Economics of Integrated Watershed and Reservoir Management

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Selected Paper prepared for presentation at the Agricultural & Applied Economics Association

AAEA & ACCI Joint Annual Meeting, Milwaukee, Wisconsin, July 26-29, 2009

Abstract (50 words)

A dynamic optimization framework is used to analyze integrated watershed management and suggest appropriate policies. Soil conservation, reservoir level sediment release, downstream water allocation and water quality are subject to control. Application of the model to the Aswan Dam watershed illustrates the need for international cooperation to manage shared watersheds.

Key Words: Watershed management, Soil erosion, Reservoir sedimentation
JEL classification: Q25, Q53

Economics of Integrated Watershed and Reservoir Management

I. Introduction

Growing populations and rising incomes are leading to increased demand for agricultural products in many countries. Some of the more common consequences of meeting this demand include deforestation to increase farm land, dam construction to secure year-round irrigation, and extensive use of chemical inputs to improve productivity. While such activities help increase agricultural yields, they also result in external costs to society that are often ignored. For example, deforestation causes soil erosion which worsens downstream water quality. Eroded soil may also accumulate behind dams, reducing reservoir storage capacity. Similarly, extensive use of chemical inputs may not only exacerbate groundwater pollution, but also degrade water quality in reservoirs (Ribaudo, et al., 1999).

In this paper, we introduce an integrated model of watershed and reservoir management that incorporates such externalities with a view towards proposing policies for increasing social welfare. We develop a dynamic optimization framework to maximize net social benefits with respect to soil erosion and reservoir sedimentation, water pollution, and allocation of different water uses. The model is applied to the Aswan High Dam watershed which is shared by Egypt and Sudan.

The paper is organized as follow. Section II reviews the literature on soil erosion, reservoir management, and downstream impacts of reservoir operation. Section III describes our theoretical model. Section IV presents the results of the Aswan High Dam watershed case study. Section V concludes the paper with a summary of the findings and suggestions for further research.

II. Literature Review

A watershed is an area of land that catches fresh water and drains it off in places such as rivers and lakes. Humanity has lived in and actively impacted watersheds. Anthropogenic activities in a watershed have beneficial aspects but can also cause severe damage to the environment and generate losses to the economy. A common example of anthropogenic activities is the release of agricultural residuals to environment like sediment and pesticides that may degrade the quality of water and reduce storage capacity of downstream reservoir.

Ribaudo and Johansson (2006) document the impacts of agriculture on reservoir water quality due to runoff from farms. In the United States, agriculture nutrients contribute to fresh water degradation by 37% while pesticides do the same by 26% (Ongley, 1996). Sediments from such sources that are trapped behind world’s dams account for approximately 50 billion tons every year (McCartney, et al., 2000). In Asia, reservoir storage capacity loss due to upstream soil erosion of nine major reservoirs on Java, Indonesia, is estimated to be $16.2 to $74.8 million annually (Barbier, 1996). Increasing rates of soil erosion reduce storage capacity of a reservoir and the productivity associated with it. This is, of course, in addition to the direct damage done by soil erosion to agriculture. The replacement cost for losses of top soil nutrients is estimated to be $1 billion in the United State every year (Larson, et al., 1983).

Although dams and reservoirs are very important components in a watershed, only a limited body of economic literature discusses sedimentation issues. Palmieri, et al. (2001) develop a theoretical model for reservoir sedimentation. Pattanapanchai (2005) extends this model by introducing upstream watershed management for multi-purpose dams. However, there is much evidence that dam operations also impact the downstream environment in many ways. There is not much economic literature that addresses downstream externalities generated by reservoirs and dams. Among the few examples that do so are Kotchen, et al. (2006) and Patten, et al. (2001) who examine the situations in which water outflow changes from dams may improve downstream environmental conditions.

More general impacts of reservoir operation have been documented by biologists and hydrologists. According to McCully (1996), environmental impacts of dams operation fit within three categories: (1) changes in downstream morphology of riverbed and banks; (2) changes in downstream flows with extreme high and low flows; (3) reduction of sediment load of downstream flood plains. Although it is hard to estimate all of these downstream impacts, clear evidence has been reported in Egypt that reduction of sediment load from the reservoir increases downstream agriculture production costs requiring more fertilizer (Dixon, et al., 1989).

In summary, several individual dimensions of watershed management have been studied in economic literature, but an integrated watershed model that includes a dam has not yet been developed.

