

Basin water use accounting method with application to the Mekong Basin

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Abstract

The Challenge Program on Water and Food undertakes research to maximise water productivity in several of the world's major river basins including the Mekong. The research must be underpinned by information on how much water there is in a basin, where it goes and how it is used. There should, furthermore, be an understanding of future constraints (such as the impact of climate change), opportunities (such as increased diversions for irrigation) and trade-offs (such as changed land use improving dryland productivity but leaving less water for downstream use).

We describe a water use account for the Mekong that provides monthly estimates of major water uses. We have used it for historical estimates, but in principle it can also be used for prediction. Starting with rainfall, the account tracks the partitioning of water into runoff, and evapotranspiration by dryland vegetation. The runoff is tracked as it becomes flow down the rivers, with losses (such as evaporation and seepage) and gains (such as tributary inflows), storages in lakes and reservoirs, diversion for irrigation or other purposes, floods in lowland floodplains and finally discharges to the sea. The account estimates the water use by the major irrigation industries and other uses. The account helps develop understanding of the water uses in the Mekong Basin, and the likely consequences of large changes, such as climate change, land use change, increased diversions and irrigation water use, and changed storages.

The water use account is developed as an Excel spreadsheet. It is a tool for integrated water resources management, and provides a sound basis for integrating hydrology, environment, social and economic issues and policy and institutional issues in a river basin.

Introduction

The international Challenge Program on Water and Food aims to explore threats, opportunities and trade-offs in water access and impact on agricultural productivity and hence poverty / livelihoods and the environment for several major river basins around the world. The Mekong Basin is one of its focal river basins. The program must be founded on sound information about how much water there is, when and where it is available, and how it is used. It requires the means to explore trade-offs amongst uses, opportunities such as increased irrigation, and threats to the water resource such as land use change and climate change. Furthermore, it requires the means to assess the interactions between water and food, poverty and the environment. These needs are addressed by water use accounting (Molden, 1997; Molden et al., 2001a).

Water use accounting is used at national (ABS, 2004; Lenzen, 2004) and basin (Molden, 1997; Molden et al., 2001a) scales to allow assessment of the consequences of economic growth; the contribution of economic sectors to environmental problems; the implications

of environmental policy measures (such as regulation, charges and incentives); to identify the status of water resources and the consequences of management actions; and, identifying the scope for savings and improvements in productivity. However, those accounts are static, providing a snapshot for a single year or an average year. Furthermore, they do not link water movement to use.

In this paper, we describe a water use accounting method. In contrast to the static national and basin water use accounts referred to above, our accounts are dynamic, with a monthly timestep, and thus account for seasonal and annual variability. They can also examine dynamic effects such as climate change, land use change, changes to dam operation, etc. The accounts are assembled in Excel, and are quick and easy to develop, modify and run. We have applied this accounting method to several major river basins including the Murray-Darling and the Limpopo (Kirby et al., 2006). Here we describe the application to the Mekong.

We emphasise that the account is a high level, whole-of-basin account: necessarily, it averages or glosses over much detail. It is not a hydrology model for river planning management, nor is it a detailed account such as might be used, for example, to determine small zones of high seepage loss from a river channel (e.g. Gippel, 2006).

In contrast to water use accounting, hydrologic modelling is generally developed with a narrower focus of river or catchment planning and management. The hydrologic models of the Mekong Basin (such as those of Kite, 2001, and Podger et al., 2004) generally do not deal with all water uses, are often too complex (in spatial, temporal and/or process resolution) to use for analysis of broad scale trade-offs, and several deal only with part of the basin (such as those of Herath and Yang, 2000; Takeuchi et al., 2000; Fujii et al., 2003; Kummu et al., 2005).

Nevertheless, the hydrology of the basin is an important element of the water use account. The Decision Support System (MRC, 2004) (see accompanying Box) is the most comprehensive and carefully calibrated hydrology model of the Mekong Basin, and was accompanied by much gap filling and error checking of discharge records and other information. We have used it to develop and test the hydrology part of the water use account.

The Mekong Decision Support System

The Decision Support System is based on SWAT (Neitsch et. al., 2002), IQQM (Simons, et. al. 1996) and ISIS. SWAT simulates catchment runoff based on estimates of daily rainfall, potential evapotranspiration (PET), the topography, soils and land cover. IQQM then routes these flows through the river system, making allowance for diversions for irrigation and other consumptive demands, and for control structures such as dams. The ISIS hydrodynamic model represents the complex interactions caused by tidal influences, flow reversal in the Tonal Sap River and over-bank flow in the flood season with the varying inflows from the IQQM model at Kratie. The Decision Support Framework has been successfully used as the planning and trans-boundary analytical tool to assess various scenarios by the MRC (Podger et. al., 2004; Jirayoot and Trung, 2005). It is also the only modelling package that has been accepted by all MRC member states (MRC, 2005).

Outline of water use in the Mekong Basin

The water use and hydrology of the Mekong Basin are described in MRC (2003, 2005). The Mekong Basin (Figure 1) covers 795,000 km², and is drained by the 4200 km long River Mekong. The basin is mostly long and thin, particularly in the upper, Chinese part, and the Mekong is fed mostly by many short tributaries draining small catchments. The largest catchments are the Mun-Chi (about 100,000 km²), the Se San (80,000 km²) and the Tonle Sap (85,000 km²).

