

Thailand's Kaeng Sua Ten Dam Revisited: The Flood Protection Benefit of A Controversial Agricultural Project

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INTRODUCTION

In 1997, TDRI conducted a re-examination of the case for the construction of Kaeng Sua Ten (KST) dam, in Thailand's northern province of Phrae,¹ on the river Yom. The area proposed to be flooded by the dam's construction, in the upper Yom basin, encompasses one of Thailand's largest few remaining natural teak forests. Approval in principle was given by the Thai cabinet (the Council of Ministers) in November 1996 for the Royal Irrigation Department (RID) to design and budget for the construction of the dam. The project's economic feasibility had earlier been affirmed in a 1991 report² by the Food and Agriculture Organization (FAO) under FAO/World Bank Co-operative Program (the FAO report). TDRI was commissioned by the Bureau of the Budget, of the Prime Minister's Office, to re-examine the project as a case study in the analysis of publicly-funded investments in infrastructure.

THE FAO REPORT 1991

TDRI's case study, which was published in July 1997, focused on the cost-benefit assumptions and values bearing on the economic justification of the KST agricultural dam project as determined by the FAO report. The purpose was to bring to attention critical parameters and premises which needed to be revaluated in view of the six-year time lapse since the FAO report was written, but which had not been duly updated when the project was submitted to the Council of Ministers in 1996. The review of key project variables which TDRI undertook included market indicators which were observed to have changed significantly since 1991, or which must take into account the exchange rates and expectations – particularly with regard to crop prices – following the devaluation of the Thai currency in early July 1997 and the float of the baht thereafter. But as an

illustrative case study in public sector investment, TDRI's remit was also to scrutinize other assumptions which were as likely to impinge on the dam's economic justification, and which might have affected the validity of previous assessment of the costs and the benefits of the project.

In the course of the review it was found that one assumption singularly overshadowed the FAO report's economic analysis. TDRI's case study noted that the low economic values which were assigned to farm labor costs in the project area were arguably unrealistic and potentially misleading. Farm wages were assumed to be constant in real terms throughout project life, and their economic values were discounted at half the market wage rates for unskilled workers (equivalent to an economic conversion factor of 0.5 for labor). For the purpose the FAO report's economic analysis, labor input costs for crop production therefore ranged from no more than 25 to 35 baht per man-day. The assumption of so low an economic opportunity cost for labor detracted from the credibility of the project's economic feasibility, which largely rested on increased farm incomes and profits. The nominal or market wage used as reference was based on the rate that prevailed in 1990 for hired farm labor in the northern and central provinces. But the fact was that rural wages in Thailand had gained steadily and markedly in real terms across all regions, and that discounted economic pricing of agricultural labor in a market presumed to be distorted by underemployment did not apply in the Thai context. The labor market from mid-1980's and throughout the 1990's was characteristically mobile and competitive. The evidence of steady upward shifts of the wage rates as labor migrated out of the agricultural sector would suggest that the rural wage structure was undistorted by underemployment, and that the market price of labor for the period fairly represented its true economic opportunity cost. From the National Rural Development Committee (NRDC) statistics for rural villages, the

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median rural wage rate rose from 30 baht in 1984 to 50 baht in 1990, from which point it was doubled in six years to 100 baht in 1996. It was a rate of increase that outpaced domestic inflation and was equivalent to an annual 2 percent compounded growth of the rural wage in real terms.³ Figure 1 shows the progressive rise of the daily wage rates for all rural areas compiled from the NRDC village census data. The median value at the 50th percentile is representative of the price of unskilled agricultural labor.

The KST project's major crops were paddy and soya beans, the incremental value of which largely made up the economic benefits from the availability and use of water for irrigation, drawn from and regulated by the dam's storage capacity. In assuming as it did an unchanging farm wage rate in real terms throughout project life, and in setting the economic value of labor at one-half its market rate by a rule-of-thumb that was inappropriate in Thailand's case, the FAO report had undervalued the costs and overvalued the benefits of incremental cropping. TDRI's concluding view was that the economic return from incremental farm outputs justifying investment in the dam had been overstated.