III. Theoretical Model

In our model, the integrated watershed is divided in three parts: namely, upstream, reservoir, and downstream   At the upstream-level, agriculture is considered as the anthropogenic activity that generates soil erosion and water pollution. Although upstream farmers try to maximize their profits from agricultural land by soil conservation efforts and fertilizer use, these efforts may not reach socially optimal levels if there is a reservoir downstream and eroded soil results in reduction of reservoir storage capacity over time. Additionally, chemical fertilizer and pesticide use by upstream farmers causes downstream water pollution.

At the reservoir-level, dam managers are assumed to maximize their own benefits that are dependent on reservoir storage capacity and water quality. Dam managers are responsible for maintaining reservoir water quality above threshold level. Without appropriate consideration of downstream effects, for example, they may not implement sufficiently frequent sediment removal due to the relatively high cost of doing so.[1] However, reservoir-level sediment impoundment over extended periods provides downstream farmers virtually silt-free water that has few nutrients. As a result, the farmers try to compensate with more extensive use of chemical fertilizers, which exacerbates water quality.

Downstream water quality is also affected by changes in water release, which is controlled by dam managers to maximize returns from irrigation and⁄or hydropower. Water quality has a direct impact on health of residents who depend on drinking water from rivers. A downstream damage function (based on fertilizer use and in-stream water flow) is used to capture damage to residents due to lower water quality.

The above problem can be analyzed in a dynamic optimization framework, for which an optimal control formulation is described later in this section. Key components of the social net benefit function are: (1) a lifetime revenue function for upstream farmers; (2) water pollution concentration associated with fertilizer use; (3) a lifetime net benefits function for a reservoir based on storage capacity and water treatment cost; (4) downstream net benefits function associated with a downstream damage function.

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[1] Detail descriptions on sediment removal costs can be found in Morris, G. L., and J. Fan. *Reservoir Sedimentation Handbook: Design and Management of Dams, Reservoirs, and Watersheds for Sustainable Use*: McGraw-Hill Professional, 1998.

(1) Lifetime Revenue Function for Upstream Farmers

Following a slightly modified form of the approach used by McConnell (1983), we assume that upstream farmers try to maximize their lifetime net revenue, which is a function of soil depth, soil loss, soil conservation effort, amount of fertilizer use, and other inputs such as labor, irrigation, and machinery. On the other hand, soil depth and soil loss are affected by soil conservation efforts as follows:

$$L = L_{max} - E\ ;\ \partial D \big/ \partial t = -L$$

where L = annual soil loss per hectare.

L_{max} = the maximum soil loss per hectare

E = soil conservation effort per hectare

D = depth of top soil

Assuming constant returns to scale on land, the per hectare net benefits function for upstream farmers is as follows:

$$NR = P_c \cdot Y(D, E, F, Z) - C_e \cdot E - C_f \cdot F - C_z \cdot Z$$

$$\partial Y / \partial D > 0\,,\ \partial Y / \partial E \geq 0\,,\ \partial Y / \partial F \geq 0$$

where: NR = net revenue per hectare

P_c = price of crop

Y = crop output per hectare

F = fertilizer use per hectare

Z = other inputs such as labor and capital

C_e = annual cost per hectare of soil conservation at given effort level

C_f = unit cost of fertilizer per ton

C_z = unit cost of other inputs

Without considering off-site damage of soil erosion, upstream farmers will try to maximize their lifetime net benefits. Since soil conservation efforts and fertilizer use are control variables for upstream farmers, lifetime net revenue for upstream farmers can be written as:

$$\underset{E,F}{Max}\ NBUF = \int_{t=0}^{T} \eta_1 \cdot NR_t(D_t, E_t, F_t, Z_t)e^{-rt}dt + \eta_1 \cdot SV_L e^{-rT}$$

subject to: $$\frac{dD}{dt} = \dot{D} = -L_t = -(L_{max} - E_t)$$

$$0 \le D \le A$$

where: $NBUF$ = total upstream farmers net benefits of agricultural production

η_1 = total hectare of upstream agricultural land

SV_L = salvage value of farm land per hectare when depth of top soil is completely depleted