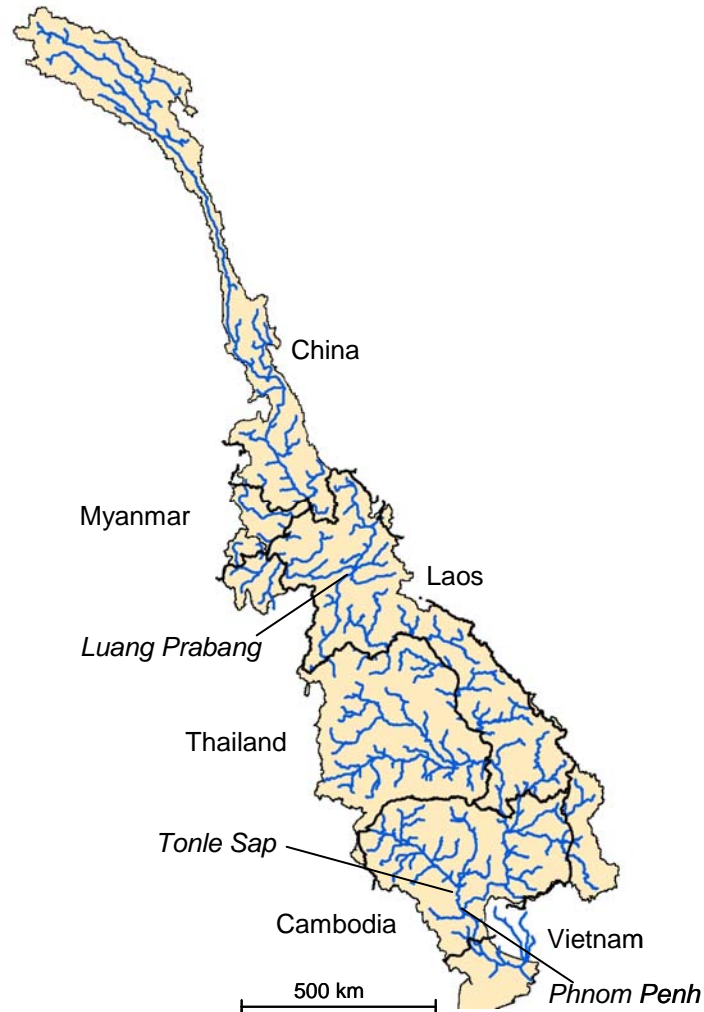


Figure 1: The Mekong River Basin, showing the major drainage network, the riparian countries, and three locations (Luang Prabang, Tonle Sap and Phnom Penh) at which observed and calculated flows are compared in the paper.

The source of the Mekong is fed by snowmelt. The Lower Mekong is fed by runoff, characterised by a pronounced wet and dry season. The peak flow from the Upper Mekong more or less coincides with the peak inflows from runoff into the Lower Mekong. Furthermore, the wet season affects the whole of Lower Mekong more or less simultaneously. The consequence is that the Mekong has a very pronounced annual flow cycle, with the high season flow being 15 – 30 times the low season flow. Furthermore, the high season flow occurs along the whole length of the Mekong at more or less the same time, with only a short lag between upstream and downstream.

The floodplain of the lower basin is extensively flooded during the high flows / wet season. The floods take water from the main channel above Phnom Penh and divert it into the Tonle Sap, across the floodplain back to the river below the Phnom Penh, or to the delta. Some of the flood water is consumed as evapotranspiration, and does not return to the river.

When the Mekong is at peak flow, its water level is above that of the Tonle Sap River which drains the Tonle Sap (Great Lake). Hence water is pushed up the Tonle Sap River and is stored in the lake. This reverse flow reverts to normal flow when the Mekong flow recedes, and the Tonle Sap River then drains the stored water plus additional water from runoff within the Tonle Sap catchment. The storage of water within the lake is of great importance to local fisheries and livelihoods.

Water use in the upper Mekong basin is dominated by evapotranspiration from forests and grasslands, with more than a third of the precipitation becoming runoff. In the mountainous eastern part of the basin (mainly Laos), water use is also dominated by evapotranspiration from forests and runoff which account for more than three quarters of the rainfall, with the remainder being mainly cropping. The western part of the basin, in northeast Thailand, is mainly under cultivation, and evapotranspiration from rainfed croplands accounts for about three quarters of the water use. Rainfed cropping and irrigation are important water uses in the lower part of the basin, with irrigation being especially important in the delta.

Method

The water use account is a top-down model (Sivapalan et al., 2003), based on simple lumped partitioning of rainfall into evapotranspiration and runoff at the catchment level. The evapotranspiration is further partitioned into the proportion accounted for by each vegetation type or land use, including evapotranspiration from wetlands and evaporation from open water. Runoff flows into the rivers, with downstream flow calculated by a simple water balance. Flow is stored in dams and other storages and, during high flows, in the channels and floodplains. Water is lost from rivers (especially downstream sections in rivers in arid or semi-arid zones) by evaporation and seepage, or by the consumption as evapotranspiration of a proportion of flood discharge onto the floodplain. Water is diverted from the rivers mainly for use in irrigation, and unused water flows to the sea.