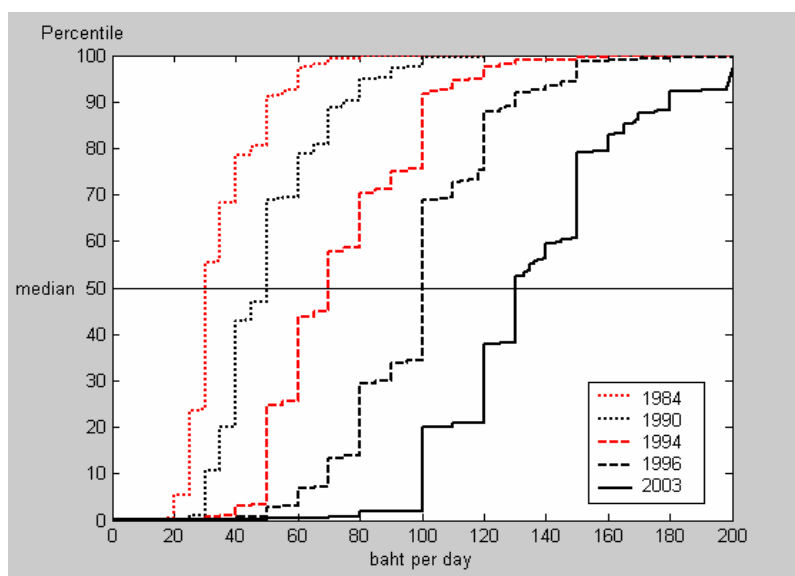
The FAO report analyzed and presented the KST dam primarily as an investment in agriculture, with sustainable benefits being derived mainly from an expansion in dry-season cropping downstream and better yields from pre-existing wet-season paddy farming. Although construction of the dam was expected to lessen damages from annual floodings, the probable benefit of flood protection was considered marginal and subsidiary to the main benefit in agriculture from extended cropping. The FAO report estimated the flood protection benefit of the dam at 3.2 million baht on average per

year over project life at 1991 prices, equivalent to less than 1 percent of the project's total net present value (NPV).

THE RID STUDY 2001

New parameters of the dam's flood protection benefit were introduced in a feasibility study of the KST project completed in August 2001 by a consortium of consultants commissioned by the Royal Irrigation Department⁴ (the RID study). The study revised the flood protection benefit of the project to 232 million baht on average annually over project life in 1995 prices, approximately a *sixty-fold* increase in real terms over the FAO report's original estimate. The boundaries of the dam's flood protection were redrawn by the RID study to extend to areas as far as 520 kilometers downstream,⁵ to varieties of crops other than paddy, to other land-use activities, and to buildings, properties and infrastructures. Without the dam, flood damages were estimated at 525 million baht annually on average. With the construction of the dam, the potential annual flood damages were estimated to be lessened by 54 percent, the difference being the dam's protection value. In terms of NPV, the total flood protection benefit of 1.2 billion baht⁶ was 40 percent of the project's total (also revised) NPV of 3 billion baht. Flood protection value of such magnitude and proportion could not be considered a subsidiary and marginal element of the dam's benefit. It was an extreme shift of the baseline scenario and a radical makeover of the project's benefit profile as originally appraised by the FAO report.

