VALUATION AS A TOOL FOR THE INTERNALISATION OF ECOLOGICAL-ECONOMIC FACTORS IN UPSTREAM-DOWNSTREAM RELATIONS

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1 INTRODUCTION

Scarcity of necessary resources induces disputes. Availability of water, the vital resource of global significance, is governed by the hydrological cycle. At different times and in different regions scarcity of water emerges. In recent years, a number of environmental and political analysts have expressed the view that dwindling water resources have the potential of undermining national and international security. Swain (2002) has observed that the social and political tensions caused by water scarcity can threaten existing water distribution pacts. In the words of Homer-Dixon (1994:5-40),

> *Conflict is most probable when a downstream riparian is highly dependent on river water and is strong in comparison to upstream riparians. Downstream riparians often fear that their upstream neighbours will use water as a means of coercion. This situation is particularly dangerous if the downstream country also believes it has the military power to rectify the situation.*

The increasing demand on the limited water resources and the associated complexities of the disputes, often aggravating to conflicts between the upstream-downstream riparian states, regions or villages have encouraged new research on several important aspects, that so far did not receive much attention. Most research undertaken in this area has concentrated mainly on the political and strategic aspects of the conflicts and their resolution. In the absence of objective mechanisms for joint decision-making, military threats or crude diplomatic tactics have so far been the dominant instruments used in the resolution of riparian conflicts.

In the past few years, important advancements have also been observed towards the generation of a comprehensive and interdisciplinary understanding of the challenges facing water resource management. One crucial aspect of this emerging knowledge base is the process of the gradual recognition and internalisation of the economic values of the ecological services provided by water along the terrestrial path traversed by water from its precipitation to its return to the oceans. As a topic for research, valuation of the water resources, has the potential of producing a more realistic and practical basis for evolving mechanisms for negotiated settlements of the conflicts (Ghosh and Bandyopadhyay, 2002:3). There is no doubt that as and when the methodology for such valuations becomes widely acceptable, new ideas on river basin management will also emerge.

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2 THE APPROACH TO VALUATION

The work presented here is part of an ongoing research. At the global level also very few attempts have been reported on the valuation of uplands water resources. Valuation of the water resources, as a topic of research, has attracted the attention of researchers because of its potential to produce a more objective and practical basis for negotiated settlements of the conflicts. Tthe growing scarcity of water and recent worldwide orientation towards pricing and deriving principles for pricing of this natural resource has also encouraged such research (Gittinger, 1982; Southgate, 2000; Guerrero-G.R. and Howe, 2000). A majority of the studies conducted in this respect have looked at the economic use and benefits of water (Young, 1996; Omezzine et al.,1998; Bouhia, 2001). In addition to the economic use of water in the downstream, systematic research on the valuation of the immensely significant ecosystem services provided by water has also drawn attention in the recent past. As a part of the study on the *Sierra Nevada Ecosystem Project* Stewart (1996) has tried to arrive at a comprehensive economic valuation of the ecosystem services provided by water in the upland-plain framework. This has been based on the use of water in industry, agriculture, and for ecosystem services. It is our contention in this paper that valuation of the ecosystem services along with the economic uses of water can provide a theoretical basis for pricing and mediation in upstream and downstream relations.

The present analysis is a step towards extending the exercise of economic valuation of water along its movement from a hypothetical upstream catchment area to a hypothetical downstream plain area, mediated by hypothetical storage sites in between. Though the ecological economic valuation is not part of the present exercise, at a suitable point in future, such work is expected to provide an entry to a more comprehensive ecological economic valuation. In addition to assessing the economic use of water in the downstream, systematic research on the valuation of the ecosystem services provided by water in the upstream would provide a basis for comprehensive pricing and conflict resolution. Financial instruments based on the values of ecosystem services provided by water in both the upstream and the downstream areas is envisaged as a realistic foundation for the evolution of hydro-solidarity among the co-riparians entities, be it the countries, states of a country or local self-governments.