The account is based on a monthly timestep, which we consider adequate for our purpose.

The account links known quantities in the water balance, such as rain and streamflow measured at gauging stations, with simple, physically plausible models, guided by the data.

Rainfall / evapotranspiration / runoff

The partitioning is derived from the reasoning of Budyko (1974) (which applies to average annual runoff), with the addition of a storage of which varies from month to month.

Rainfall (P) plus irrigation (Ir) is first partitioned at the surface into the runoff (Ro) and infiltration (I), where conservation must be observed:

$$P + Ir - I - Ro = 0 \quad (1)$$

Rainfall plus irrigation is the supply limit, whereas the unfilled portion of a generalised surface storage, ΔS_{max} , is the capacity limit governing the partition and includes soil storage and small surface stores. A Budyko-like equation is used to smooth the transition from the supply limit to the capacity limit:

$$\frac{I}{\Delta S_{s \max}} = \left(\frac{((P + Ir)/\Delta S_{s \max})^{a1}}{1 + ((P + Ir)/\Delta S_{s \max})^{a1}} \right)^{1/a1} \quad (2)$$

Figure 2 shows that with larger values of the parameter $a1$ this equation makes a sharper transition from the supply limit to see capacity limit. Thus, given precipitation, irrigation and the parameter $a1$, the infiltration into the generalised surface store is found from equation (2) and the runoff from equation (1).

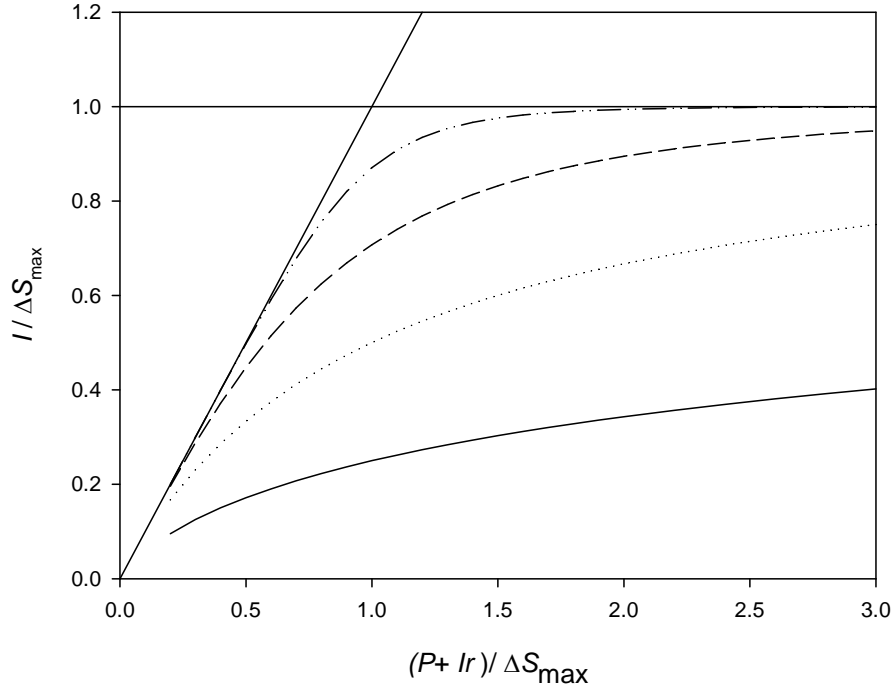


Figure 2. Behaviour of the runoff infiltration partition equation with different values of the parameter $a1$.

The evapotranspiration depends on the potential evapotranspiration (ET_{pot} , capacity limit) and the surface storage (S_s , supply limit). Although soil and other surface stores are not differentiated, the implication is that evaporation occurs from small ponds, puddles, and the soil surface, whereas transpiration comes from deeper soil storage. A similar equation to the above, with a second adjustable parameter $a2$, is used to smooth the transition from the supply limit to the capacity limit:

$$\frac{ET}{ET_{pot}} = \left(\frac{((S_s^{t-\Delta t} + I)/ET_{pot})^{a2}}{1 + ((S_s^{t-\Delta t} + I)/ET_{pot})^{a2}} \right)^{1/a2} \quad (3)$$

This equation also behaves as shown by the figure with the obvious changes to the parameters. In all the examples described in this paper, we shall use $a2 = a1$, so the rainfall-runoff model has two adjustable parameters.

The surface storage is increased by the infiltration and decreased by the evapotranspiration and a drainage-to-baseflow component, D_B :

$$S_s^t = S_s^{t-\Delta t} + I - ET - D_B \quad (4)$$

where t is time and Δt is the timestep (one month). Baseflow is a small component of the total flows in the Mekong, so the baseflow component was assumed to be a small value, constant with time, varying from catchment to catchment.

River flow and storage upstream of Kratie

River flow is modelled as a series of reaches, with mass balance observed between reaches. The large difference between the high and low flows implies considerable storage within the river channels. Furthermore, floods also imply considerable storage, particularly further downstream.