Figure 1
Daily Wage Rates, All Rural (non-Urban) Areas 1984-2003



FLOOD FREQUENCY ANALYSIS

The occurrence of floods, from which damages are estimated by association with the peak flow rates, cannot be predicted with certainty. Peak flood discharges are random chance events with statistical probabilities of occurrence for each year and recurrence within project lifetime, according to the available hydrological records. The most likely pattern of annual floods – measured as the probable recurrence intervals of varying annual peak discharges over time – is found by statistical best fit of the historical data. The distribution types more commonly tested for best fit in flood frequency analysis are differently-shaped asymmetrical functions, such as the Gamma, the Extreme Value (Gumbel), the Lognormal and the Log Pearson Type III. The parameters which describe the distributions are estimated to fit the sample mean and variance – in the case of the Log Pearson additionally the sample skew – of the data. The FAO report reconstructed a time series of annual maximum flows at the KST dam site for 40 years between 1950 to 1990 and tested for Log Pearson Type III probability distribution. By extrapolation the FAO report estimated a probabilistic peak flow of 2,500 cubic meters per second (m^3/sec) occurring once over an interval of one hundred years (a 100-year flood) and a probabilistic flow of 3,800 m^3/sec once in a thousand years (a 1000-year flood). The actual maximum peak flood discharge in the 1950-1990 time series was recorded in 1952 at the rate of 2,013 m^3/sec .

In Figure 2, the 1950-1990 time series of annual peak floods at KST dam site as reconstructed in the FAO

report are shown as an empirical (with stepped appearance) cumulative density function, in comparison with estimated continuous cumulative density functions of Extreme Value Type I (Gumbel), Lognormal, and Gamma distributions.⁷ The comparison shows the Gamma probability distribution to correlate best with the empirical data, with a correlation coefficient value of 0.95. Because the coefficient of skewness of the logarithms of the annual peak discharges is near to zero in value, there is virtually no difference between the Lognormal distribution shown in Figure 2 and the Log Pearson Type III distribution which was fitted to the data in the FAO report.⁸

The inverses of the estimated cumulative density functions give the estimated annual peak floods at specific probabilities – the extrapolations of maximum annual flood levels at corresponding recurrence intervals.⁹ The best-fitting Gamma distribution in Figure 2 estimates the discharges of a 100-year flood at 2,145 m^3/sec , and of a 1000-year flood at 2,823 m^3/sec . These estimates diverge markedly from the extrapolations in the RID study of 2,511 m^3/sec for a 100-year flood, and 3,722 m^3/sec for a 1000-year flood.¹⁰ The differences in the estimated maximum annual peak discharge scenarios for different distribution types emphasize the need for caution in extrapolating floods of extreme recurrence intervals or return periods from a relatively small baseline flood data of 40 years. Table 1 compares the extrapolated peak flow figures in m^3/sec for different probability assumptions based on 1950-1990 records, against the projections of the RID study based on flood data extended to the years 1995-1996.

Figure 2
Comparative Cumulative Density Functions Empirical, Lognormal, Extreme Value and Gamma

