Available online at www.sciencedirect.com
SCIENCE DIRECT®

PERGAMON

Physics and Chemistry of the Earth 28 (2003) 175–182

PHYSICS and CHEMISTRY of the EARTH

www.elsevier.com/locate/pce

The water value-flow concept

I.M. Seyam *, A.Y. Hoekstra, H.H.G. Savenije

IHE Delft, P.O. Box 3015, 2601 DA Delft, The Netherlands

Received 8 May 2001; received in revised form 1 November 2001; accepted 1 November 2001

Abstract

The value of water is a key issue in managing water resources in an efficient, equitable and sustainable way. Efforts to assess the value of water are often not linked to the properties of the natural water system, which makes it difficult to analyse upstream–downstream dependency. In order to account for the cyclic nature of water in the assessment of water value, Chapagain [Exploring methods to assess the value of water: a case study on the Zambezi basin. Value of Water Research Report Series No. 1, IHE Delft, The Netherlands, 2000] and Hoekstra et al. [Water value flows: a case study on the Zambezi basin. Value of Water Research Report Series No. 2, IHE Delft, The Netherlands, 2000] have introduced the 'value-flow concept'. This concept aims to provide the missing link between water valuation and hydrology. The hypothesis is that the full value of a water particle depends on the path it follows within the hydrological cycle and the values generated along this path. The full value of a water particle in a certain spot at a certain point in time is supposed to be the sum of its in situ value and all values that will be generated along its path later. It follows that all values generated by water can ultimately be attributed to rain. This simple concept implies that there is a direct analogy between the flow of water and the flow of values, with one crucial difference. Water values flow backward in time and in a direction opposite to that of the water. In other words, the value-flow attributes local water values to the upstream water flows within the natural system.

This paper puts the value-flow concept in a proper mathematical model that is able to attribute the value of water produced in a certain place and at a certain time to the source of that water. Three models are considered in a progressive manner, to arrive at a generic form of the value-flow concept. The first two models were developed and used by Chapagain and Hoekstra et al. Here a third model is introduced, in order to properly account for the dynamic nature of the hydrological cycle. It is shown that this third model is the most generic one, able to correctly describe the flow of values in a dynamic water system. The parameterisation of the model is based on the hydrological characteristics of the water system. Further analysis of the value-flow concept addresses the way in which return flows generate a multiplier effect on the value of water.

1. Introduction

The principle that water should be managed as an economic good was generally agreed upon at the International Conference on Water and the Environment, in Dublin in 1992 (ICWE, 1992). Recently, the Ministerial Declaration of the Second World Water Forum, held in The Hague in March 2000, emphasised that water should be managed in a way that reflects its economic, social, environmental and cultural values. Despite the increasing recognition of 'water as an economic good' by the international community, there is still debate on how one can measure the value of water. There is also confusion and disagreement about what the idea implies for policy makers—see Savenije and Van der Zaag (2000), Van der Zaag and Savenije (2000), Briscoe (1996) and Perry et al. (1997). In practice, water valuation remains a very illusive subject, for which a unifying approach is needed (Abu-Zeid, 1998). Most efforts have focused on measuring the value of water in certain water-using sectors, so that only the part of the water cycle nearest to the end user is recognised as an economic good.

In addition to the conceptual and methodological difficulties encountered in the assessment of the in situ values of water used at a certain time and location, it is necessary to deal with the cyclic nature of water. A water particle used for a certain purpose will always remain within the water cycle. As hypothesised by Hoekstra et al. (2000), the value of a water particle in a certain place and at a certain point in time is equal to its value in situ plus its contribution to downstream benefits generated in later stages. In other words, the full

* Corresponding author. Tel.: +31-15-2151715; fax: +31-15-2122921.
E-mail address: seyam@ihe.nl (I.M. Seyam).

1474-7065/03/$ - see front matter © 2003 Published by Elsevier Science Ltd.
doi:10.1016/S1474-7065(03)00028-7

value of a water particle consists of two components: a direct value which is the in situ value and an indirect value which results from transferring downstream values back to the source of the water. As opposed to a water flow, which goes from upstream to downstream, attributing a value to the source of water can be seen as the reverse process, in which water values move in upstream direction and backward in time.