Thus, the reach outflow, Q_o , is given by the inflow, Q_i , plus any tributary flows, Q_t , plus the runoff from the adjacent catchment, R_o (as calculated above), plus a baseflow component, B_f , less any diversion (for industrial or agricultural use), D , less any losses (evaporation, seepage), L , plus the change in reach storage ΔS_r :

$$Q_o = Q_i + Q_t + R_o + B_f - D - L + \Delta S_r \quad (5)$$

The reach storage is taken to be a function of the inflow:

$$S_r = c1 Q_i^{c2} \quad (6)$$

where $c1$ and $c2$ are parameters. The change in reach storage is the difference between reach storage at two timesteps:

$$\Delta S_r = S_r^t - S_r^{t-\Delta t} \quad (7)$$

The reach storage is recovered as river flow during recession. Outflow from one reach becomes inflow to the next reach. Where tributaries join a reach, the inflow is the sum of the outflows from the joining reach and the tributaries.

The monthly baseflow, B_f , was considered to be equal to the monthly average drainage-to-baseflow component, D_B . This implies that the groundwater levels are sustainable (inflows balance outflows over a long period). The implications of other assumptions can be calculated.

Flow and flood spill downstream of Kratie

Downstream of Kratie, floods spill from the river on to a wide floodplain and, in general, do not return to the river (Fujii et al, 2003; Morishita et al, 2004). Some water flows to the Tonle Sap, some re-enters the Mekong downstream of Phnom Penh (that is, in a downstream reach), some flow is directed to the delta region, and some is presumably consumed on the floodplain as evapotranspiration. The reach outflow is given by:

$$Q_o = Q_i + Q_t + R_o - D - L - F_o + F_i \quad (8)$$

where F_i is overland flood inflow from an upstream reach (which equals zero for the first reach downstream of Kratie, since this is the first reach to contribute overland flood flow to downstream reaches), F_o is overland flood outflow, given by the river height, H , above a threshold value, H_t :

$$\begin{aligned} F_o &= c3(H - H_t) & H > H_t \\ F_o &= 0, & H \leq H_t \end{aligned} \quad (9)$$

and $c3$ is a parameter. The river height is assumed to be a function of the inflows:

$$H = c4Q_i^{0.5} \quad (10)$$

where $c4$ is a parameter. Note the implicit assumption (contained in the exponent of 0.5) that the flow is proportional to the cross sectional area of the channel, which in turn is related to the square of the flow height. We also make this assumption below.

Tonle Sap and reverse flow

Flow in the Tonle Sap River, Q_{TS} , and consequently storage in the lake, depends on the difference in height between the Tonle Sap River and the Mekong. It is also assumed that the flow capacity of the Tonle Sap River increases with increasing height. Thus:

$$Q_{TS} = c6(H_{TS} - H_M - c7) H_{TS}^2 \quad (11)$$

where $c6$ and $c7$ are parameters, and H_{TS} and H_M are the heights of the Tonle Sap River and the Mekong. The terms in the brackets account for the flow dependence on height difference, whereas the H_{TS}^2 term accounts for the increasing flow capacity of the Tonle Sap River with increasing height. The $c7$ parameter accounts for the fact that the absolute heights in the two rivers are not calculated. Rather, relative heights are calculated from the volume of water stored in the Tonle Sap lake, S_l and the flow in the Mekong as:

$$\begin{aligned} H_{TS} &= c8(S_l + c9)^{0.5} \\ H_M &= c9Q_{MK}^{0.5} \end{aligned} \quad (12)$$

Note that the height of the Mekong, H_M , is calculated from the flow at Kratie, Q_{MK} . $c8$ and $c9$ are parameters. When $(H_M + c7) > H_{TS}$, Q_{TS} is negative, indicating flow reversal.

Lake storage, S_l , is given by the storage at the previous timestep, plus runoff from the Tonle Sap catchment, minus losses (evaporation, etc), minus flow in the Tonle Sap River.

$$S_l^t = S_l^{t-\Delta t} + Ro - L - Q_{TS} \quad (13)$$

Irrigation demand and supply

We use a crop factor approach, in which the crop factor, K_C , is 0 when there is no crop, or takes a value often about 1 when there is a crop. The basis of this approach is given in FAO 56 (Allen et al., 1998) and companion publications. We assume here that crops are always well watered, and that the area cropped is limited when water supply is limited. Thus, decreases in crop production result from reduced area, not reduced yield. The monthly irrigation demand per unit area, $Irr_{Demandij}$, for crop i in month j is:

$$Irr_{Demandij} = \frac{(K_{Cij} ET_{potj} - P_{eij})}{IE_i} \quad (14)$$

where K_{Cij} is the crop factor for the i th crop, IE_j is the irrigation efficiency and P_{eij} is the effective rainfall. Note that if $P_{eij} > K_{Cij} ET_{potj}$, $Irr_{Demandij} = 0$. The irrigation demand per unit area for that crop, $Irr_{DemandAi}$, is summed for the following 12 months, in order that a full year's demand may be compared with a full year's supply:

$$Irr_{DemandAi} = \sum_{j=1,12} Irr_{Demandij} \quad (15)$$

The total irrigation demand per unit area for n crops for the subsequent 12 months, $Irr_{DemandT}$, is:

$$Irr_{DemandT} = \sum_{i=1,n} \left(Irr_{DemandAi} \frac{A_{iI_{max}}}{A_{TI_{max}}} \right) \quad (16)$$