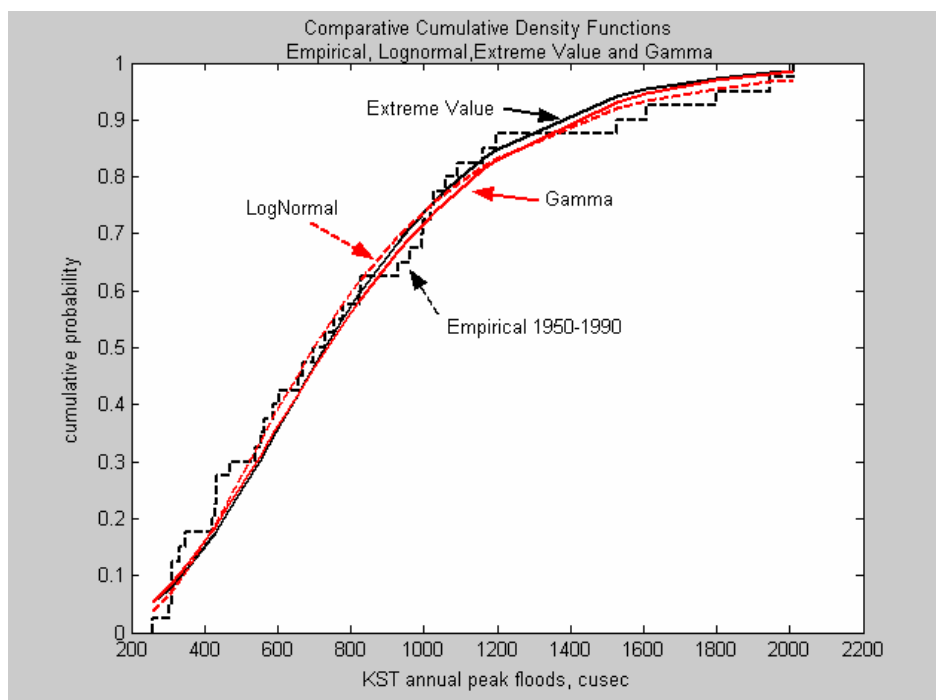


Table 1
Predicted Annual Maximum Flows at KST Dam Site, in Cubic Meters per Second

Return Period Years	Exceedence Probability	Lognormal Distribution	Gamma Distribution	Extreme Value Distribution	RID Study Table Kor 2-1
2	0.5	700	737	731	899
5	0.2	1,118	1,138	1,102	1,262
10	0.1	1,428	1,395	1,348	1,521
20	0.05	1,749	1,633	1,583	1,806
25	0.04	1,855	1,707	1,658	1,904
50	0.02	2,195	1,930	1,889	2,196
100	0.01	2,555	2,145	2,117	2,511
200	0.005	2,936	2,354	2,345	2,846
500	0.002	3,474	2,623	2,646	3,308
1,000	0.001	3,909	2,823	2,873	3,722
10,000	0.0001	5,548	3,468	3,627	5,145
Correlation Coefficient Value¹¹		0.9312	0.9478	0.9416	0.9416

The exceedence probability in column 2 of Table 1 represents the likelihood of occurrence of an annual maximum discharge rate that equals or exceeds the flood flow extrapolations variously indicated in the respective row of the Table. From column 2, the percent chance in any one year and in every year of an annual maximum discharge being equal to or exceeding a 100-year flood is shown to be constant at 1 percent, a 200-year flood at 0.5 percent, and a 1000-year flood at 0.1 percent. The conventional measure of exposure to flood risk over a time span of t years is determined by binomial probability as the chance for a n -year flood as follows:

$$1-(1-1/n)^t$$

where the term $1/n$ denotes the exceedence probability. By way of examples derived from the foregoing formula, the percent chance a 20-year flood occurring over a time span of 30 years is 78.5 percent, whereas for a 100-year flood the chance would be 26.03 percent. For a project lifetime of 50 years, the likelihood of an annual peak discharge equalling or exceeding a 20-year flood is evaluated at 92.31 percent, for a 100-year flood 39.5 percent, and for a 1000-year flood 4.88 percent. The formula evaluates the risk of a flood of specific return period, but the broader risk which addresses *all* probabilistic floods of all possible return periods over the span of project lifetime is unresolved by the above formula.

FLOOD DAMAGES AND FLOOD PROTECTION

Flood frequency analysis which relates peak flood discharges to return periods is normally undertaken with a parallel examination of the rating curve which relates the discharges to flood stages (water levels), from which may be derived estimates of damages due to the flood's duration and depth. The FAO

report estimated that a flood depth of between 0.5 to 1.0 meters over five days would reduce paddy yield by 40 percent, which translated into a loss of 1,250 kilograms of paddy per hectare under cultivation.¹² The estimate was based on the 1973 flood which was one of the biggest floods in the Yom basin on record, rated at 2,315 m^3/sec at Phrae township¹³ at a distance of over 90 kilometers downstream from dam site. The KST dam's storage capacity was expected to prevent losses in the Phrae floodplain by reducing the peak discharges and lowering the associated flood stages. The dam's flood protection benefit as estimated by the FAO report was derived from losses discretely estimated for 5-year, 10-year, and 20-year floods. But the total economic value of protection from such floods for the duration of project life was limited to wet-season paddy cropping between August and September over an area of 5,250 hectares¹⁴ in Phrae. At an annualized average of 3.2 million baht per year, flood protection benefit of the dam estimated by the FAO report was equivalent to a total of 17 million baht in NPV at the start of the project in 1991 prices.¹⁵