The aim of this paper is to introduce a proper mechanism by which direct values of water can be attributed to the source of water. The paper builds on previous work by Chapagain (2000) and Hoekstra et al. (2000), who applied simple mathematical equations for the value-flow concept to a case study on the Zambezi basin. The contribution of the current paper is in identifying the limitations of the previous work and introducing a more generic mathematical equation for the value-flow concept. The measurement or assessment of direct values is not discussed in this paper. It is assumed here that all direct values are known and the main question addressed is how to calculate the indirect values.

The paper presents briefly the original value-flow equations used by Chapagain (2000) and Hoekstra et al. (2000), followed by the main contribution of this paper, namely the introduction of a more generic value-flow equation. The generic value-flow equations are applied to a hypothetical water system, to explain where and why the previous value-flow equations fail. Finally the new value-flow equation is applied to a water system that has return flows which generate a multiplier effect on the value-flow calculation.

2. The value-flow equations

2.1. General

Obviously, water management problems stem from extreme conditions of water availability rather than averaged or aggregated conditions. Therefore, water values need to be given in a way that reflects temporal and spatial variations in the value of water. In other words, temporal and spatial resolution of water values should be properly selected to meet the information demand. The full value of water can differ greatly from place to place and from time to time. Here we address the question of how to assess the *total* full value of a water flow in a certain time step (for instance a month) and in a certain place. [1] To begin with, consider a water system with m inflows, n outflows and a storage component S as shown in Fig. 1.

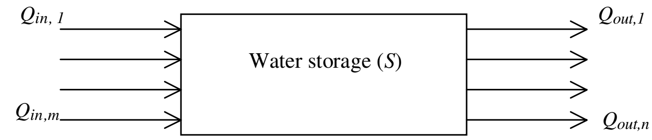

Fig. 1. The water balance of a water storage system.

In general, the total full value of a water inflow ($FVQ_{in,i}$) at a given time (t) is given as

$$FVQ_{in,i}(t) = DVQ_{in,i}(t) + IVQ_{in,i}(t) \tag{1}$$

where $DVQ_{in,i}$ is the total direct value of the inflow $Q_{in,i}$ and $IVQ_{in,i}$ is the total indirect value of that inflow at the same point in time. As mentioned before, in this paper the direct values are assumed to be known and the main goal is to work out the second term on the right-hand side of the equation, the indirect value. In the water system shown in Fig. 1 an inflow has an indirect value if it contributes to the direct values of the outflows. Thus the contribution of an inflow to an outflow determines the fraction of the outflow value to be attributed to the inflow. Below, the value-flow equations introduced by Chapagain (2000) and Hoekstra et al. (2000) are presented.

2.2. Value-flow in a system without delays (Model A)

In Fig. 1, if the inflow and outflow hydrographs are identical, that is if water storage does not change over time, the indirect value of water inflows must equal the total outflow values. Therefore the indirect value of a single water inflow is proportional to its contribution to the total water inflows as follows:

$$FVQ_{in,i}(t) = DVQ_{in,i}(t) + \sum_{j=1}^{n} FVQ_{out,j}(t) \times \frac{Q_{in,i}(t)}{\sum_{i=1}^{m} Q_{in,i}(t)} \tag{2}$$

In this particular case the outflow values are immediately translated into indirect values of inflows. This equation is suitable in the case of a large time step (average year), in which the assumption that water stocks do not change will generally hold good. However, water management problems concern situations where water stocks vary both from year to year and within the year. If a water store changes over time, then the simple attribution of outflow values to inflows as presented in Eq. (2) cannot be valid. For instance, if the total inflow is larger than the total outflow within a certain time step, in other words part of the inflow is stored, the indirect value of the inflows does not only depend on the value of the outflows in the time step considered, but also on the value of future outflows. If the total inflow is however less than the total outflow, it follows that part of

[1] We speak in this paper about the *total* full value, as distinguished from the *marginal* full value. Whereas marginal full value refers to the full value of the 'last unit' of a water flow, total full value refers to the full value of the water flow as a whole. The value-flow equations introduced are applicable for the process of attributing total values of water from downstream to upstream, not for attributing marginal values back along the water flow lines.

the value of the outflows should be attributed to the inflows in the same time step while the remaining part should be attributed to the inflows in previous time steps. In other words, there should be a mechanism to account for the effect of residence time of water on the attribution of outflow values to inflow values.