The ecosystems services provided by water are diverse. Among those important from the point of the linkage between the uplands and the plains are sustaining the upstream forest ecosystems of hydrological importance and the related biodiversity, mitigation of floods in the downstream plains, generation and transportation of sediments from uplands to the plains, maintaining the physical and chemical strengths of soils, recharge of surface and ground water resources in the plains, sustaining diverse aquatic ecosystems and related biodiversity, all along the flow from uplands to the downstream plains to the delta, dilution and transportation of pollutants etc.

This paper contemplates valuation in the context of the limited spectrum of the hydrological flow in the area where the uplands and the plains meet. Based on the principle of 'beneficiaries pay', the paper approaches the derivation of optimal economic returns that the beneficiaries need to pay to all those incurring the cost, without really receiving benefit in the process. The optimal amount is taken as the one, which maximises the total social benefits. This has been derived within static and dynamic frameworks under competitive equilibrium. The next two sections of the paper describes the two approaches.

3 A STATIC MODEL OF VALUATION

In the static model of valuation, it has been proposed that in the downstream the use of water is for irrigated agriculture and industry. Dams and reservoirs and multiple storage units can be built in the upstream for storing water that flows along the streams and rivers emerging from the uplands. The two sub-economies that have been talked of, involve the upstream and the downstream. The dam is primarily built considering the downstream benefits, which involve availability of irrigation in the dry season, though we will find that in the course of the paper, the model can be extended to involve several other hypothetical situations. We have attempted to capture the value of water in the entire spectrum of the hydrological flow, right from its origin to the point of its use in the downstream. Water emanates from the melting of ice in the high mountains or surface run-off after rainfall. During its upstream flow, it provides certain ecosystem benefits to the upstream. This includes recharge of the natural springs, soil moisture supply for the maintainance and growth of the forests, etc. The upstream community extracts a portion of the water for domestic consumption and other economic activities. The remaining flows through the streams and rivers. When a dam is built in the uplands, a portion of it gets stored in the dam, while another portion might not do so due to evaporation, return flow and other factors. The water stored in the dams and reservoirs can be used up for various purposes in the downstream. However, while the upstream obtains certain ecological benefits, there are certain other ecological benefits that are lost by the downstream because of the impediment caused in the natural hydrological flow by the dams and barrages.

The symbols used in the model are as follows:

$B_U(X, S_U)$ ≡ upstream benefits as a positive function of upstream extraction X and storage S_U;

$\overline{W}$ ≡Total water availability in the catchment ;

T_U ≡ water inflow to the dam;

$\overline{I}$ ≡ initial capital investment ;

$E_U()$ ≡ ecosystem services of water in the upstream as a function of total water originating from the source;

$\overline{S}$ ≡ Storage capacity (this can be increased by building extra storage units over time);

$B_D(w_D)$ ≡ Benefit to the downstream economy as a positive function of water released from the dam to the downstream, w_D;

$C_O(S_U, \overline{S})$ Cost of Operations and Maintenance of the dam as a positive function of storage and storage capacity;

$C_T(w_D, \overline{I})$ Transfer cost of water to the downstream as a function of the water released from the dam and the initial capital investment;

$C_U(X)$ Cost of extraction of water in the upstream;

$E_D(.)$ Ecological services of water in the downstream;

$C_I(\overline{S}, \overline{I}) \equiv$ Cost of installation of new storage, $\frac{\partial C_I}{\partial \overline{S}} \geq 0, \frac{\partial C_I}{\partial \overline{I}} \leq 0.$

Due to diversion from the dams, the natural hydrological flow along the riverbed is altered, there are costs borne by the downstream in terms of the loss of the ecological services provided by water. If $\overline{W}$ flows smoothly to the downstream without any disruption in the natural flow, the ecosystem benefits would be $E_D(\overline{W})$. Due to water storage and diversion, quantity of water that provides ecosystem benefits to the downstream in its natural flow is:. $\overline{W} - X - S_U - w_D$

Hence, the downstream loss in ecosystem benefits =. $E_D(\overline{W}) - E_D(\overline{W} - X - S_U - w_D)$

Again, the other part of the downstream obtains certain ecological benefits from the diverted water, w_D. We denote that by E_D (w_D).