A = initial soil depth

(2) Water Pollution Concentration

We assume that the reservoir manager has responsibility to maintain a certain water quality standard before providing any amount of water to downstream residential users. Pollution concentration in the reservoir is calculated based on the zero-dimensional reservoir water quality model (Vollenweider, 1976). The first point to note is that upstream fertilizer use determines the pollution concentration of the incoming water. Pollution concentration of the outgoing water depends on this as well as factors like the residence time of water in the reservoir. Finally, cost of water treatment to bring it to the acceptable standard depends on the quality and quantity of the water to be treated. The following equations present these three ideas in mathematical terms:

$$C_{in} = \frac{\omega \cdot \eta_1 \cdot F}{Q_{in}} \ ; \ C_{out} = \theta \cdot e^{-Tres} \cdot C_{in}(F) \, ; \ C_{WT} = Q_{out} \cdot C_U$$

where: C_{in} = incoming pollutant concentration depended on upstream fertilizer use

C_{out} = outgoing pollutant concentration

ω = fertilizer residual rate ($0 \le \omega \le 1$)

Q_{in} = volume of incoming water

Q_{out} = volume of outgoing water

θ = regenerated eutrophication ($\theta \ge 1$)

$Tres$ = the residence time of water in the reservoir

C_{WT} = water treatment cost for the dam manager

C_U = unit cost of water treatment per volume (= $\psi \cdot \left\{ \left(C_{out} - C_{stan} \right) / C_{out} \right\}^2$)^2

ψ = water treatment adjustment parameter

C_{stan} = water quality standard

When the pollutant concentration is lower than the water quality standard ($C_{stan} > C_{out}$), then C_{WT} is set to zero for no treatment.

(3) Lifetime Reservoir Net Benefits

Sediment retention significantly reduces life of reservoir when there is high sediment deposition. Periodic sediment removal can recover storage capacity of reservoirs. The technical efficiency of any given sediment removal technique depends on many physical and hydrological conditions of reservoirs. For the sake of simplification, we consider only Hydrosuction Sediment Removal system (HSRS) as a sediment removal technique that can remove either all the incoming sediment or some of it.[3] HSRS involves installation of

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[2] Details are available in Hsieh and Yang Hsieh, C. D., and W. F. Yang. "Optimal nonpoint source pollution control strategies for a reservoir watershed in Taiwan." *Journal of Environmental Management* 85(2007): 908–917.

[3] Morris and Fan (1998) identify many types of reservoir-level sediment management techniques, such as flushing, dredging, trucking, and HSRS. Our model could be extended easily to incorporate any of these techniques. For our illustrative case study in Egypt, however, there are no flushing gates. Therefore, we cannot consider

sediment removal pipes. This system can remove only incoming sediment. When the incoming sediment volume is larger than the technical capacity of HSRS, there is only partial removal occurs.

The benefit of water storage is calculated via Gould's-gamma function ($W(S_t)$), which gives reliable water yield as a function of remaining storage capacity.[4] We make four additional assumptions related to reservoir-level management: (1) the dam has two season flows (wet and dry); (2) there is fixed proportion between active storage capacity and flood control capacity; (3) dam benefits to be calculated relate only to irrigation and hydroelectric power; and (4) the dam manager seeks to maximize net benefits by implementing HSRS[5] to remove incoming sediment. The conceptual model can be written as:

$$\begin{aligned}\underset{X,\beta_w,\beta_D}{Max}\ DB_t = \int_{t=0}^{T} \left\{P_H \cdot W(S_t) + P_W \cdot \beta_w \cdot W(S_t) + P_D \cdot \beta_D \cdot W(S_t) - C(X_t) - OMC\right\} e^{-rt} dt \\ + SVe^{-rT} - IC\end{aligned}$$

Subject to: $\dot{S} = \partial S / \partial t = -M + X_t,\ 0 < \beta_w < 1,\ 0 < \beta_D < 1,\ \overline{\beta_I} \le \beta_I < 1$,

$\beta_w + \beta_D + \beta_I = 1$, and $0 \le X_t \le M$

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flushing. Also trucking would usually be considered infeasible for such a large dam. Dredging could be used, but this technique may have no effect on downstream environment, even though it may increase reservoir life.

[4] Technical details are available in Kawashima, S., et al. (2003) Reservoir Conservation: Volume II- RESCON Model and User Manual, World Bank-Washington, DC.

[5] Without HSRS, life of reservoir is reduced and the periodic net benefits of the dam will be decreased until the dam has been fully silted by sedimentation.