2.3. The dynamic model proposed by Chapagain (Model B)

In a dynamic water system with storage, inflow and outflow hydrographs are not necessarily identical. If the water balance of a certain time step is not zero, the residence time of water in storage should be accounted for in the calculation of the indirect values. The following equation proposed by Chapagain (2000) accounts implicitly for the effect of storage fluctuation

$$\mathrm{FV}Q_{\mathrm{in},i}(t) = \mathrm{DV}Q_{\mathrm{in},i}(t) + \sum_{j=1}^{n} \mathrm{FV}Q_{\mathrm{out},j}(t) \times \frac{Q_{\mathrm{in},i}(t)}{\sum_{j=1}^{n} Q_{\mathrm{out},j}(t)} \tag{3}$$

This equation says that the indirect value of a certain inflow can be determined by the ratio of that inflow to the total outflow. If in a specific time step the net water balance is zero, that is if the total inflow equals the total outflow, then this equation reduces to Eq. (2). If the total water inflow of a time step is larger than the total water outflow, then the indirect value of the inflow consists of the outflow value in the period considered plus part of the outflow value in a next period. If, on the contrary, the total water inflow is smaller than the total water outflow, one cannot attribute the outflow value completely to the inflow of the time step concerned. Part of the outflow value should be attributed to earlier inflows. For a better understanding, Eq. (3) can be rearranged as follows:

$$\mathrm{FV}Q_{\mathrm{in},i}(t) = \mathrm{DV}Q_{\mathrm{in},i}(t) + \frac{\sum_{j=1}^{m} \mathrm{FV}Q_{\mathrm{out},j}(t)}{\sum_{j=1}^{m} Q_{\mathrm{out},j}(t)} \times Q_{\mathrm{in},i}(t) \tag{3a}$$

One can now see that the value of a water inflow in a certain time step is in fact defined as the unit value of outflow in that time step times the quantity of the inflow. This equation holds true only if the unit value of outflow does not change over time.

2.4. A dynamic model based on hydrological properties (Model C)

The indirect value of an inflow can be interpreted simply as the product of the water inflow and the unit value of the water in the stock, as follows:

$$\mathrm{FV}Q_{\mathrm{in},i}(t) = \mathrm{DV}Q_{\mathrm{in},i}(t) + \frac{\mathrm{FV}S(t)}{S(t)} \times Q_{\mathrm{in},i}(t) \tag{4}$$

In this formulation the unit (indirect) value of the inflow and the unit value of the stock are equal. This is different from Eq. (3a) in the previous model, where it was assumed that the unit (indirect) value of the inflow equals the unit value of outflows.

The new value-flow model represented by Eq. (4) can be derived by drawing an analogy between the two processes of water flow and value flow. As mentioned earlier, a water flow attains an indirect value at a certain point in time and space because the same water generates values downstream or in later stages. It follows from this that the process in which values of water outflows are translated into indirect values of water inflows goes backwards in time and in an upstream direction, exactly the opposite to the water movement. This analogy allows the derivation of a value-flow equation based on key hydrological characteristics of the water system, which govern the flow of water.