The RID study, on the other hand, based its estimates of damages on the 1995 flood, which recorded a 2,243.6 m^3/sec peak flow in Phrae township,¹⁶ and on the smaller flood of 1996 for regression analysis. The relationship between flood damages and flood peaks is described by the regression equation:

$$D = a + b \cdot \ln Q$$

where D is the value of damages, in million baht and $\ln Q$ is the natural logarithm of the peak flow Q , in m^3/sec .

The constant a and the coefficient b of the regression equation are estimated for each and every district of the affected provinces of Phrae and Sukhothai, to determine damages to crops and properties from flood

discharges above local critical thresholds. On such bases, the RID study estimated the annual flood protection benefit of the dam in reducing potential crop damages in Phrae at 46 million baht in 1995 prices.¹⁷

The FAO report described flood damages in terms of reduced paddy production in the floodplain starting from the Yom river's confluence with the Ngao tributary to Denchai district in Phrae – a distance of 128 kilometers downstream from the proposed dam site. No protection benefit was attributed by the FAO report to the KST dam in areas further downstream, where the annual flood would be significantly influenced by the Yom's other tributaries, and also by the Nan river further south in Sukhothai province. The impact on the flood flow that could be attributed to the dam beyond the Phrae floodplain was described as 'difficult'¹⁸ to estimate. Notwithstanding the reservation expressed by the FAO report, the RID study's assessment was that without the KST dam the overall attributable flood damage to all crops and properties downstream including the districts of Sukhothai would be as much as 525 million baht per year. With the construction of the dam flood attributable damage would be reduced to 282 million baht, equivalent to a protection benefit of 243 million baht.¹⁹ Excluding all other crops and properties, the paddy-cropping area in the big flood of 1995 receiving attributable protection was estimated by the RID study to amount to a total of 87,103 hectares (544,395 *rai*),²⁰ of which Sukhothai province accounted for 85 percent (73,712 hectares), and Phrae for only 15 percent (13,391 hectares). Flood-affected cropping area in Phrae as originally estimated by the FAO report at 5,250 hectares was therefore increased by more than 2.5 times in the RID study. Inclusive of downstream paddy-cropping area in the Sukhothai province, the overall affected area was 16.6 times that of the earlier FAO report's estimate.

For the purpose of project evaluation, the annual benefit of flood protection is best derived from the annual probable risk of damaging floods, determined from a pattern of probability fitting the frequency of annual peak flows recorded at or near to the dam site. The FAO report duly fitted a Log Pearson probability function to the available flood records, to determine the likely magnitudes of 5-, 10-, and 20-year floods. The damages were assessed on the effect of the flood magnitudes on paddy productivity in the affected cropping area. The RID study on the other hand did not update flood records to extend the FAO report's 1950-1990 peak flow data series at the KST dam site, but instead based the flood frequency analysis on 1960-1996 reconstructed records of peak flows at eight gauging stations downstream on the Yom river, only two of which were sited in Phrae.²¹ The annual August-October data were fitted to Extreme Value (Gumbel) probability distribution function and extrapolated to 2-, 5-, 100-, 1000-, and 10000-year flood peaks, but with no

evaluation regarding the goodness of fit relative to other distribution types.

FLOOD RISK ANALYSIS

Estimates of flood protection benefit are based on the difference in expected flood damages with and without the dam. The FAO report estimated damages over the project lifetime on the basis of predicted annual floods with return periods of up to 20 years, whereas the RID study included floods with return periods of up to 10,000 years. But the magnitudes of damaging floods are random chance events. The risk corresponds to the events' probability. Using the Monte Carlo simulation method of risk analysis, repeating trials of annual floods can be simulated as random events defined by given probability distribution statistics, to forecast likely damages over project life year by year related to the respective magnitudes of the probabilistic flood discharges.