Where: DB = dam's net benefits (excluding flood control benefits)

P_H = price of hydroelectric power

P_W = price for wet season water; P_D = price for dry season water

T = terminal time (could be finite or infinity)

β_w, β_D = the fraction of water allocation respectively to wet and dry season agriculture

β_I = fraction for in-stream water flow

$\overline{\beta_I}$ = fraction for mandatory in-stream water flow;

$W(S_t)$ = Gould's-gamma function of remaining storage capacity (S_t)

$C(X_t)$ = cost of sediment removal (X_t) by HSRS

OMC = operation and management cost for dam

e^{-rt} = discount factor

SV = salvage value of dam at time T (if T is finite)

IC = initial construction cost for dam

M = incoming sediment from upstream to reservoir

For the dam manager, X_t, β_w, and β_D are control variables to maximize the net benefits of dam. However, the existence of dam or dam operation certainly creates downstream environmental externalities.

(4) Net Benefits Function for Downstream

Since downstream farmers may be impacted significantly by sediment retention, the production function for downstream farmers can be written as:

$Y = Y(F, U, W)$[6]

Where: Y = crop output per hectare; F = fertilizer use per hectare; U = per hectare sediment spread which is a function of the amount natural sediment (*N*) and sediment removed (*X*) out from reservoir: $U = U(N, X)$; and W = per hectare irrigation water use.

Using the general profit function, downstream farmers try to maximize their lifetime net benefits by controlling fertilizer use, which can be written as:

$$\underset{F}{Max}\, NB_{DF} = \int_{t=0}^{T} \left[\eta_2 \left\{P_c \cdot Y(F,U,W) - k \cdot F\right\} - IB\right] e^{-rt} dt$$

Where: NB_{DF} = net benefits for downstream farmers; P_c = price of crop per tons; k = fertilizer price per tons; η_2 = total hectare in the downstream agriculture land; and IB =

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[6] For purpose of simplifying the analyses, soil erosion at the downstream agriculture is ignored.

irrigation benefits from the lifetime reservoir net benefits:[7]

$$IB = P_W \cdot \beta_w \cdot W(S_t) + P_D \cdot \beta_D \cdot W(S_t) .$$

Assuming that pollution in a river is diluted by increasing current water flow, downstream water quality is calculated as function of in-stream flow and the amount of agriculture pollutant:

$$PC^D = AP / V \quad \text{and} \quad V = \beta_I \cdot W(S_t)$$

Where: PC^D = downstream pollution concentration; V = annual in-stream water flow; AP = agriculture pollutants, which is proportional to downstream fertilizer use: $AP = F(F)$.

Finally, downstream environmental damage (D_D) is a function of pollution concentration: $D_D = D(PC^D)$; $\partial D_D \big/ \partial PC^D > 0$.

(5) Socially Optimal Solution

The socially optimal discounted stream of net benefits for the entire watershed is calculated as follows:

$$\underset{E,X,F,\beta_w,\beta_D}{Max} \; SB = \int_{t=0}^{T} \left\{ \begin{array}{l} \eta_1 \cdot NR_t(D_t, E_t, F_t) + P_H \cdot W(S_t) + P_W \cdot \beta_w \cdot W(S_t) + P_D \cdot \beta_D \cdot W(S_t) - C(X_t) \\ -OMC + \eta_2 \left\{ P_c \cdot Y(F,U,W) - k \cdot F - IB \right\} - D_D(PC^D) \end{array} \right\} e^{-rt} dt$$
$$+ \left\{ SV + SV(D_T) \right\} e^{-rT} - IC$$

subject to all the equations of motion and technical constraints described previous section.

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[7] Since farmers use water from the dam to irrigate, irrigation benefits have to be subtracted from farmer's profit function to avoid double counting.

IV. Application

Data and Empirical Specification

We apply our model to the watershed of the Aswan High Dam (also called Aswan Lake) that is located between Egypt and Sudan. Although the Aswan High Dam was originally designed for more than 500 years, the actual life of the reservoir has recently been estimated as 176 years due to higher than anticipated rates of soil erosion from the Sudanese agricultural area (Jobin, 1999). Moreover, as Sudanese farmers use massive amount of fertilizer and pesticide, water quality in Aswan Lake is below the WHO standards in some parts. Since the Aswan High Dam captures almost all incoming sediment, chemical fertilizer use of downstream farmers in the Nile River, which is currently 13,000 tons annually, has increased by more than five times since construction of the Aswan High Dam, but despite this the agricultural productivity in Egypt has declined over 23% (WCD, 2000).