In general, the water balance of a water system can be written as

$$\frac{\mathrm{d}S(t)}{\mathrm{d}t} = \sum_{i=1}^{m} Q_{\mathrm{in},i}(t) - \sum_{j=1}^{n} Q_{\mathrm{out},j}(t) \tag{5}$$

Similarly, the value balance of a water store can be written as

$$\frac{\mathrm{dFV}S(t)}{\mathrm{d}t} = \sum_{j=1}^{n} \mathrm{FV}Q_{\mathrm{out},j}(t) - \sum_{i=1}^{m} \mathrm{IV}Q_{\mathrm{in},i}(t) \tag{6}$$

where FVS is the *total* full value of the water stock. [2] In fact this value balance equation can be extended to include a direct value of the stock (DVS, expressed as value per unit of time), as in the equation below. Such an extension is in order to account for the direct values of the stock, such as recreational value of lakes, wetlands and reservoirs.

$$\frac{\mathrm{dFV}S(t)}{\mathrm{d}t} = \mathrm{DV}S(t) + \sum_{j=1}^{n} \mathrm{FV}Q_{\mathrm{out},j}(t) - \sum_{i=1}^{m} \mathrm{IV}Q_{\mathrm{in},i}(t) \tag{7}$$

In order to arrive at the correct value-flow equation, it is necessary first to have a water resources equation that can describe the water flow in a reversed direction and then to use the hydrological properties of this equation in the value-flow equation. For any water system, the water stock can be related to the water outflow by using a residence time parameter (k_w) as follows:

$$k_w(t) = \frac{S(t)}{\sum_{j=1}^{n} Q_{\mathrm{out},j}(t)} \tag{8}$$

[2] We have to emphasise again here that we talk about the *total* full value, not about the *marginal* full value of the stock. The value balance does not hold good if we were to speak about marginal full values.

Table 1
Comparison of water flow and value-flow processes

Flow process	Balance components	Balance equation	Residence time
Water flow	$\xrightarrow{Q_{in,\,i}(t)} \boxed{\text{Water storage (S)}} \xrightarrow{Q_{out,\,j}(t)}$	$\frac{\mathrm{d}S(t)}{\mathrm{d}t} = \sum_{i=1}^{m} Q_{\mathrm{in},i}(t) - \sum_{j=1}^{n} Q_{\mathrm{out},j}(t)$	$k_w(t) = \frac{S(t)}{\sum_{j=1}^{n} Q_{\mathrm{out},j}(t)}$
Value flow	$\xleftarrow{IVQ_{in,\,i}(t)} \boxed{\text{Value of stock } FVS(t)} \xleftarrow{FVQ_{out,\,j}(t)}$	$\frac{\mathrm{dFV}S(t)}{\mathrm{d}t} = \sum_{j=1}^{n} \mathrm{FV}Q_{\mathrm{out},j}(t) - \sum_{i=1}^{m} \mathrm{IV}Q_{\mathrm{in},i}(t)$	$k_v(t) = \frac{S(t)}{\sum_{i=1}^{m} Q_{\mathrm{in},i}(t)}$

In the reversed process of the water flow, it is possible to relate the water stock to the water inflow by using another residence time parameter (k_v) as follows:

$$k_v(t) = \frac{S(t)}{\sum_{i}^{m} Q_{\mathrm{in},i}(t)} \tag{9}$$

Logically, this residence time (k_v) is the residence time of the value as it flows in an upstream direction and backwards in time. Therefore, the value-flow equation can be written in a form that relates the full value of the stock to the indirect value of the inflow as follows:

$$k_V(t) = \frac{\mathrm{FV}S(t)}{\sum_{i=1}^{m} \mathrm{IV}Q_{\mathrm{in},i}(t)} \tag{10}$$

Based on this equation, it is now possible to write the value-flow equation as follows:

$$\mathrm{FV}Q_{\mathrm{in},i}(t) = \mathrm{DV}Q_{\mathrm{in},i}(t) + \frac{\mathrm{FV}S(t)}{k_v(t)} \times \frac{Q_{\mathrm{in},i}(t)}{\sum_{i}^{m} Q_{\mathrm{in},i}(t)} \tag{11}$$

If the equivalent of k_v from Eq. (9) is introduced into Eq. (11), one can arrive at Eq. (4) presented earlier. The analogy between water flow and value flow that has been used to derive the new value-flow model is summarised in Table 1.

3. Testing and evaluation

3.1. General

The value-flow models introduced so far need to be evaluated against transparent criteria. The first criterion is that in the long run in a balanced water system, the sum of indirect values of inflows must equal the sum of total values of outflows. In other words, if there is no change in the storage of the water system over the period concerned, there should be no change in the storage value. The second criterion is that if the value of an outflow is attributed to an inflow, the model should properly account for the time delay between inflow and outflow.

