The Regional Water Balance Statement: a new tool for water resources planning

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Abstract
It is widely accepted that the effective planning of water resources becomes more urgent with each passing year. Some would argue that this need is driven by the increasing size and density of human populations at the catchment and urban scale. Others point out that exponential growth in economic output and consumption produces ever higher volumes of waste water. It is also asserted that global climate change will require every society to develop strategies capable of dealing with regional shifts in the mean and variance of hydrological variables. Such planning should take place within a framework determined by the quest for a sustainable society and strategy for the water sector should be balanced by programmes on both the supply- and the demand-side. Moreover, whilst our developing understanding of the hydrological cycle provides the vital natural science input to strategy, it must be the hydrosocial cycle which sources the language of supply and demand programmes. At this level, the key intellectual inputs come from politics, law, civil engineering, human geography, environmental studies and political economy. The objective of this paper is ambitious. Derived from the hydrosocial cycle perspective on supply and demand, the paper seeks to develop a quantitative tool for water resource planning which within a decade could be used across the globe for strategy development in respect of abstracted water for outstream uses. This tool is the regional water balance statement and it provides an encapsulating planning framework for a wide variety of measures aimed at making better use of water resources.

Introduction
It is widely accepted that the effective planning of water resources becomes more urgent with each passing year. Some would argue that this need is driven by the increasing size and density of human populations at the catchment and urban scale. Others point out that exponential growth in economic output and consumption produces ever higher volumes of waste water (1). More recently, it is also asserted
that global climate change will require every society to develop strategies capable of dealing with regional shifts in the mean and variance of hydrological variables such as precipitation.

In *Introduction to the Economics of Water Resources: an International Perspective* I have proposed that such planning should take place within a framework determined by the quest for a sustainable society, and that strategy for the water sector should be balanced by programmes on both the supply- and the demand-side (2, p.187). Moreover, whilst our developing understanding of the hydrological cycle provides the vital natural science input to strategy, it must be *the hydrosocial cycle* - illustrated in Figure 1 - which sources the language of supply and demand programmes. At this level, the key intellectual inputs come from politics, law, civil engineering, human geography, environmental studies and political economy.

The objective of this paper is ambitious. Derived from the hydrosocial cycle perspective on supply and demand, the paper seeks to develop a quantitative tool for water resource planning that within a decade could be used across the globe for strategy development in respect of abstracted fresh water for outstream uses. This tool is the regional water balance statement and its derivative, the change statement.

**The basic framework**

The fundamental ideas are simple and Table 1 will help develop them. The regional water balance statement relates to any defined geographic space; the term ‘region’ is used advisedly because of its inherent ambiguity. A region could be a catchment, a country, a city, an irrigation district, a province, or what you will.

The statement has four columns: the first two are the categories of supply and the quantity supplied per unit period of time; the second two are the categories of use and the quantity used per unit period of time. The quantitative measure of flow will be chosen on pragmatic grounds. For convenience of exposition, it is assumed here that we refer to flows in megalitres per day within the defined region, averaged over the year 1998.

The boundary between supply flow and use flow should also be chosen on practical grounds - this paper is not intended to be a visionary text. Such a boundary might be the point where the user first possesses or has a right to the use of the water. Here, total use includes the leakage, evaporation and wastage which...
occurs on user properties, as well as beneficial use. For simplicity’s sake, in Table 1 there is only one user, the agriculture sector.

Table 1 has only two supply sources: the abstraction of ground water and of surface water. From these are deducted the leakages and evaporation in the supply system, that is, between the points of abstraction and the supply/use boundary.

The calculation of flows in the regional water balance statement requires a procedure I shall call double-entry water accounting. The approach is taken from the double-entry book-keeping first developed in medieval Italy, and now universally used in modern financial accounting (3).