where $A_{iI_{max}}$ is the maximum area available for crop i and $A_{TI_{max}}$ is the maximum area available for all irrigated crops. The actual area that may be supplied for an irrigated crop, A_{iI} , depends on the available supply of water, and is given by:

$$A_{iI} = MIN \left(A_{iI_{max}}, \frac{W_{Avail}}{Irr_{DemandT}} \frac{A_{iI_{max}}}{A_{TI_{max}}} \right) \quad (17)$$

where W_{Avail} is the volume of water that may be available from flow and/or storage, and the MIN function limits the area irrigated. The volume, D_i , diverted to supply crop i is:

$$D_i = A_{iI} Irr_{DemandAi} \quad (18)$$

and the individual diversions to each crop are summed to give the total diversion, D :

$$D = D_1 + D_2 + \dots + D_n \quad (19)$$

Partitioning of dryland evapotranspiration by land use / vegetation type

Equation (3) gives an estimate of the monthly evapotranspiration for each catchment which is constrained by and consistent with the measured outflows. This can be partitioned into the evapotranspiration from each land use / vegetation type in several ways, using vegetation water use modelling principles. The FAO crop factor approach is a suitable candidate, since it is a simple model closely based on observed crop water use, and has been applied all over the world. As well as providing a better estimate of the partition, it would also provide an independent check of the rainfall-evapotranspiration-runoff partitioning of the simple hydrological model. At this stage, we have used a simple pro-rata partitioning based on land use areas derived from remotely sensed data.

$$ET_{iD} = \frac{A_{iD}}{A_{TD}} ET_{TD} \quad (20)$$

where A_{iD} is the i th dryland land use, A_{TD} is the total dryland area, and ET_{TD} is the total dryland evapotranspiration.

We emphasise that this simple partitioning is not a restriction in the method. It is merely an expedient used here for this demonstration. Using something like the FAO CROPWAT approach is quite easy to implement.

Calibration

We used two main calibration steps.

1. The runoff into any reach must equal the sum of the outflow, losses, diversions and changes to storage minus the sum of the inflows. This is true for any period, from a single month to the full length of the record being considered. We set the sum of the runoff (by varying S_{max} , and $a1$ - which we made equal to $a2$ - in equations (2) and (3)) over the full period to be modelled to equal the sum over the full period of the outflows and changes to storage less the sum of the inflows. We did not calibrate monthly or seasonal behaviour.
2. We made the calculated annual average diversions equal to independently measured values where we had them, by adjusting K_{Ci} , $A_{iI_{max}}$ or $A_{TI_{max}}$ in equations (14), (16) and (18). Again, we did not calibrate monthly or seasonal behaviour.

Balance checks

The spreadsheet has two checks of the overall water balance for each sub-basin. The first check is that the sum of the monthly rain over the full period equals the sum of the monthly evapotranspiration plus the sum of the monthly runoff plus the difference in the surface storage, S_s , between the beginning and end of the period.

The second check is that for each sub basin the sum of the monthly inflows equals the sum of the monthly losses to discharge, evaporation from storages and diversions plus the difference in storages between the beginning and end of the period.

Results: Mekong water use account

The Mekong was divided into 12 sub-basins. Climate and flow data for each sub-basin were partly supplied by the Mekong River Commission, and partly gathered from other sources as part of a project within the Challenge Program on Water and Food. Land use data were obtained from the IWMI website (www.iwmi.cgiar.org). We show here the flow modelling for an upstream location and a downstream location on the Mekong, and for the Tonle Sap catchment.

Upstream location: Luang Prabang

The reach from Chiang Saen to Luang Prabang drains an area of about 53,000 km² (not including the Muong Ngoy catchment, which was modelled separately). The behaviour of this reach was modelled using equations (5) to (7).

The calculated flows were matched to the observed flows in two stages. First, the rainfall - runoff partition was used to derive a runoff record in which, over the full length of the flow record, the runoff equalled the difference in the observed inflows and outflows less the inflows from the Muong Ngoy catchment. Parameter a_1 in equation (2) (with $a_2 = a_1$ in equation (3)) was adjusted to achieve this match. Then, the calculated monthly outflows were matched to the observed outflows using Solver to minimise the sums of squares of differences between observed and calculated, while varying parameters c_1 and c_2 in the equations above. The results are shown in Figure 3. The model was fitted to the total flows (Figure 3, left). The observed local flow contribution (ie the difference between reach inflow and outflow in Figure 3, right) shows occasional apparently negative flows, which indicate reach inflow greater than outflow in some months, due to water held up in river storage. These are modelled reasonably well.