3.2. Hypothetical example

In order to test the methods introduced here against the above criteria, a hypothetical water system of one inflow, one outflow and a single store is used. The data for the inflow and outflow hydrographs as shown in Fig. 2 and Table 2 have been selected so that outflows do not follow any specific water resource equation, but, achieve

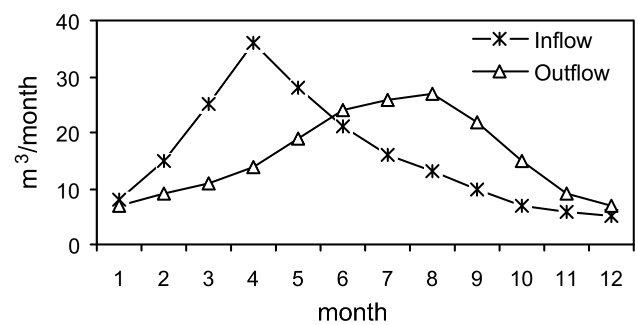

Fig. 2. Inflow and outflow hydrographs.

Table 2
Water resources data

Month	$Q_{\mathrm{in}}(t)$ (m^3/month)	$Q_{\mathrm{out}}(t)$ (m^3/month)	$S(t)$ (m^3)	$k_w(t)$ (month)
1	8	7	50	7.1
2	15	9	51	5.7
3	25	11	57	5.2
4	36	14	71	5.1
5	28	19	93	4.9
6	21	24	102	4.3
7	16	26	99	3.8
8	13	27	89	3.3
9	10	22	75	3.4
10	7	15	63	4.2
11	6	9	55	6.1
12	5	7	52	7.4
Total	190	190		
Average			71	5.0

Table 3
Inputs and outputs of the value flow calculations, Case 1 (constant unit value of outflow)

t Month	Inputs		Model A		Model B		Model C			
	$FVQ_{out}(t)$ (\$/month)	$uVQ_{out}(t)$ (\$/m^3)	$FVQ_{in}(t)$ (\$/month)	$uVQ_{in}(t)$ (\$/m^3)	$FVQ_{in}(t)$ (\$/month)	$uVQ_{in}(t)$ (\$/m^3)	VS(t) (\$)	$FVQ_{in}(t)$ (\$/month)	$uVQ_{in}(t)$ (\$/m^3)	$k_v(t)$ (month)
1	21	3.0	21	2.6	24	3.0	153	24	3.0	6.4
2	27	3.0	27	1.8	45	3.0	171	45	3.0	3.8
3	33	3.0	33	1.3	75	3.0	213	75	3.0	2.8
4	42	3.0	42	1.2	108	3.0	279	108	3.0	2.6
5	57	3.0	57	2.0	84	3.0	306	84	3.0	3.6
6	72	3.0	72	3.4	63	3.0	297	63	3.0	4.7
7	78	3.0	78	4.9	48	3.0	267	48	3.0	5.6
8	81	3.0	81	6.2	39	3.0	225	39	3.0	5.8
9	66	3.0	66	6.6	30	3.0	189	30	3.0	6.3
10	45	3.0	45	6.4	21	3.0	165	21	3.0	7.9
11	27	3.0	27	4.5	18	3.0	156	18	3.0	8.7
12	21	3.0	21	4.2	15	3.0	150	15	3.0	10.0
Total	570		570		570			570		
Average		3.0		3.8		3.0	214		3.0	5.7

the mass conservation of water over the period considered. Thus the correct value-flow equation should achieve the mass balance of value as well.

In addition to the water flow data, the full value of the outflow in this hypothetical example is also given (see the inputs in Table 3). We have chosen to express values here in terms of US dollars, but we could equally have used a different unit. As the purpose of the example is to test the value-flow equations, it is assumed that the direct values of the inflow and the stock are equal to zero. We test the three value-flow models on two cases. In the first case the unit value of outflow (uVQ_{out}) is assumed to be constant over time, while it varies arbitrarily in the second case. As will be shown, this distinction makes a difference for the performance of Model B. Table 3 and Fig. 3 show the results obtained from each model under the conditions specified for the first case. Table 4 and Fig. 4 show the results for the second case.