We acquired 40 years of time series data from sources such as FAO and International River Networks relating to sedimentation as well as agricultural inputs and outputs in Egypt and Sudan. Water quality data was obtained from the Nile River Basin Institute and Egyptian government documents. Lal (1981) estimates the agricultural production function in 10 African countries, and shows that their agricultures have high correlation between accumulative soil loss and production yield. Based on his results, we take the upstream agriculture production function to be:

$$Y = 6.7 \cdot \exp(-0.003 \cdot ASL) + F^{0.67}$$

where: Y = total crop yield for 4 major crops per hectare (ton/ha)

ASL = accumulative soil loss (ton/ha) , which is proxy for soil depth

F = average fertilizer use per hectare for 4 major crops (ton/ha)

Time series data of Egyptian agriculture was obtained from FAO agriculture statistic database from 1961 to 2004. Using total cereal yield and total fertilizer use per hectare data, we estimated following production function for Egyptian agriculture:

$$\ln \hat{Y} = -2.9 + 0.39 \ln F + 0.38 \ln W \qquad (R^2 = 0.54)$$

Also we find a strong negative relationship between downstream fertilizer use and sediment release from the reservoir (i.e., $\rho_{F,U} = -.71$). Based on the experimental results from Smiciklas and Moore (1999), we assume that 30% of extensive fertilizer use by farmers impacts the downstream environment in linear form. This implies that $AP = 0.3 \cdot \eta_2 \cdot F$. Using this information, we conclude that downstream damage function has the following form:

$D_D = \$26 \cdot population$ when $PC^D > water\ quality\ standard$

$D_D = 0$ when $PC^D \leq water\ quality\ standard$

We use 2007 Egyptian population which is 80,000,000. According to APRP Water Policy Program (2002), there is an evidence that COD (Chemical Oxygen Demand) level can be impacted by fertilizer use. Based on Egyptian water quality standard in APRP survey, 10*mg/l* COD level is used for the proxy of water quality standard.[8] Economic and hydrologic parameters are summarized in Table 1.

Preliminary Results

For comparison purposes, we consider different management scenarios for upstream farmers, the reservoir manager, and downstream farmers as well as downstream residents. First, we calculate the baseline case which replicates existing management strategies which seem to reflect a myopic perspective. For example, upstream farmers apply some level of fertilizer based on short-term profit maximization and carry out no soil conservation efforts. Likewise, for the reservoir manager, who is assumed to continue to follow the current practice of using no sediment management technique so the reservoir only lasts for about 160 years. Downstream farmers also maximize their benefits based on the fertilizer use which leads to severe downstream damage.

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[8] To analyze the impact of fertilizer use on water quality, T-N or T-P should be used as a proxy for water quality. However, there is lack of information about these measures. Therefore, we use the other proxy (i.e., COD) as a water quality in the downstream Nile River.

Second, we calculate the non-corporative case where all the agents in the integrated watershed maximize their own long-term benefits, but without considering impacts on the other agents. Thus, we assume that upstream farmers maximize their lifetime net benefits without considering downstream sedimentation and water quality. For the sake of simplification, we assume that upstream farmers adopt an all-or-nothing approach towards control of soil erosion (maximum soil conservation efforts can reduce 18 ton/ha of soil erosion), and the dam manager has two sediment removal options, which are partial sediment removal or full sediment removal by HSRS with initial set up costs of $400 million and $800 million, respectively. In this scenario, upstream farmers' net benefits achieve the maximum value, approximately $18 billion, which is about $4 billion higher than the baseline case. Due to the linear functional form of soil loss assumed above, the bang-bang solution that results leads to relatively less incoming sediment. Therefore, the need for practicing HSRS is low for the reservoir manager. However, downstream farmers still suffer from silt-free water, so that approximately $42 billion in downstream damages occur, which similar to the baseline case.

Lastly, we calculate the corporative scenario where the goal is to maximize the social net benefits of the entire watershed. Upstream farmers and the reservoir manager sacrifice their own benefits to increase downstream agriculture profits. Since downstream agriculture benefits are a large portion of the social net benefits, the optimal level of upstream soil conservation efforts is less than the non-cooperative case. To maximize social net benefits, the dam manager adopts HSRS relatively early to release more sediment downstream and increase in-stream water flow to reduce downstream damages. Although total net benefits for upstream farmers and the dam manager decease about $19 billion compared to the non-corporative case, the social net benefits are maximized at about $153 billion due to increased downstream benefits. The non-cooperative and the cooperative case both give a sustainable reservoir storage capacity with removing all of the incoming sediment by HSRS. Although partial removal of incoming sediment by HSRS does not provide sustainability for storage capacity, both cases increase life of reservoir more than 500 years. These illustrative simulation results are reported in more detail in Table 2.