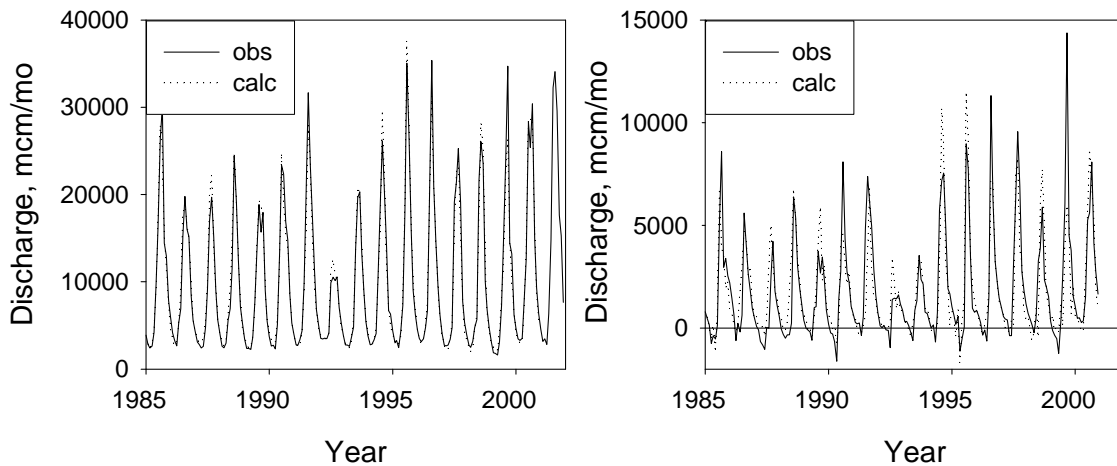


Figure 3. Measured and modelled flows at Luang Prabang, 1985 to 1999. Left: hydrograph of observed and modelled outflows. Right: comparison of difference between observed inflows and outflows, and difference between modelled inflows and outflows.

Tonle Sap

The Tonle Sap catchment is about 85,000 km². Several small rivers drain into the Tonle Sap (Great Lake), which in turn is drained by the Tonle Sap River which discharges into the Mekong at Phnom Penh. Applying the Tonle Sap flow model in equations (11) to (13), with parameters c_6 to c_9 optimised using Solver in Excel, gives the flow in the river. Figure 4 shows the comparison between observed and modelled flows. The flow reversal is evident both in the observed and modelled flows.

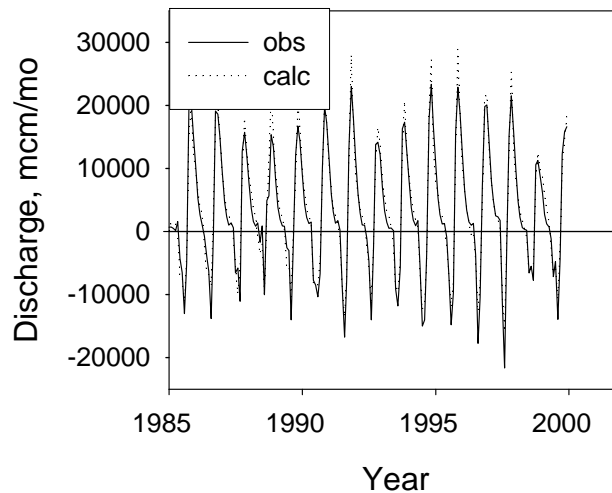


Figure 4. Observed and modelled flows in the Tonle Sap River, 1985 to 1999.

Downstream location: Phnom Penh

The reach from Kratie to Phnom Penh floods during the wet season. Evapotranspiration is assumed to consume part of the flood and part returns to the river system.

This reach was modelled using equations (8) to (10). In the same manner as the upstream reach, the rainfall - runoff partition was used to derive a runoff record in which, over the full length of the flow record, the runoff equalled the difference in the observed inflows and outflows. Then, the calculated monthly outflows were matched to the observed outflows using Solver to minimise the sums of squares of differences between observed and

calculated, while varying parameters c_3 , c_4 and H_t in the equations above. The results are shown in Figure 5. The model was fitted to the total flows (Figure 5, left). The observed local flow contribution was calculated from the difference between reach inflow and outflow (Figure 5, right). In this downstream reach, total flows were large and the differences between them small, so the difference showed considerable noise. As a result, the modelled local flow contribution does not accurately fit the noisy observed trace, but it matches well a curious feature of the observed trace. The observed flows show an annual cycle of small positive peak followed by an apparent negative peak, followed by a second small positive peak. This results from an increase in river height with the onset of the wet season (the first small positive peak), followed by a flood spill (the apparent negative peak, indicating a loss from the channel). On recession, the flood stops and there is a second small positive flow contribution. The model reproduces this feature.