3.3. Discussion of test results

In the first case of constant unit value of outflow, the results given in Table 3 and Fig. 3a and b show that all models conserve the value balance, that is the sums of inflow and outflow values are equal. However, Model A obviously does not take the storage effect into account. As shown in Fig. 3b, the dynamic models B and C result in a unit value of the inflow equal to the unit value of the outflow, which means they correctly account for the storage effect in this case.

In the second case, where the unit value of outflow is variable, Model B fails to conserve the value balance because it assumes that the unit values of the inflow and the outflow are equal. This leaves the new model, Model C, presented here, as the correct model that performs accurately without any limitations. Table 5 summarises the findings of the test.

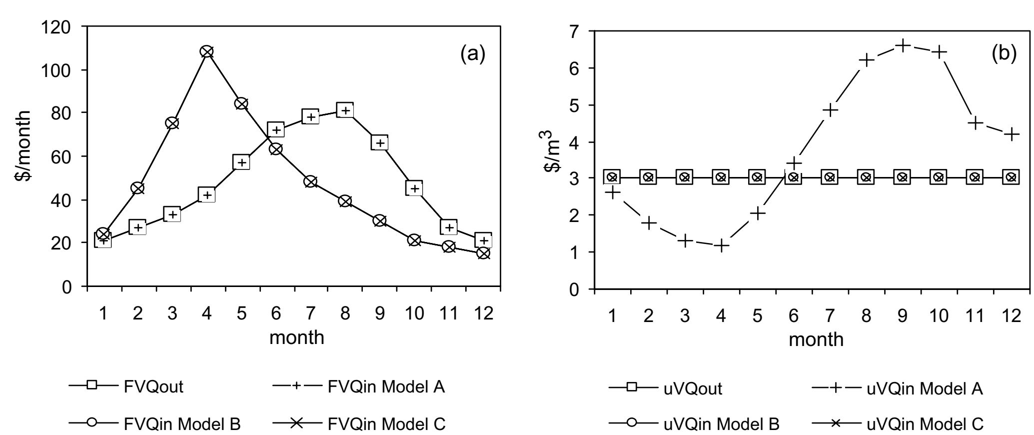

Fig. 3. (a) Full values of inflow and outflow, Case 1. (b) Unit values of inflow and outflow, Case 1.

Table 4
Inputs and outputs of the value flow calculations, Case 2 (variable unit value of outflow)

t Month	Inputs		Model A		Model B		Model C			
	$FVQ_{out}(t)$ (\$/month)	$uVQ_{out}(t)$ (\$/m^3)	$FVQ_{in}(t)$ (\$/month)	$uVQ_{in}(t)$ (\$/m^3)	$FVQ_{in}(t)$ (\$/month)	$uVQ_{in}(t)$ (\$/m^3)	VS(t) (\$)	$FVQ_{in}(t)$ (\$/month)	$uVQ_{in}(t)$ (\$/m^3)	$k_v(t)$ (month)
1	14	2.0	14	1.8	16	2.0	135	21	2.6	6.4
2	18	2.0	18	1.2	30	2.0	159	42	2.8	3.8
3	22	2.0	22	0.9	50	2.0	211	74	3.0	2.8
4	28	2.0	28	0.8	72	2.0	298	116	3.2	2.6
5	38	2.0	38	1.4	56	2.0	359	99	3.5	3.6
6	72	3.0	72	3.4	63	3.0	364	77	3.7	4.7
7	104	4.0	104	6.5	64	4.0	317	57	3.6	5.6
8	108	4.0	108	8.3	52	4.0	253	44	3.4	5.8
9	88	4.0	88	8.8	40	4.0	196	31	3.1	6.3
10	60	4.0	60	8.6	28	4.0	156	20	2.8	7.9
11	36	4.0	36	6.0	24	4.0	136	16	2.6	8.7
12	21	3.0	21	4.2	15	3.0	128	13	2.6	10.0
Total	609		609		510			609		
Average		3.0		4.3		3.0	226		3.1	5.7