Within this routine, the company accountant has a large number of separate accounts such as a bank account, a creditors account, a debtors account, a cash account, a sales account and so on and so forth. Within the full set of a company’s accounts, each transaction is recorded twice. In the account deemed to provide funds for the transaction, the transaction is recorded as a credit item. In the account deemed to receive the funds, the same transaction is recorded as a debit item. For example, the transaction of paying cash into the bank will be recorded as a credit in the cash account and as a debit in the bank account; the transaction of a cash receipt for the sale of goods is recorded as a debit item in the cash account and as a credit item in the sales account. In the process of ‘balancing the books’, because of this double entry approach, the aggregate of all credit items in the separate accounts must equal the aggregate of all the debit items. Should this not happen, the accounts contain one or more errors of recording.

The application of financial accounting practice to the regional water balance statement must now be described. The statement is treated as a single ledger containing all the appropriate entries either as supply items on the left-hand side or as use items on the right-hand side. For any flow of water to be recorded in the statement, it must qualify as some hydrosocial category of input to the regional system. These input flows will be referred to as red molecule flows. In Table 1, flows A and B are red molecule flows. Such flows are parallel to the credit items described above and are entered on the left hand side of the water accounts ledger.

Once so entered, each molecule must be assigned to one of the hydrosocial output flows. These output flows are referred to as blue molecule flows. In Table 1, flows H and U are blue molecule flows. Such flows are parallel to the debit items
described above and are entered either as negative values under the supply column or as positive values under the use column.

Using these two colours in writing and printing any specific statement has a heuristic value - water accounting throws up some puzzling questions. Because each red molecule from the ground or surface abstraction flows is re-entered as a blue molecule in supply-side leakage and evaporation, or agricultural use, total net supply is mathematically identical to total use. In the water accounts ledger, with comprehensive and accurate records, the statement always balances.

**Use categories**
The water accounts of Table 1 included only agricultural use. Table 2 expands the use categories by adding households, mining, manufacturing, public services, commercial sectors and the catch-all term ‘other uses’. The appropriate classification of uses, or demand as it is conventionally referred to, varies substantially between regions; the pattern of use in an irrigation district, for example, is quite distinct from that in a metropolis. Ideally, the selected categories would distinguish between principal uses and would be designed to facilitate demand forecasting. This issue of use classes is important and one that should be handled pragmatically. The regional water balance statement is intended to be a practical, routine, everyday tool in resource planning. Note that all uses are blue molecule flows.

**Expanding the supply categories**
Table 3 expands the red molecule flows to include the desalination of salt or brackish water and the import of water from another region. This is big-time supply-fix territory, this is the western USA, this is California. Also added, for the sake of symmetry in water transfers, is the blue molecule flow of water exported to another region. As with every statement, total net supply (here A+B+C+D-H-J) remains identically equal to total use (here T+U+V+W+X+Y+Z).

**Recycling**
The hydrosocial cycle of Figure 1 includes the flow of waste water back to the sources of fresh water. Where regional abstraction takes place downstream of recycling points to river or aquifer, such abstraction flows can be decomposed into two parts: the abstraction of first-time water and the abstraction of recycled water. The quantitative ratio of these two flows can be taken to be equal to the ratio of fresh water to recycled water in the stream flow at the abstraction point. Table 4 incorporates the distinction by breaking down into two parts each of the red
molecule abstraction flows. But note that the recycled flow into the fresh water source is neither a red nor a blue molecule flow. Recycled water is recorded in the statement only when it is abstracted.

In some regions, it may be right to ignore this break-down because it has no policy interest, no relevance to foreseeable infrastructural investment. But where sustainable water resource planning seeks to protect the hydrological cycle by the use of properly-treated recycled water, the distinction may be vital and measurement justified. Recycling adds to effective rainfall as a source of water for abstraction, as can be seen from the planning documentation of the Thames catchment (4). The water flows of the Thames are amongst the most intensively used in the world.