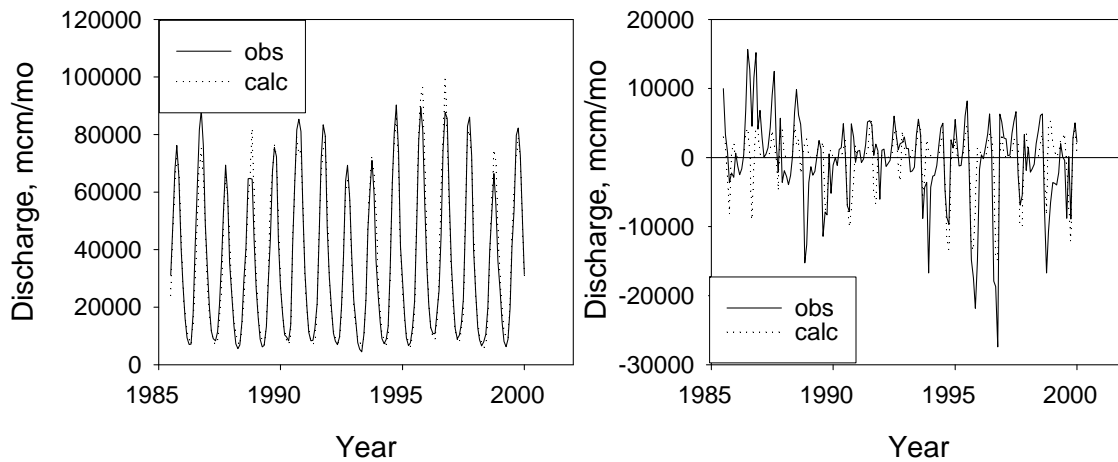


Figure 5. Measured and modelled flows at Phnom Penh (Mekong main channel below the confluence with the Tonle Sap River), 1985 to 1999. Left: hydrograph of observed and modelled outflows. Right: difference between observed inflows and outflows, and difference between modelled inflows and outflows.

Water use by major land uses

The water use by major rainfed and irrigation land uses was calculated by equations (14) to (19). The monthly calculations aggregated to an annual average water use are shown in Figure 6. The figure shows the dominance of forestry and runoff in the eastern parts of the basin and of cropping and irrigation in the southern and south-western parts of the basin.

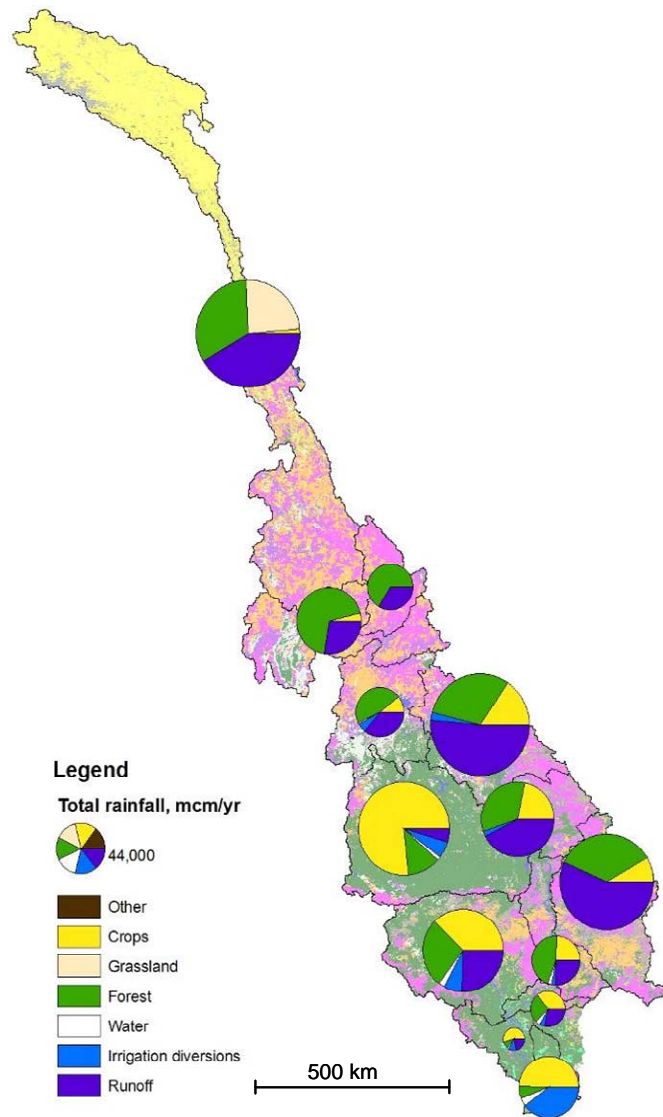


Figure 6: Major water use for main catchments within the Mekong Basin. The area of each pie chart is proportional to the volume of mean annual rainfall in each catchment.

Discussion

The water use account spreadsheet is an example of top-down modelling in that it describes the overall behaviour of a basin based on observed responses, which Sivapalan et al. (2003) regard as the defining feature of a top-down approach. It is at a level of detail appropriate to an overview of the Mekong Basin. Individual model components are inferred from the data, rather than pre-conceived.

The elements of the water account (flow, storage, water use) are linked to time-series graphs (such as the hydrographs in Figures 3 to 5, comparing observed and calculated flows). Systematic learning about catchment and basin behaviour is facilitated, gaps and deficiencies in data are readily apparent, and hypothesis testing is quick and easy. Parameter estimation can be automated through the Solver function in Excel, though care is required in its use: the user must be satisfied that the underlying sub-model is reasonable

and that the optimum is sensible. We use this method in some of our calibrations to fit parameters.

A significant advantage of a water use account for a whole basin is that there are often many sources of data with which to constrain or calibrate a model. We have used many flow gauges, known annual discharge, and the Mekong Decision Support System (IQQM) estimates of diversion volumes for irrigation districts. Furthermore, the requirement to balance all gains, losses and changes to storage, both across the basin and for each and every component, places severe constraints on permissible use, flows and storages. When several tributaries contribute to a main channel, the calculated flow in each is constrained so that, even if one or more is ungauged, tight limits can be placed on the flow from each. This is even more the case if there are independent estimates of vegetation water use. In another context, Raupach et al. (2001) noted the usefulness of mass balances in providing physical constraints to material flows, particularly when several flow calculations are linked (their context was several entities – carbon, energy, water, nutrients - in one place, whereas here we deal with one entity – water – in several places).