V. Summary and Conclusion

This paper presents an optimal control model of integrated watershed management focused on soil conservation efforts, sediment management, and pollution control. When the watershed lies between two nations, an upstream country's decision related to soil erosion significantly impacts reservoir management and agriculture in the downstream country. Although upstream soil conservation increases their own agricultural productivity and downstream reservoir storage capacity, downstream farmers still suffer from silt-free water in the non-cooperative case. For the socially optimal case, however, upstream farmers compromise their own productivity and reservoir level sediment release starts earlier so as to benefit downstream farmers.

Suffice it to say that this although paper provides an economic framework for analyzing integrated watershed management, it should be viewed as starting point for further research. Several modifications could be made. First, the prices of water and crops could be endogenously determined. Second, only a few environmental aspects of sediment removal techniques and only some of the indirect costs of operating a reservoir are considered in the model. Full impacts of sediment removal and other externalities, caused by reservoir operation, need to be considered. Third, sediment management at the reservoir level is restricted to one simplified method. There is a need to consider other techniques and to bring greater realism in the engineering dimensions at the reservoir level. Fourth, flood control benefits are not taken into account in our model, leading to underestimation of dams' net benefits. Empirical studies that estimate such benefits are clearly needed. Fifth, population is assumed to be constant. This is clearly a conservative procedure as benefits from improved reservoir management would be expected to increase with growing population. Sixth, although global climate change has a significant impact on integrated watershed management, it is not considered in this paper. The results of this paper could be different when the impact of global climate change is taken into account. Finally, this paper relies mostly on existing published documents but the data available for Nile watershed and Sudanese agriculture is incomplete and out of date. The empirical results from the model could be greatly improved with better data.

Table 1. Selected Economic and Hydrologic Parameters for Aswan Watershed

Upstream Watershed (Agriculture)

Description	*Notation*	*Value*	*Unit*	*Source*
Price of crops	P_c	215	\$/ton	FAOSTAT
Cost of soil conservation efforts	C_e	6	\$/ton/ha	Pimentel, et al. (1995)
Cost of fertilizer	C_F	160	\$/ton	FAOSTAT
Upstream agriculture land	η_1	2	million ha	
Annual soil loss	L	30	ton/ha	Calculated
Sediment delivery ratio	·	50	%	Calculated

Reservoir-level Water Quality

Description	*Notation*	*Value*	*Unit*	*Source*
Fertilizer residual rate	ω	50	%	Arbitrary
Mean water flow	·	80	BCM	ILEC database
Remaining storage capacity	S	31.5	BCM	
Water quality threshold	C_{stan}	10	ppm	APRP (2002)
Cost of water treatment	C_u	0.02	$\$/\text{m}^3$	Bates, et al. (2008)

Reservoir-level

Description	*Notation*	*Value*	*Unit*	*Source*
Price of water (dry season)	P_D	0.04	$\$/\text{m}^3$	Aly, et al. (2005)
Price of water (wet season)	P_W	0.02	$\$/\text{m}^3$	
Price of hydropower	P_H	0.01	$\$/\text{m}^3$	KOTRA (2005)
Initial HSRS set up cost	C_x	800	million \$	Kawashima (2004)
Annual reservoir operation cost	OMC	10	million \$	Calculated
Incoming sediment	M	200	million ton	Jobin (1999)
Trap efficiency	·	99	%	Jobin (1999)

Downstream (Agriculture & Damage)

Description	*Notation*	*Value*	*Unit*	*Source*
Agriculture land	η_2	2.9	million ha	FAOSTAT
Population	pop	80	million	CIA World Fact Book
Discount factor	r	5	%	Arbitrary

Table 2. Preliminary Simulation Results (Unit: billion $)

	Upstream(+)	***Reservoir(+)***	***Downstream(+)***	***Damage(-)***	***Social***
Baseline	14.25	59.33	54.74	42.63	85.69
Non-corporative Scenarios(soil conservation)					
*HSRS (P)**	18.36	59.34	54.81	42.54	89.97
*HSRS (F)***	18.36	59.35	54.76	42.64	89.83
Corporative Scenarios (soil conservation)					
HSRS (P)	15.16	43.83	94.35	0.81	152.53
HSRS (F)	15.04	45.94	101.7	9.41	153.27

Note: Social net benefits = upstream + reservoir + downstream - damage

* HSRS (P) indicates that only half of incoming sediment is removed from the reservoir

** HSRS (F) indicates that all the incoming sediment is removed from the reservoir

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