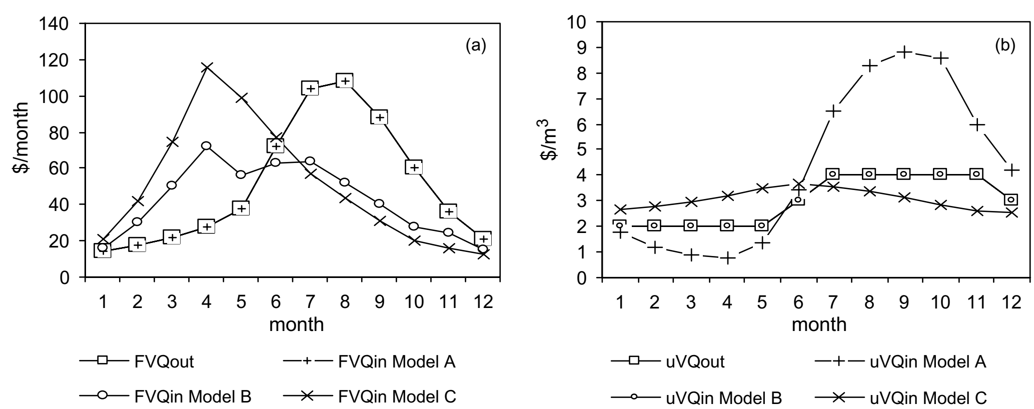

Fig. 4. (a) Total values of inflow and outflow, Case 2. (b) Unit values of inflow and outflow, Case 2.

Table 5
Summary of test findings

Model	Case 1 (constant value of unit outflow)		Case 2 (variable unit value of outflow)	
	Value balance	Res. time properly accounted for	Value balance	Res. time properly accounted for
A	Yes	No	Yes	No
B	Yes	Yes	No	No
C	Yes	Yes	Yes	Yes

4. The multiplier effect

In the water cycle, part of a certain outflow may return to the water storage, thus generating a multiplier effect in the calculation of indirect values. For example, part of the water withdrawn from ground water for irrigation use may return to the groundwater, thus contributing to the irrigation benefits in later stages. Another example is when evaporation in a river basin contributes to the rain that falls within the same basin. In the previous section it was shown that the dynamic

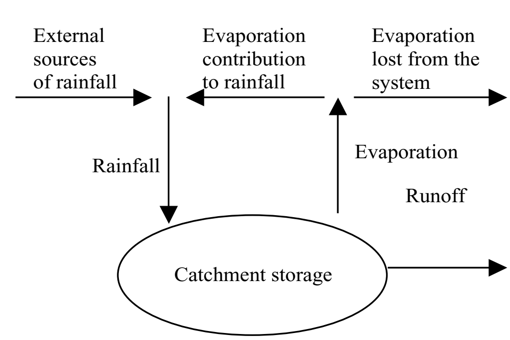

Fig. 5. Schematisation of the water flows and stocks of a catchment.

Table 6
Water resources data for the irrigation system

Year	Rainfall (Mm^3/year)	Evaporation (Mm^3/year)	Runoff (Mm^3/year)	Change in catchment storage (Mm^3/year)	Evaporation contribution to rainfall (Mm^3/year)	Evaporation lost from the system (Mm^3/year)
1	500	400	88.4	11.6	40	360
2	600	480	91.3	28.7	48	432
3	600	480	98.5	21.5	48	432
4	400	320	103.9	−23.9	32	288
5	300	240	97.9	−37.9	24	216
Total	2400	1920	480	0.0	192	1728

Table 7
Input and calculated values of the water flows

Year	Direct value of evaporation (\$/year)	Total value of evaporation (\$/year)	Total value of evaporation contribution to rainfall (\$/year)	Total value of rainfall (\$/year)	Total value of catchment storage (\$)
1	800	873	73	909	664
2	960	1050	90	1123	737
3	960	1038	78	978	677
4	640	690	50	631	618
5	480	523	43	532	628
Total	3840	4174	334	4174	

model C is the correct value-flow model. This model is now further tested to show that it accounts for the multiplier effect.

