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Hydrology and Earth System Sciences
Discussions

Interactive comment on “A dynamic water accounting framework based on marginal resource opportunity cost” *by* A. Tilmant et al.

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The authors would like to thank the reviewer for his/her constructive comments. Our detailed responses to the comments and the proposed changes/corrections are given below.

1)The authors may want to further highlight the niche of their proposed methodology, especially in terms of exhaustion of value (that value of flows and stocks balance out at system scale in some sense) since it is based on hydro-economic principles (or KKT conditions in particular). They may also want to highlight, when comparing with other water accounting methods, where the proposed method is similar and where it advances the state-of-the-art.

There is quite some diversity in the existing water accounting methods, which is due to the fact that those accounts are designed for different purposes (with different policy objectives in mind). However, to the best of our knowledge, the proposed approach differs from the others in that it explicitly relies on the marginal values of water (MROC) to assess the value/cost of each water flux in the river basin. Moreover, those values/costs are also calculated on a finer temporal scale (here monthly time steps), making it possible to examine the accounts on a seasonal time step to analyze, for example, drought issues. The similarities with the most advanced accounting methods are to be found in the hydrologic component and the representation of the river system using multiple arcs and nodes, which allow a relatively fine spatial resolution. The example focuses on surface water resources but it could easily be extended to subsurface resources. Those issues are highlighted in the second half of the introduction. Regarding the product exhaustion problem, we agree with you that the value of flows and stocks balances out at the system scale. Since the hydro-economic model mimics a perfectly competitive market, paying water equal to its marginal physical product exhausts the total output (Hicks-Samuelson solution). Because the MROC vary in space and time, the principle is applied at each node (space) and for each stage (time), as illustrated with eq (7)-eq (9).

2) The authors may want to highlight the assumptions of their accounting scheme such as basin scale efficient solution and others at one place for tractability. A format of Assumption 1, Assumption 2. . . before the mathematical program is introduced would be helpful

The main assumptions are now highlighted before the presentation of the mathematical formulation: "Assuming that (A) the basin-wide allocation is economically efficient (i.e. there is only one decision-maker seeking to maximize the productivity of water), (B) water users are price takers (i.e. they cannot influence the price through their production) and (C) the main source of uncertainty comes from the hydrologic processes. With these assumptions, a water resources allocation problem in a river basin can formulated as a centralized hydro-economic optimization problem."

3) The variable q_t is now defined and the term uncontrolled flows is specified by "(e.g. reservoir spillages)"

4) Equation 6: A more formal treatment of Lagrange multipliers is desirable for the mathematical program defined in (1)-(4). We know that there is a law of motion for the lambdas (similar to mass balance for water at system nodes).

The optimization problem (1)-(5) could be solved analytically if the size of the problem were small. Here, considering the size of the river basin (number of nodes j = 1...23) and the number of time periods (t = 1...120), it is solved numerically. The Lagrange multipliers associated with all the constraints are thus directly calculated by the solver. If, at time t, we focus on the J mass balance equations (one for each node), the Lagrange multipliers correspond to the J marginal values of water at that time period. Eq (6) presents the economic meaning of the Lagrange multiplier associated with the mass balance equation at node j.

5) Comparison between equations (7)-(8): the water, r_t(1), is sold by agents 1 at a (virtual) price that is different from the (virtual) price at which agent 2 buys. Where does the surplus go?

Actually the surplus corresponds to the economic value generated by the power station #1, hpp(1), attached to reservoir#1, i.e. res(1). Res(1) sells r(1) to hpp(1), which uses it to generate electricity and then sells that water to the downstream agent (here res(2)) but at a price corresponding to the value of water in res(2). So, the surplus is given by r(1)*[λ(1)-λ(2)]. It is also the economic rent that enjoys hydropower companies when they do not have to pay of water. In the proposed accounting framework, those surpluses/economic rents are made explicit, they are organized/classified but they do not “go” somewhere (they are “dummy” transactions).

6) Equations (7) and (8): It appears that the accounting scheme has a big role for

the RBA in buying and selling of uncontrolled flows I_t(1). Please explain what these uncontrolled flows physically mean and why should RBA mediate in its transaction.