To sum up, the net benefits should be =

$$B_U(X, S_U) + E_U(\overline{W}) + B_D(W_D) - C_O(S_U, \overline{S}) - C_U(X) -$$
$$C_T(w_D, \overline{I}) - C_I(\overline{S}, \overline{I}) - E_D(\overline{W}) + E_D(\overline{W} - X - S_U - w_D) + E_D(w_D) \ldots (1)$$

Here, (1) needs to be maximised subject to certain economic, structural and ecological constraints. The constraints are as follows:

Constraint 1:

Water inflow to the dam is constrained by the difference between the total water originating from the source, and the water extracted by the upstream community, i.e.

$$T_U \le \overline{W} - X$$

The constraint can be rewritten as:

$$X + T_U \le \overline{W} \ \ldots \text{(A)}$$

Constraint 2:

The storage in the dam is the difference between the inflow to and the outflow from the dam.

$$S_U = T_U - w_D \ldots (B)$$

and (B) lead to (C):

$$S_U \le \overline{W} - X - w_D \ldots \text{(C)}$$

Constraint 3:

The storage in the dam is constrained by the total storage capacity:

$$S_U \le \overline{S} \ldots \text{(D)}$$

Finally, we talk of a cost constraint or a budget constraint, beyond which the cost cannot move. Hence, $C_O(S_U, \overline{S}) - C_U(X) - C_T(w_D, \overline{I}) - C_I(\overline{S}, \overline{I}) \le \overline{C}(\overline{I})$ …(E),

Hence, we pose the problem as:

$$\text{Max} \quad \begin{array}{l} B_U(X, S_U) + E_U(\overline{W}) + B_D(W_D) - C_O(S_U, \overline{S}) - C_U(X) - \\ C_T(w_D, \overline{I}) - C_I(\overline{S}, \overline{I}) - E_D(\overline{W}) + E_D(\overline{W} - X - S_U - w_D) + E_D{}'(w_D) \end{array}$$

S.t.

$$S_U \le \overline{W} - X - w_D \ldots (C)$$
$$S_U \le \overline{S} \ldots (D)$$
$$C_O(S_U, \overline{S}) - C_U(X) - C_T(w_D, \overline{I}) - C_I(\overline{S}, \overline{I}) \le \overline{C}(\overline{I}) \ldots (E)$$

…(2)

In order to do this exercise, we form the Lagrangian L =

$$\begin{array}{l} B_U(X, S_U) + E_U(\overline{W}) + B_D(w_D) + E_D{}'(w_D) - C_O(S_U, \overline{S}) - \\ C_U(X) - C_T(w_D, \overline{I}) - C_I(\overline{S}, \overline{I}) - E_D(\overline{W}) + E_D(\overline{W} - X - S_U) \\ + \lambda.[\overline{W} - X - w_D - S_U] + \mu.[\overline{S} - S_U] + \gamma.[\overline{C}(\overline{I}) - C_O(S_U, \overline{S}) - C_U(X) - C_T(w_D, \overline{I}) - C_I(\overline{S}, \overline{I})] \end{array}$$

The Lagrangian expression has been differentiated with respect to X, w_D, S_U,, , and in order to obtain the optimality conditions.

$$\frac{\partial L}{\partial X} \le 0, \text{ and } \frac{\partial L}{\partial X^*}.X^* = 0 \;\therefore\; \frac{\partial B_U}{\partial X} - \frac{\partial C_U}{\partial X}(1+\gamma) - \frac{\partial E_D}{\partial X} \le \lambda \ldots (3)$$

$$\text{and } \frac{\partial L}{\partial w_D} \le 0 \text{ and } \frac{\partial L}{\partial w_D{}^*}.w_D{}^* = 0 \;\therefore\; \frac{\partial B_D}{\partial w_D} - \frac{\partial C_T}{\partial w_D}(1+\gamma) - \frac{\partial E_D}{\partial w_D} + \frac{\partial E_D{}'}{\partial w_D} \le \mu \ldots (4)$$

$$\frac{\partial L}{\partial S_U} = 0 \Rightarrow \frac{\partial B_U}{\partial S_U} - \frac{\partial E_D}{\partial S_U} - \frac{\partial C_O}{\partial S_U}(1+\gamma) = \lambda + \mu \ldots (5)$$