*Crystal Ball*²² risk analysis software was used to generate 10,000 trial simulations of annual flood discharges covering districts (*amphoe*) of Phrae province on the Yom, for which the RID study has extrapolated flood damages. The statistics which were used to generate the simulations were of Gamma, Lognormal, and Extreme Value (Gumbel) probability distribution functions which were fitted to the FAO report's 1950-1990 series of annual maximum flows, based on readings at KST dam site. The damages (D) to crops were estimated from the simulations using RID study's coefficient (*b*) and constant (*a*) values from bivariate regressions at district levels,²³ on condition that the simulated random discharges exceeded the respective damage thresholds (Q_0) indicated in the RID study. The simultaneous simulations of annual floods at various districts downstream were assumed first to be perfectly correlated with an assigned correlation coefficient value of 1.0, and alternatively as completely unrelated with correlation coefficient value of zero, for every year of project life. The sum values of the mean and median predicted annual damages (using RID study's damage parameters) resulting from the simulated discharges over the project lifetime of 50 years were discounted to give the present value of the total probabilistic damages *without the project*, from which the annualized damage value may be derived by the periodic payments formula.²⁴ The alternative correlation assumptions for the simulated discharges affect the respective predicted median value, but not the mean, of the damages.

The summary results in annual crop losses²⁵ from the flood discharge simulations for Phrae are tabulated in Table 2, all values of which were found to be larger than the FAO report's average annual assessment of 3.2 million baht, which was limited only to losses in paddy production and covered a lesser area of cultivation. But the results of the simulations in Table 2 conversely indicate that the RID study's estimate of 54 million baht²⁶ in annualized damages overstated the likely risk

by up to 7 times, depending on the distribution functions fitted to the data series.

Table 2
Summary of Simulation Results in Annualized Flood Damages to Crops in Phrae,
for Different Probability Distributions of Annual Flood Peak Flows, in Million Baht

<i>FAO Series 1950-1990</i>	<i>Annualized</i>	<i>LogNormal</i>	<i>Gamma</i>	<i>Extreme Value</i>
	Mean	12.63	10.12	8.95
Correlation = 1.0	Median	11.34	9.28	8.09
No Correlation	Median	12.30	9.86	8.68
<i>FAO Series + 1995, 1996</i>	<i>Annualized</i>	<i>LogNormal</i>	<i>Gamma</i>	<i>Extreme Value</i>
	Mean	15.68	13.11	11.49
Correlation = 1.0	Median	14.29	12.19	10.57
No Correlation	Median	15.29	12.88	11.19

Extending the same probabilistic simulation methodology of risk analysis to the province of Sukhothai further downstream on the Yom and its tributaries, estimates of likely crop losses from 10,000 simulation trials of annual flood discharges are summarized in Table 3, under similar alternative assumptions of correlation and probability distribution. The predicted losses are similarly based on the regression parameters and damage thresholds used in the RID study, with the simulated annual peak discharges as predictor variables for each of the province's downstream districts. The RID study's estimate of average pre-project annual crop losses at 287 million baht in Sukhothai was found to be up to 3 times higher than the likely risk of crop damages as indicated by the probabilistic simulations.

CONCLUSION

Project appraisal is a due process of evaluation which determines if a project is worth undertaking, in so far as its expected dividends are judged to outweigh the costs. The process supports rules-based allocation of resources predicated on expected outcomes. Predictions of outcomes affecting a project's costs or benefits which are dependent on random chance events of uncertain magnitudes, such as rainfalls or floods, are best dealt with as probabilistic risk problems. The probabilistic approach for evaluating the risk of events and their consequences, using the Monte Carlo method of

probabilistic simulations, is a refinement on single-point evaluation based on scenarios of best- and worst-case projections of outcomes.

