9 months data of the sediment volume was employed for the rating curve at approximately 25 years in return period, it is unreliable for calculating values. The first method is better than the second method to calculate the reservoir lifespan as the result.

Determination of reservoir lifespan

To determine the distribution of sediment deposition in the reservoir the Empirical Area Reduction Method of USBR (1974) was employed. The followings are the steps for determining the lifespan of Kwae Noi reservoir

1) Trap efficiency of the rate of reservoir sediment deposition is calculated from the relationship between the capacity-inflow and sediment trapped value. In this study, the trap efficiency is

calculated at 0.5329, comparing the capacity-inflow value with sediment trapped value in Burnes curve (Fig. 4). Then approximately 97 % of the sediment inflow will deposit and store in the reservoir.

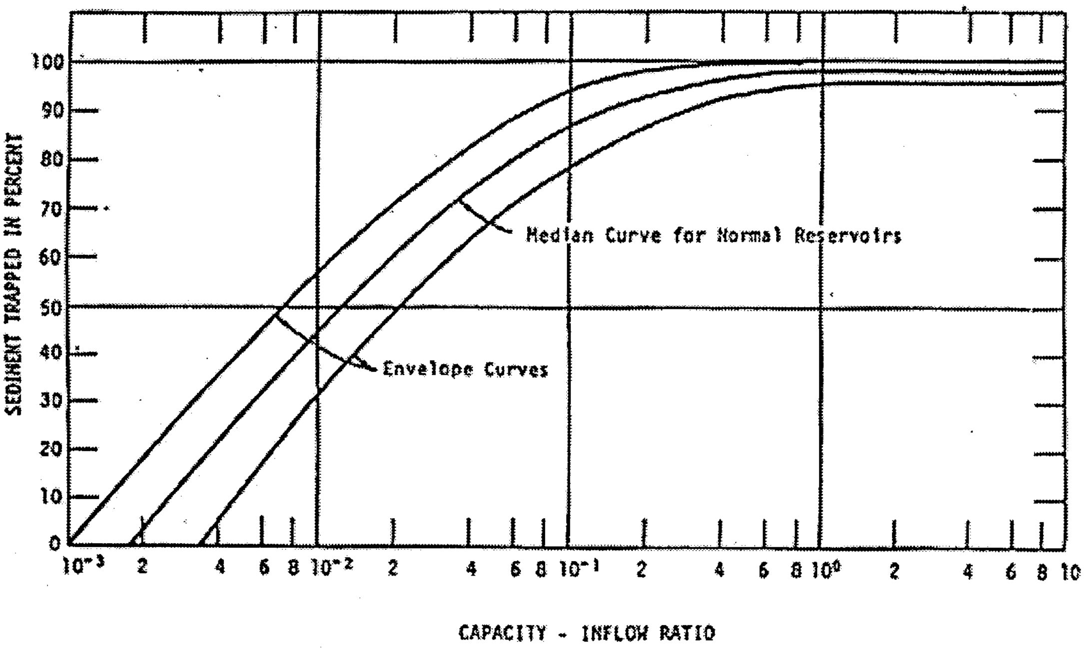

Fig. 4 Burne Curve for Determine the Trap efficiency

2) Topographic feature of reservoir is resulted from the relationship between the percentage of total reservoir depth and total reservoir sedimentation volume. From the Lara's method reservoirs are classified into four types as shown in Table 7.

Table 7 Classification of reservoirs based on the Lara's method (after USBR 1974)

Reservoir type	Classification	Slope(M=1/n)	Coefficient
1	Lake	3.5-4.5	5.047
2	Flood-plain foothill	2.5-3.5	2.487
3	Hill	1.5-2.5	1.967
4	Gorge	1.0-1.5	1.486

As the M-value was resulted at 2.83, so the reservoir will be classified into type 2.

3) The reservoir operation affects to the area and the volume of lateral sedimentation in the reservoir. In case of varying the unit weight of sediment, the volumetric percentage of clay and silt can be examined. In this study the reservoir operation is classified into the moderate reservoir drawing down. The unit weight for the K-value of clay and silt are 10.7 and 2.70 respectively.

4) Particle size distribution causes the change in bed shape and the sedimentation area of reservoirs. The bigger particle in stream flow will deposit near the confluence points of a reservoir, and the smaller particle will deposit far from the confluence points. The data of particle size distribution resulted from approximately 30 reservoirs was averaged at 14.14% of clay, 38.29% of silt, 45.36% of sand, 2.14% of coarse sand and 0.07% of gravel. The initial unit weight can be calculated from both unit weight and proportions of clay, silt, sand, coarse sand and gravel. In this study the initial unit weight resulted at 1.2685 ton/m^3. The dimensionless relative area is determined by the following equation:

$$Ap = C(p*M)[(1-p)^n]$$

Ap = dimensionless relative area

p = relative depth

C, n = dimensionless constant

M = 1/n(dimensionless constant)

From the above equation, sediment volume accumulated in the reservoir, which will decrease the reservoir capacity, indicates the "new zero elevation" for the reservoir lifespan as Table 8.