$$\frac{\partial L}{\partial \overline{\overline{W}}} = 0 \Rightarrow \frac{\partial E_U}{\partial \overline{\overline{W}}} + \lambda = 0 \quad \Rightarrow \frac{\partial E_U}{\partial \overline{\overline{W}}} = -\lambda \ldots (6)$$

$$\frac{\partial L}{\partial \overline{S}} = 0 \Rightarrow -\frac{\partial C_O}{\partial \overline{S}} - \frac{\partial C_I}{\partial \overline{S}} + \mu = 0 \Rightarrow \frac{\partial C_O}{\partial \overline{S}} + \frac{\partial C_I}{\partial \overline{S}} = \mu \ldots (7)$$

$$\frac{\partial C_T}{\partial \overline{I}}(1+\gamma) + \frac{\partial C_I}{\partial \overline{I}}(1+\gamma) = \gamma.\frac{\partial \overline{C}}{\partial \overline{I}} \ldots (8)$$

3.1 Interpretations of the optimality conditions

The relationships expressed in (3) and (4) reflect on the optimal conditions that emerge from changes in upstream extraction, X, and water outflow from the dam to the downstream, w_D, respectively. The Lagrangian multipliers, λ and μ are the shadow values expressed in terms of X and w_D respectively. As X and w_D increase by a unit, there will be associated costs and benefits. Condition (3) suggests that optimal upstream extraction is made at the point where the net benefit from the same is equal to the shadow value of upstream extraction. This shadow value is obtained by relaxing the constraint on extraction in the upstream by a unit. In other words, it captures the welfare loss or gain with one unit relaxation of the constraint, created by the total water originating from the source. Again, □ emerges as the pressure wielded by a unit rise in extraction to the social budget. It can also be interpreted as the cost of reallocating the budget between the competing uses. Condition (4) can be interpreted in the same manner as that of (3). Extraction or water release, respectively, continues till the time the net benefits are equal to the shadow costs.

More interesting is the interpretation of (5). Increase in storage brings about an increase in the *in situ* benefits, but, simultaneously, it gets associated with the ecological loss in the downstream, and the *augmented* cost of operations and maintenance of the dam. The net benefit, thus, takes all these components into consideration, and is given in the LHS of (5). According to the optimal conditions given by (5), the net benefits should be sum of the two shadow prices, λ and □. The former happens to be the shadow price of water extraction by the upstream, while, the latter happens to be the shadow price of water outflow to the downstream. There can be a unit increase in storage, only if the upstream community does not extract the extra unit of water that fetches a price, . On the other hand, storage has happened because the extra unit of water has not been released to the downstream economy, the shadow value of which is □. If the storage had not happened, the services that water would have yielded are given by λ+□. Hence, it represents the opportunities lost in the process of an extra unit of storage.

According to (6), increase in water in the catchment area enhances the opportunities of the economy by the extent, λ . Since, λ is actually a "cost", the negative sign associated with it in (6) reflects upon the degree of the benefits that the society can obtain due to water increase. This is matched by the extent of upstream ecosystem benefits rendered by the water.

Condition (7) talks of a change in the storage capacity, and its effect on the economy. If an extra storage unit is constructed, there will be extra costs of operations and maintenance and extra costs of installation of storage. This matches with the shadow value of storage, or the benefits that can be obtained from the enhancement of the storage capacity.

An interesting case has been taken up in (8). If the initial capital investment would have been a unit higher, the recurring costs of water transfers and that of operations and maintenance would have been lower, due to the availability of ready infrastructure. But, again, a higher capital investment would have lowered the basket left as the budget constraint. Hence, while on the one hand, the RHS shows the extent of pressure release on the budget constraint due to a higher capital investment, the LHS shows the pressure wielded on the budget constraint by the extra unit increase in the initial capital investment.