**Re-use**

Figure 1 also includes two further green loops: internal and external re-use. Internal re-use occurs when a household or a factory or any other organization re-uses its own waste water. The water volume of internal re-use is set equal to each molecule or cubic metre of fresh water supplied to the user multiplied by the average number of times it is re-used. External re-use occurs when the waste water of one organization or group of households is re-used by a separate body, as in the re-use of treated sewage by agriculture. These loops are included in Table 5 as the red molecule flows F and G.

The same volumes are entered as blue molecule flows in the terms T to Z. In this way, the fundamental mathematical identity is retained. Total net supply including re-use supply is equal to total use including its re-use flows.

My remarks above on the policy relevance of measuring recycled water apply also to re-use. Note that the distinction between recycled and re-used water is that the former is water returned after its first use to river, lake and aquifer whilst the latter goes for re-use before disposal to fresh or salt water sinks.

**Water shortage**

Up to this point, the balancing of the water accounts ledger has derived from the notion that each and every molecule of water recorded as an input to the regional system in a given year, as part of a red molecule flow, is then recorded as an output from the system in that year as part of a blue molecule flow. The question then arises: does the existence of water storage infrastructures destroy the accounting balance? Our understanding of this issue will be strengthened if we
imagine the region’s storage capacity as composed of just three reservoirs, one black, one gold and one green.

The black reservoir is dedicated to the storage of water abstracted in 1998 that in the same year is distributed in its entirety to users or lost to leakage and evaporation. Clearly, storage of these pass-through molecules in the black reservoir does not change the systemic balance for 1998.

The gold reservoir contains stored water from time-periods prior to 1998. These molecules are, so to speak, a gift from the past to the present. In 1998 some of the stored water is lost to supply leakage and net evaporation, some may be delivered as water exports to another region, and some is distributed to users. The fall in the quantity of water stored in the gold reservoir during 1998 is expressed in megalitres per day and is deemed to be a red molecule flow. Once again, the identity of total net supply and total use is maintained.

The green reservoir is dedicated to the receipt of water abstracted during 1998, which will be stored for distribution from 1999 onwards, a gift from the present to the future. The increase in the volume stored in the green reservoir during 1998 is expressed in megalitres per day and is deemed to be a blue molecule flow. This flow precisely matches the abstraction flow pumped to the reservoir and, for the third time, the mathematical identity holds.

In practice, of course, each dam in a real regional system combines the functions of all three reservoirs described above. What we observe is only the net outcome of the component processes, that is, either no change in 1998 in the volume of stored water, or a fall or a rise. Thus, with respect to the value of K in Table 6, no change in the total volume of stored water gives a value of zero; a fall is expressed at its daily rate and is recorded as a red molecule flow; and a rise in storage is expressed at its daily rate and is recorded as a blue molecule flow.

The change statement

By this point, the regional water balance statement has been developed as far as is appropriate in this paper. The ex post statement for the region may be for a single year, such as 1998, or a period of weeks or months, or an average over several years, such as 1994-98. Similarly we may choose to construct ex ante statements, such as for the year 2001, or for a hypothetical drought year. Ex post tables will be referred to as baseline statements, and ex ante tables as scenario statements. When the baseline and the scenario statement have the same structure, we can subtract
the entries of the former from the entries of the latter to give a regional water balance change statement. This result is illustrated in Table 7, where lower case letters are used to indicate we are dealing with differences in values. Ten rules for the change statement are worth setting out; they are all derived from a single arithmetic rule of subtraction of baseline (positive, zero and negative) values from scenario (positive, zero and negative) values.

- Where the value of a cell is unchanged between the baseline and the scenario statements, the change value is zero.

- In the case of each of the red molecule flows from first-time-through ground water abstraction to external re-use, if the value in the scenario year exceeds that of the baseline year, the change value is positive.

- In the case of each of the red molecule flows from first-time-through ground water abstraction to external re-use, if the value in the scenario year falls short of that of the baseline year, the change value is negative.