Table 8 Expected values of new zero elevation for each period

Time (year)	Sediment Volume (mcm)	New Zero Elevation (m. above the see level)
5	2.36845	70.65
10	4.70148	71.09
25	11.62728	72.17
50	23.05518	73.66
200	90.59985	80.78
437	195.99999	90.00

RESULTS AND DISCUSSION

On-site erosion in the entire catchment

From the result of estimating magnitude of on-site erosion using the method proposed by Atkinson E. (1995), it is clear that there has been no significant changes in erosion volume and little changes in storage capacity of reservoir. In such case that the particle size can be constant from upstream to downstream, sediment delivery ratio will be ranged from 0.1 to 1.0. The above results then indicate that the USLE can be successfully applied to estimate the sediment delivery rate from the Khwae Noi catchment. As a result, the erosion rate is moderate level (32-125 ton/ha/yr) and is likely to be very small impact to the reservoir. Although many problems lie in the calculating process by USLE for any catchments, most of them are solved through approximations and assumptions for estimating many variables.

Sediment inflow to the reservoir

The calculation of sediment volume for any specified period by a number of methods including continuous integration was examined. The RQS program was also applied for producing the relationships between the actual data and the hydrological data at station. As a result, the 4,254 km^2 in entire catchment area has contributed to produce totally 1,513 mcm in discharge, and then to reduce 40.5 km^2 as the reservoir water surface. At last the reservoir catchment area of the Kwae Noi project decreased at 4,213.5 km^2 . These decreasing was converted to 1,468.9 mcm by the USLE equation and transformation to 30.601149 mcm in annual sediment discharge. So the rate of SDR was calculated at 1.57 % with 1.2685 ton/m^3 in unit weight, the sediment inflow to the reservoir is expected at 0.480392 mcm.

Expectation of lifespan prediction of the reservoir

By using the Empirical Area-Reduction Method the reservoirs sedimentation patterns can yield the relationship of the depth versus capacity. The total capacity of the Khwae Noi reservoir was 769 mcm at retention 130.00 m (a.s.l.) and dead storage was at last 90.00 m (a.s.l.). The total annual sediment inflow was predicted at 0.480392 mcm. From the equation above, if the sedimentary sequences between on-site erosion and accumulation to the reservoir through years keep accelerating, the Khwae Noi reservoir lifespan can be computed from sedimentation predicting. The result suggests that the lifespan of reservoir since its completion until the attainable dead storage was predicted at 437 years.

CONCLUSION

The volume of sediment yielded from the Khwae Noi catchment and the decreasing rate of the reservoir capacity due to sedimentation were measured. Finally we principally concluded as follows:

1. The estimated erosion rate was ranged under 91.25 ton/ha/yr, which is less than 125 ton/ha/yr, and sediment volume was 30.601149 mcm/yr. Measuring data was approximately equaled to the estimated erosion rate in Thailand.
2. Sediment Delivery Ratio (SDR) calculated from the mean sediment yield volumes in both upstream and downstream catchments was 1.57 % .
3. As the total annual sediment inflow was amounted at 0.480392 mcm/yr, so the lifespan of reservoir was resulted to 437 years after the reservoir completion .

For further study of GIS techniques should be established for developing plan in a catchment and regional area through the distributed model of sediment. Increasing in the ability to predict soil erosion aids land managers in choosing crops and management techniques to keep soil erosion within moderate limits. Designing of reservoir lifespan will use the techniques for estimatingg sediment yield. We thus can apply such calculation systems, which was successfully done in Khwae Noi catchment, to the others area.

ACKNOWLEDGEMENTS

This study was undertaken with the Atmospheric and Hydrosphere Science Division, NIED, Tsukuba, Japan. We greatly appreciate to staff of the NIED for their sufficient help. Royal Irrigation Departmant (RID) gave a opportunity and logistical support for us, especially Mr. Panya Ponsaen, Chief Office of Hydrological and Water Management Center for Lower Northern Region, RID in Phisanulok Province, Thailand, and his staffs apply themselves to collect the field data available for this study. We would like to express special thanks to Science and Technology Agency of Japan (STA) for their friendship and funding.

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