What this static model proposes is that due to the non-availability of market prices of the resource, shadow values can be used in pricing of the same. At the same time, pricing of water in the upstream-downstream framework based on the principles obtained from the above equations, would maximise the societal benefits subject to the constraints. If the downstream derives the benefits from dam construction, then the onus of payment for the water used lies with them. On the other hand, the upstream should also be made responsible for paying the water extracted by them, based on the above principles. The model has also extracted the value of the water stored in the dam in terms of the benefits obtained by the society as a whole. This gets reflected in (5). Interestingly, as conceived in this model, both parties are beneficiaries from storage. According to the *beneficiaries pay* principle, both parties should pay for the water. Now, an important question looms: to whom? Of course, the payment should be made to the affected. In every endeavour of human intervention in the natural hydrological process, there is a beneficiary, and an affected party. When the upstream extracts water, downstream benefits get affected, and they deserve to be paid for the same. On the other hand, if the downstream builds dams by displacing the upstream community, the cost of rehabilitating the displaced should be paid by the downstream. In the framework of this static model, the downstream diverts water for its own use, thereby creating a loss in the ecosystem benefits for communities further downstream. The same is the case with the mangrove vegetation in Sundarbans in the Ganga-Brahmaputra delta in India. Due to water diversion from Farakka barrage to resuscitate the Calcutta port, the communities further downstream have to incur costs due to loss in mangrove vegetation. The linkage between mangroves and fisheries are well-known. Eventually, it is the fishermen community that has been finally affected. They deserve to be compensated for the loss. The compensation should follow certain economic conditions so as to maximise the societal benefits, like the one derived in this static framework.

4 A DYNAMIC MODEL OF VALUATION

Like its static counterpart, the dynamic model also assumes the existence of the two sub-economies, namely, upstream and the downstream. Dam construction happens in the upstream at the catchment area. The water inflow to the dam depends on the amount of the water in the catchment area, and the extraction by the upstream community. Upstream derives benefits from extraction in the upstream before water enters the dam, dam storage, and the ecosystem services of water, while downstream derives benefits from the dam outflow. The upstream extraction reflects water demand in the upstream. Again, water outflow from the dam to the downstream depends on the downstream demand that is time dependent. Time has been assumed to be a continuous variable in this analysis. Downstream demand is also stochastic and is assumed to be following rectangular or uniform distribution with [0, β]. Even in the upstream, demand has been assumed to be perfectly inelastic, and follows rectangular distribution with [0,□]. We have assumed a planning horizon [0, T] for this maximisation exercise. The symbols used are as follows:

N (t): total water in the catchment at time t;

n (t): appropriation by the upstream community at time t;

h (t): water entering the dam at time t;

S (t): storage at time t;

w (t): water flowing out of the dam at time t;

φ(n (t)): upstream demand function at time t;

θ (w (t)): downstream demand function at time t following rectangular distribution [0,];

S*(t): total storage capacity that can be increased by constructing extra storage unit.

The benefits of the upstream community is given by the area under the demand function, with the same being given as $\varphi (n (t)) = 1/\alpha$, where α is assumed to be the maximum demand that can occur at any point of time. The benefit function, thus, emerges as $F (n (t)) = n (t)/\alpha$.

Again, we assume that the cost of extraction by the upstream follows exponential distribution:

$$\kappa (n (t)) = \lambda .\, e^{-\lambda .\, n (t)}$$

Hence, the total cost for extraction is $\int_0^{n(t)} \lambda . e^{-\lambda . x} dx = 1 - e^{-\lambda . n(t)}$

Similarly, the downstream demand function should also emerge as D (w (t)) = w (t)/β.

The upstream also derives ecosystem benefits from the total water in the catchment area, and this is given by $\int_0^T E_U(N(t))dt$. The upstream also obtains "in situ" benefits from water stored in the dam, given by $\int_0^T U(S(t))dt$.

It is further assumed that the total storage capacity is a function of time, given by S*(t). Over a certain expanse of space, extra storage units in the form of dams or reservoirs can be constructed to increase the storage capacity. This involves incurring extra cost of installation. The cost of installation is given by C_I (.).Again, we consider an initial capital investment, I*, which, if put in place, reduces the installation cost of new storage. Thus, we write the function as: $C_I(S^*(t), I^*, t)$, where, $\partial C_I(.)/ \partial S^*(t) \geq 0$ and $\partial C_I(.)/\partial I^* \leq 0$. Hence, over the planning horizon, the cost of installation should be $\int_0^T C_I(S^*(t), I^*, t)dt$