Sivapalan et al. (2003) note problems and caveats with the top-down approach. Finer scale processes are glossed over, and the user must be confident that key features are not ignored, and that large scale models are physically reasonable interpretations of the processes. There are dangers in generalisations and extrapolations to new situations. Thus, the water use accounts should be used to investigate scenarios that are but modest perturbations of the conditions for which they are tested and calibrated.

The water use account spreadsheet provides a basin overview of major natural, dryland and irrigated water uses, flows, storage, major losses and discharge. It provides a basis for examining the impact of physical changes to the system and for interactions with agricultural productivity, economics and livelihoods.

As an example of use of the spreadsheets to examine physical impacts, Figure 7 shows the impact on downstream flows of a 7 % increase in rainfall. The IPCC Fourth Assessment described in the estimated impact of climate change in the Southeast Asian region, and noted that in 2080 the temperature is expected to increase by 3°C and the rainfall is expected to increase by 7 %. Figures for potential evapotranspiration were not given, but we assume that effect of increased temperature (which will increase potential evapotranspiration) is offset by the increased rainfall and presumably cloudiness (which will decrease potential evapotranspiration). We thus assume that the potential evapotranspiration will not change. We assume that the rainfall is increased everywhere by 7 %. Figure 7 shows that the modelled flood peaks are greater under this scenario. These results are broadly similar to those of Hoanh et al. (2003).

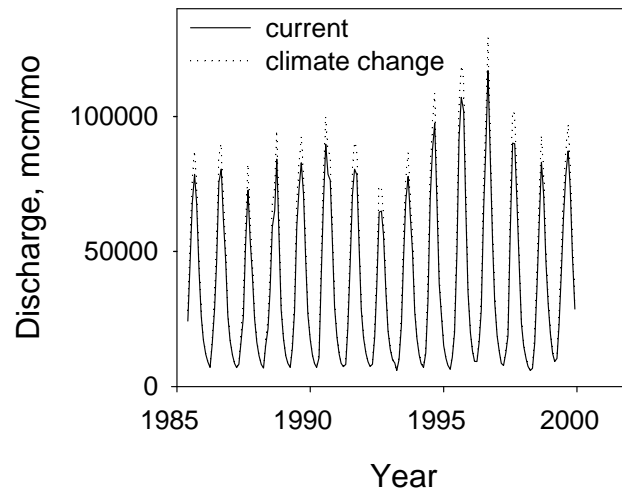


Figure 7: Comparison of modelled historical flows and flows assuming increased rain due to climate change, at the border between Cambodia and Vietnam, 1985 to 1999.

However, our main motivation for developing water use accounts is to study the impacts on agricultural productivity, economics and livelihoods. Many of the purely physical changes mentioned above, particularly flow regimes, could be examined as well or better with the Mekong Decision Support System SWAT-IQQM-ISIS catchment – hydrology model. We do not propose that water use account spreadsheets should be used in place of such models.

Molden et al. (2001b) and Sakthivadivel and Molden (2001) show that basin water use accounting is central to linking institutions to water resources development and conservation. They develop static water account that aggregate water uses across whole basins. Such accounts do not readily indicate which parts of a basin (if any) might be most vulnerable to change or in need of institutional attention, nor do they indicate issues such as seasonal shortages, floods, or agricultural or ecosystem productivity. Biltonnen et al. (2003) show that water use accounting is central to water policy development of the Mae Klong Basin in Thailand. In contrast to Sakthivadivel and Molden (2001) and Molden et al. (2001), they develop accounts for different parts of the basin, though the accounts are nevertheless static.

Our accounts are dynamic and thus suited to investigation of a wider range of issues. We have also developed water use accounts for the Murray-Darling, Karkheh and Limpopo river basins (Kirby et al., 2006). We have used water use accounts, particularly in the Murray-Darling Basin, as the basis for assessments of water allocation under various policy scenarios (eg Qureshi et al, 2006a, 2006b), and water use in optimal decision making about water trading and environmental water use (Kirby et al., 2006). In our future work we aim to use the water use account outlined in this paper to investigate impacts of changes to water availability and use on poverty and livelihoods in the Mekong.

Conclusions

Water use accounts are a powerful way of describing the overall water use and flow behaviour of a river basin. They capture the main aspects of the behaviour, both spatially and temporally (seasonally, annually), and the balance between different types of water use (dryland, irrigated, forest, wetland and other water uses).

The water use accounts spreadsheets we have developed are useful for systematic learning and hypothesis testing, and also help the user rapidly identify gaps and limitations in the data. They can be applied in cases where data are limited, and it is possible to construct a reasonable account based on data available on the Internet.

The water use accounts spreadsheets provide basin overviews of water uses, and provide a basis for examining the impact of physical changes to the system and for interactions with agricultural productivity, economics and livelihoods. We emphasize, however, that they are not detailed catchment hydrology models, and are not suited to river planning and management, nor to investigations of small-scale, detailed effects.

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