The case of rainfall recycling in a catchment is considered here through a hypothetical example, where 10% of evaporation returns to the catchment area as rainfall, as shown in Fig. 5. The water balance of the catchment is simplified, with one storage component for the whole catchment. Data on rainfall, evaporation and runoff at the catchment outlet are assumed in such a way that the catchment storage is balanced over a period of five years (see Table 6).

Data on direct values are assumed in such a way that only evaporation has a direct value (e.g. for plant growth) while all other water flows have no direct value. In a particular time step, water flows and stocks that contribute to evaporation gain an indirect value. Thus water stored in the catchment obtains an indirect value and so does rainfall that contributes to water stored in the catchment. This gives an indirect value to the part of evaporation that contributed to rainfall and therefore gives an indirect value to evaporation in the previous time step. Over successive time steps in which the water system is balanced, the total value of evaporation becomes more than merely its direct value.

The water flow values calculated for this example using the dynamic value-flow model C are given in Table 7.

The total value generated in the system over the five-year period is the sum of the direct values of evaporation, that is \$3840. However, over the same period, both evaporation and rainfall have a total value of \$4174, which is higher due to the multiplier effect. As can be seen from Table 6, 8% of the rainfall in the catchment area originates from local evaporation. The same percentage can be found by relating the total value of evaporation that contributes to rainfall to the total value of rainfall (334/4174). Also, it can be seen that the total value of evaporation is 8% higher than the direct value of evaporation.

One can arrive at the total value of each water flow in the system analytically by tracing the source of water. For instance, the total value of evaporation over the 5-year period (TVE) can be calculated as:

$$\mathrm{TVE} = 3840 + (3840 \times 0.08) + (3840 \times 0.08^2) + (3840 \times 0.08^3) + \cdots$$

or, more precisely:

$$\mathrm{TVE} = \sum_{i=0}^{n} 3840 \times 0.08^i$$

with n an infinite large integer.

5. Conclusion

The objective of this work was to derive a value-flow model that under various hydrological conditions correctly attributes the value of a water flow to the source of the water. In this paper we introduce and test a water value-flow model that is more generic than the models earlier formulated by Chapagain (2000). The new model builds on the hypothesis that the residence time of value in a water store depends on the hydrological characteristics of this store. It is shown that the residence time of value is equal to the ratio of water storage to water inflow.

In addition to value flows the new model distinguishes value stocks, which allow direct stock values such as recreational values of surface water bodies to be included. Moreover the new model was applied to a partially closed water system, showing that it accounts for the multiplier effect in such a system.

References

Abu-Zeid, M.A., 1998. Water and sustainable development: the vision for world water, life and the environment. Water Policy 1, 9–19.

Briscoe, J., 1996. Water as an economic good: the idea and what it means in practice. In: Proceedings of the ICID World Congress, Cairo, Egypt.

Chapagain, A.K., 2000. Exploring methods to assess the value of water: a case study on the Zambezi basin, Value of Water Research Report Series No.1, IHE Delft, The Netherlands.

Hoekstra, A.Y., Savenije, H.H.G., Chapagain, A.K., 2000. Water value flows: a case study on the Zambezi basin, Value of Water Research Report Series No. 2, IHE Delft, The Netherlands.

ICWE (International Conference on Water and the Environment), 1992. The Dublin statement and report of the Conference, World Meteorological Organisation, Geneva, Switzerland.

Perry, C.J., Rock, M., Seckler, D., 1997. Water as an economic good: a solution, or a problem?, Research Report No. 14, International Irrigation Management Institute, Colombo, Sri Lanka.

Savenije, H.H.G., Van der Zaag, P., 2000. Conceptual framework for the management of shared river basins; with special reference to the SADC and EU. Water Policy 2, 29–30.

Van der Zaag, P., Savenije, H.H.G., 2000. Towards improved management of shared river basins: lessons from the Maseru Conference. Water policy 2, 51–52.