- In the case of each of the blue molecule flows from household use to other uses, if the value in the scenario year exceeds that of the baseline year, the change value is positive.

- In the case of each of the blue molecule flows from household use to other uses, if the value in the scenario year falls short of that of the baseline year, the change value is negative.

- In the case of each of the supply-side blue molecule flows (supply leakage/evaporation and export of water to another region), if the absolute value in the scenario year exceeds that of the baseline year, the change value is negative. For example, if we have a shift from a base year value of 7 ML/d exported water to a scenario year value of 11 ML/d, the value of j is -4 ML/d.

- In the case of each of the supply-side blue molecule flows (supply leakage/evaporation and export of water to another region), if the absolute value in the scenario year falls short of that of the baseline year, the change value is positive.
In the case of stored water, the value of $k$ is positive when a fall in the scenario year exceeds a fall in the baseline year or when a rise in the baseline year is succeeded by a fall in the scenario year.

In the case of stored water, the value of $k$ is negative when a fall in the scenario year falls short of a fall in the baseline year or when a fall in the baseline year is succeeded by a rise in the scenario year.

From these rules we can see that any single lower-case value may be positive, zero or negative. In the change statement the total change in net supply is equal to the sum of entries $a$ to $k$. Similarly, the total change in use is equal to the sum of entries $t$ to $z$.

A final rule of great importance can be established. Since total net supply and total use in the baseline year are identically equal, and since total net supply and total use in the scenario year are identically equal, it follows like the night the day that the change between the two years are identically equal. So, in the regional water balance change statement:

- total change in net supply is identically equal to total change in use.

I have suggested that the change statement is derived as the difference between the baseline and the scenario statements. In planning practice, it may be as common for a change statement to be added to a baseline statement to produce a scenario statement.

**The uses of regional statements**

The time has arrived to outline the potential value of these statements and to propose why they may become a routine tool of water resource planning in a wide range of countries within ten years.

The baseline statement can be prepared for any geographic area and provides a comprehensive, synoptic account of the scale and composition of the supply of water and its uses in that region. The approach is pragmatic: one can foresee an evolution in statements for a specific region from the simplest set of water accounts to more complex ones, as policy interests drive the expansion of the categories deployed and the accuracy of their measurement. The work process to make the baseline calculations will stimulate new directions for research and will deepen planners’ understanding of the region’s hydrosocial cycle within its
hydrological context. The four column approach gives equal weight both to supply-side and demand-side information and describes them in the language of a unified conceptual framework. This contrasts with current water balance calculations, such as a recent one for Scotland by Andersen (5), where the demand side is based on social processes whilst the resource side is derived from natural processes in the form of hydrological yields, and where the resource and demand totals do not, in fact, balance. The recycling and re-use entries will strengthen our understanding of the cyclical components of water resource planning, make them more visible. The fundamental identity of total net supply and total use provides a consistency check on individual calculations, akin to the trial balance procedure of company accountants (2, pp.115-124).

The change statement, the planning tool *par excellence*, is applicable to short-, medium- and long-term strategy, to comparison of typical years past and future, and it clarifies the quantitative choices which a regional government or catchment agency will be forced to envisage in a future year of severe drought, or as a result of climatic change in hydrological variables. The change statements can provide comprehensive, synoptic, transparent alternative scenarios within a region for infrastructural investment and for shifts in the scale and pattern of uses. It is in this way that it handles the uncertainty that, as Peter Rogers writes, is a major issue in water resources planning (6), as well as side-stepping the inadequacy of project-by-project planning (7). The change statement does not evaluate a scenario, this is the work of environmental scientists, economists and others, but it does impose a consistency check on each case, because of the fundamental identity of total change in net supply with total change in use.

Time alone will tell if these arguments for the incorporation of regional water balance statements into water resource planning are correct. The time is ripe for exploring their potential in real spaces.

**References**