The operations and the maintenance cost is a function of the water stored in the dam, and the storage capacity. The same is given by: $\int_0^T C_O(S^*(t), S(t))dt$

There remains a cost of transferring water from the dam to the downstream economy. This cost over the planning period is given by $\int_0^T C_M(w(t), I^*, t)dt$

In the similar line of the static model, we have defined the ecosystem services of water to the downstream and the subsequent loss due to water diversion. The entire expression is given by:

$$\int_0^T [E_D(N(t)) - E_D(N(t) - n(t) - S(t) - w(t))]dt + \int_0^T E'_D(w(t))dt$$

4.1 The Constraints:

Upstream water extraction and water entering the dam cannot exceed the total water at the catchment: n (t) + h (t) ≤ N (t)

The change in storage in the dam is the difference between the inflow and the outflow: dS (t)/dt = h (t) – w (t)

There is a limit on the maximum possible water that can be stored in the dam. This limit is imposed by the installed storage capacity: S (t) $\leq$ S*.

There is a ceiling on the maximum cost that the society can incur over the planning horizon. This ceiling is given by M, and it needs to be allocated over time. By the logic similar to the static model, we assume M= M (I), with* $\partial M/\partial I^* \leq 0$. *Accordingly, we define* $M(I^*) = \int_0^T C^*(I^*, t)\, dt$ *where,* $C^*(I^*, t)$ *is the maximum amount allotted for the cost to be incurred at time t, with* $\partial C/\partial I^* \leq 0$.

The constraint, eventually, is: $\int_0^T C^*(I^*, t)\, dt \geq \int_0^T [C_I (S^*(t), I^*, t) + C_O (S^*(t), S(t)) + C_M (w(t), I^*, t) + (1- e^{- \cdot n(t)})]\, dt$

The problem can thus be posed as:

$$\text{Max} \int_0^T [\{\frac{n(t)}{\alpha} - (1 - e^{-\lambda . n(t)})\} + E_U(N(t)) + U(S(t) + \frac{w(t)}{\beta} - C_O(S(t), S^*(t))$$
$$- C_M(w(t), I^*, t) - C_I(S^*(t), I^*, t) - E_D(N(t)) + E_D(N(t) - n(t) - S(t) - w(t))$$
$$+ E'_D(w(t))]dt$$

Subject to

1. $dS(t)/dt = h(t) - w(t)$
2. $n(t) + h(t) \leq N(t)$
3. $n(t) \leq \alpha$ …. (9)
4. $w(t) \leq \beta$
5. $S(t) \leq S^*$
6. $S(0) = S_0$
7. $\int_0^T C^*(I^*, t)\, dt \geq \int_0^T [C_I (S^*(t), I^*, t) + C_O (S^*(t), S(t)) + C_M (w(t), I^*, t) + (1- e^{- \lambda. n(t)})]\, dt$

Based on the above, we form the Hamiltonian:

$$H = n(t)/\alpha - (1 - e^{- \cdot n(t)}) + E_U(N(t)) + U(S(t)) + w(t)/\beta - C_O(S(t), S^*(t))$$
$$- C_M(w(t), I^*, t) - C_I(S^*(t), I^*, t) - E_D(N(t)) + E_D(N(t) - n(t) - S(t) - w(t)) +$$
$$E'_D(w(t)) + \chi(t)[h(t) - w(t)] + \square(t)[N(t) - n(t) - h(t)] + \gamma(t)[\alpha - n(t)] + \pi(t)[\beta -$$
$$w(t)] + \sigma(t)[S^*(t) - S(t)] + \eta(t)[C^*(I^*, t) - C_I(S^*(t), I^*, t) - C_O(S^*(t), S(t))$$
$$- C_M(w(t), I^*, t) - (1- e^{- \cdot n(t)})]$$

The control variables in the system are n(t), w(t), S*(t), and I*, while, the state variables are S(t) and h(t).