For KST project, the risks are floods which exceed certain threshold rates of flow and the consequences are the damages they inflict on crops and properties. Protection from such floods is a benefit. The RID has commissioned a new study which has mapped a new profile of the dam's protection benefit based on a revised baseline of predicted annual flood damages. The dam's protection was supposed to range over an area of potential damages extending from the Phrae floodplain immediately below the dam into all of Sukhothai province. In marketing terms, the magnitude of potential damages newly estimated by the RID study has effectively re-branded the KST project as no less an investment in flood protection than an investment in agriculture. But simulations of annual flood discharges by the Monte Carlo method of risk analysis, using the study's flood damage parameters, result in mean and median annual damages well below the study's predictions. Where comparable, the damages indicated by the Monte Carlo simulation trials are closer to the original findings of an earlier FAO report on the project's feasibility. Probabilistic risk analysis based on the historical flood data suggests that the RID study's baseline estimate of predicted potential damages and the flood protection benefit of the dam were much overstated. The predictions should be subject to further review if they are to be taken seriously as a call for action on the project's implementation.

Table 3
Summary of Simulation Results in Annualized Flood Damages to Crops in Sukhothai,
for Different Probability Distributions of Annual Flood Peak Flows, in Million Baht

<i>FAO Series 1950-1990</i>	<i>Annualized</i>	<i>LogNormal</i>	<i>Gamma</i>	<i>Extreme Value</i>
	Mean	128.50	124.89	116.85
Correlation = 1.0	Median	122.96	119.74	110.98
No Correlation	Median	127.12	123.98	115.88
<i>FAO Series + 1995, 1996</i>	<i>Annualized</i>	<i>LogNormal</i>	<i>Gamma</i>	<i>Extreme Value</i>
	Mean	147.02	144.50	134.96
Correlation = 1.0	Median	141.15	139.19	128.87
No Correlation	Median	145.43	143.67	133.99

It would be an ironic final twist in the long saga of the KST dam if its eventual construction as a flood barrier, aside from other objectives, were to lead to an exacerbated deforestation of the upper Yom basin, and consequently to find that the destruction of one of Thailand's last remaining natural teak forests would at best be ineffective against seasonal floods in the river's lower reaches, and at worst a self-fulfilling prophecy of the hyperbolic damages it was designed to alleviate.

APPENDIX

1. The FAO Report's flood data for the years 1950-1990 at the KST dam site are shown in the following table. The data are used for flood frequency analysis and tested for distribution probabilities as shown in Figure 2 and Table 1. The RID study's flood discharge figures of 2,193.35 m^3/sec for 1995 and 1,131.54 m^3/sec for 1996 are used to extend the series for the simulation trials, results of which are shown in Tables 2 and 3.

Year	Peak Discharge m^3/sec	Year	Peak Discharge m^3/sec
1950	656	1971	1,018
1951	1,197	1972	963
1952	2,013	1973	1,946
1953	433	1974	1,060
1954	931	1975	829
1956	1,091	1976	755
1957	1,607	1977	699
1958	312	1978	999
1959	590	1979	312
1960	670	1980	564
1961	1,799	1981	781
1962	433	1982	311
1963	1,163	1983	732
1964	428	1984	1,029
1965	333	1985	303
1966	606	1986	350
1967	994	1987	826
1968	472	1988	554
1969	540	1989	421
1970	1,529	1990	260

2. The RID study's flood damage parameters for districts (*amphoe*) of Phrae and Sukhothai provinces describe the relationship between damages (D, in million baht units) and flood peaks (Q, in m^3/sec) above critical thresholds (Q_0) in the form of regression equation $D = a + b \cdot \ln Q$. They are as follows for crop damages:

Districts	a	b	Q_0
Phrae			
Song	-445.756	62.319	1,300
Nong Muang Kai	-131.550	18.706	1,150
Muang Phrae	-190.061	26.874	1,190
Soong Men	-265.375	37.421	1,200
Den Chai	-186.755	26.470	1,190
Long	-279.562	39.594	1,190
Wang Chin	-205.295	28.456	1,250
Sukhothai			
Sri Satchanalai	-327.394	51.014	620
Sawankalok	-1,737.395	244.406	1,250
Sri Samrong	-764.314	109.284	1,090
Muang Sukhothai	-941.459	147.063	605
Kongkraiias	-1,520.235	220.202	1,000
Kirimas	-669.173	100.301	790

Source: The RID Study, Volume 2, Main Report, Table 5.5-22.

ENDNOTES

- 1 A Re-Examination of the Feasibility of Kaeng Sua Ten Project, Phrae Province, Thailand Development Research Institute, July 1997 (in Thai).
- 2 Kaeng Sua Ten Agricultural Dam Project, Interim Preparation Report, FAO, May 1991.
- 3 The last published NRDC village census for the year 2003 indicated an average rural wage rate of 141 baht and a median value of 130 baht. For provinces in the Northern Region, the average was 123 baht, with the median at 120 baht.
- 4 Review of Feasibility of Kaeng Sua Ten Project, Phrae Province by Panya Consultant Ltd., P&C Management Ltd., SDCON Corporation Ltd., Volumes 1-3, Royal Irrigation Department, [The RID Study] August 2001 (in Thai).
- 5 Ibid., Volume 3, Appendices, Table Kor 7-21.
- 6 Ibid., Volume 1, Summary Report, Table 5.1-2.
- 7 The MathWorks, Inc.'s MATLAB software was used to plot the non-parametric empirical density function and to estimate the parameters of Extreme Value and Lognormal distribution functions.
- 8 The FAO Report, Section C, Flood Frequency Analysis, Figure 10.
- 9 The exceedence probability is the reciprocal of the recurrence interval p of a repeating event, $1/p$. Thus for a flood with a return period or recurrence interval of 100 years (a 100-year flood), the exceedence probability is 0.01 or 1 percent; for a 1000-year flood, the exceedence probability is 0.001 or 0.1 percent.
- 10 The RID Study, Volume 3, Appendices, Table Kor 2-1.
- 11 The correlation coefficient value denotes the degree of correlation with corresponding evaluations of the empirical (Kaplan-Meier) cumulative distribution function based on 1950-1990 observations.
- 12 The FAO Report, Annex 6, Financial and Economic Analysis, Page 12.
- 13 Y1 Gauging Station.
- 14 FAO's estimated flood boundary was based on 1:50000 topographic map.
- 15 The RID Study, Volume 1, Summary Report, Table 5.1-2. The discount rate was 12 percent. Project period was 1993-2042.
- 16 Ibid., Volume 3, Appendices, Table Kor 7-13 at Y.1C Gauging Station, on 1st September 1995 at 18.00 hours.
- 17 Ibid., Volume 2, Main Report, Table Kor 5.5-23.

- ¹⁸ The FAO Report, Annex 6, para. 29.
- ¹⁹ The RID Study, Volume 3, Appendices, Table Kor 7-5, based on land-use maps.
- ²⁰ Ibid., Table Kor 6-2. A hectare equals 6.25 *rai*, the Thai standard unit measurement for land area.
- ²¹ Ibid., Table Kor 7-12; Station Y.20, at 8.2 kms, and Station Y.1C, at 97.3 kms downstream from the dam site. The RID study did not show the data series underlying the flood frequency analysis.
- ²² By Decisioneering, Inc., Denver, USA.
- ²³ The RID Study, Volume 2, Main Report, Table 5.5-22.
- ²⁴ Microsoft Excel's PMT function.
- ²⁵ The value of crop damages as defined in the RID study included damages to varieties of crops, live-stock and fisheries.
- ²⁶ The RID Study, Volume 2, Main Report, Table 5.5-23 (a).