The role of RBA in handling the transactions associated with spills is our own choice and, in a sense, is a “bookkeeping” issue. The alternative would be a direct transaction from the upstream agent (source of the spill) and the receiver. We choose to work with RBA because it is one of the hydraulic “neighbors” of each reservoir (the others are the associated IDA and HPP)(Figure 2). Most of the time, when there is no spill, the downstream reservoir is not directly connected to the upstream one whereas RBA is. It is important to note that it does not change the accounts because, when there is a spill, the marginal water values upstream and downstream are identical and the corresponding transaction is equal to zero: l(j)*[λ(j)-λ(j+1)]=l(j)*0=0

7) The choice variables (x) both in sections 2.2. and 2.3. is not clear. In a standard mathematical program, all except the parameters of the program and exogenous variables are treated as choice variables. Please clarify.

We have added the following sentence in section 2-3 to clarify the choice variables: "For this case study, at each time step t, the allocation decisions are the vector st+1 of storages at the end of time t, the vector of reservoir releases rt, the vector of spillage losses lt and the vector of irrigation withdrawals it."

8) Section 2.3: Please describe the mentioned 30 hydrological scenarios.

We have added the following sentences in section 2-3 to clarify the issue with the hydrologic scenarios: "In SDDP, a built-in hydrologic model can be used to generate, among other things, synthetic flow sequences (scenarios) that are needed to simulate the system for various hydrologic conditions. Using synthetic flow series instead of historical ones, allows us to increase the number of simulations in order to get smoother empirical statistical distributions of the results (allocation decisions and MROC). The disadvantages are mainly related to the structure of the hydrologic model, a periodic autoregressive model with cross-correlated residuals, which does not necessarily preserve the long-term memory of the hydrologic processes"

9) Section 3: A brief description of SDDP techniques is desirable here even though it has been extensively covered elsewhere, for completeness sake. I would be more interested in knowing how operation rules are incorporated within this dynamic programming technique.

With SDDP, the operating rules are not incorporated but rather derived. In other words, the model is prescriptive in the sense that it produces the allocation decisions including reservoir operating rules. Unfortunately, including a brief description of the model is difficult due to (1) a lack of space and (2) because the focus of the paper is on the water accounting framework, not the hydro-economic model. We are afraid that if we describe SDDP, we will dilute the scope of the manuscript. As mentioned in the text, the proposed framework is independent of the hydro-economic model and we would like to make sure that there is no ambiguity with regards to that aspect of the framework.

10) The corresponding equations are now provided in the text.

11) Why are irrigation withdrawls seen as benefits forgone? – they are input to crop production and hence generate value and income.

Irrigation withdrawals are considered as benefits forgone because irrigated agriculture is a rival use: each unit of water is no longer available for the downstream users, therefore having an opportunity cost. When the allocation decisions are economically efficient, the marginal value of irrigation water at site “j” should be equal to its marginal opportunity cost. If the marginal value were > than the marginal opp cost, then more water should be allocated to the irrigation scheme. Similarly, if the marginal value were < than the marginal opp cost, then less water should be allocated to the irrigation scheme. Hence, at the optimal solution, both marginal quantities should be equal (in absolute value). When an irrigation withdrawal is multiplied by the associated marginal value (or opp cost), the product corresponds to both the value of irrigation water and the opportunity cost of that water. It is like the two faces to the same coin.

12) Page 11749, lines 20-25: It is not clear what is meant by the value of blue water, please highlight this in equations (7)-(8). A more physical/economic interpretation would be helpful. It appears it dominates the valuation of the Eastern Nile water system (table 2). Why should this be the case?

The meaning of blue water is now made more explicit with the equations directly provided when the items are listed. Blue water dominates because it corresponds to the annual economic value of runoff in the basin. Since 80% of the Nile is generated in Ethiopia, which is the most upstream country where the marginal values of water are the highest, the total value is indeed quite significant. The fact that the marginal values are highest in Ethiopia can be explained by the cascade of hydropower stations: each unit of water generated in Ethiopia can be used several time as it flows to the sea. We have added the following sentence: This is due to combined effect of two factors: (1) as indicated above, much of the Nile waters are generated in Ethiopia and (2) the marginal value of water in Ethiopia is the highest due to the presence of a cascade of hydropower plants from the border with Sudan down to the Mediterranean sea.

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