According to the maximum principle, we have the following conditions:

$$\partial H(.)/\partial n(t) = 0 \ldots (10):\ 1/\alpha - \lambda . e^{-\lambda .n(t)}[1+\eta(t)] - \partial E_D/\partial n(t) = \square(t)+\gamma(t) \ldots (10a)$$

$$\partial H(.)/\partial w(t) = 0 \ldots (11): 1/\beta-(1+\eta(t)).\partial C_M/\partial w(t) - \partial E_D/\partial w(t) + \partial E'_D/\partial w(t) = \chi(t) + \pi(t) \ldots (11a)$$

$$\partial H(.)/\ \partial S^*(t) = 0 \ldots (12)\quad (C_O/ S^*(t) + C_I/ S^*(t))(1+ (t)) = \ (t) \ldots (12a)$$

$$H(.)/\ I^* = 0 \ldots (13)\quad (\partial C_M/\partial I^* + \partial C_I/\partial I^*)(1+\eta(t)) = \eta(t)\ \partial C^*/\partial I^* \ldots (13a)$$

$$\partial H(.)/\ \partial S(t) = d\,\sigma(t)/dt \ldots (14)$$

$$\Rightarrow U'(.) - \partial C_O/\partial S(t)(1+\eta(t)) - \partial E_D(.)/\partial S(t) - \sigma(t) = d\,\sigma(t)/dt \ldots (14a)$$

$$\Rightarrow [\{U'(.) - \partial C_O/\partial S(t)(1+\eta(t)) - \partial E_D(.)/\partial S(t)] / \sigma(t) - 1 = [d\,\sigma(t)/dt] / \sigma(t) \ldots (14b)$$

$$\partial H(.)/\partial h(t) = d\,\square(t)/dt \ldots (15)\quad \chi(t) - \square(t) = d\,\square(t)/dt \ldots (15a)$$

Along with these we can obtain the border conditions by partially differentiating the Hamiltonian with respect to the multipliers, $\chi(t)$, $\square(t)$, $\sigma(t)$, $\eta(t)$, $\gamma(t)$ and $\pi(t)$. From (10a) and (11a), we obtain the conditions similar to (3) and (4) in the static model. Their interpretations remain the same, with the only incorporation of the time variable in this dynamic framework. Even the conditions in (12a) and (13a) have connotations similar to conditions (7) and (8) in the static framework. The equations of interest are given by the families of (14) and (15). This denotes the movement of the shadow prices over time. Condition (14b) clearly shows that the movement of the shadow price of storage over time is primarily dependent on the difference of the benefits and the costs associated with the same at time t. In other words, if at a certain time point, the marginal benefits from storage are much higher than the cost associated with it, (which, according to the principle of diminishing returns, should happen at lower levels of storage), there will be a higher rise in the shadow value of storage. In other words, $\sigma(t)$ reveals the scarcity value of water stored in the dam at time t, and (14) emerges as the movement of the scarcity value over time. Family of (15), however, though not as significant as the family of (14), yet reveals the price movement of water entering the dam. It emerges as the difference between the shadow value of water entering the dam, $\chi(t)$, and the shadow value of water appropriated by the upstream, $\square(t)$. Hence, if there is a rise in scarcity value of water in the upstream, there will be an associated fall in the value of water entering the dam, at time t.

The dynamic model presents a planning horizon, with respect to which the optimisation exercise has been advocated. The aim has been to maximise the societal benefits in the given period of time, subject to the ecological and economic constraints. What we propose is that the payment to the affected need to be made based on the above principles, so that in the given period of time, the social welfare is maximised. The interpretations, in the case of the dynamic model are similar to that of the static model, except the fact that the movement of the shadow values over time have been captured by the optimisation principles derived from the former.

5 CONCLUSION

The two models presented so far only reflect upon the principles that need to be followed for the payment on water by the beneficiaries. In that sense, they present *ideal* situation. Though, hypothetical in nature, the models are indicative ones and have important potential applications in policy and conflict resolution. On the one hand, it provides a framework for broad evaluation of dams. On the other, it offers a basis for evaluating the water in the dam that has been providing certain services in its vicinity. This might also help in assessing impacts at the river basin level.

On the other hand, we have tried to argue that the affected ones should receive adequate compensation for sustainable management of the community waters. The payment should be made by none other than the beneficiaries in order to encourage economies to function in a manner that might lead to sustainable and equitable management of water resources.

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