KEY WATER RESOURCES STATISTICS IN AQUASTAT

FAO's Global Information System on Water and Agriculture

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ABSTRACT: This article describes the methodology used by AQUASTAT to assess natural and actual freshwater resources for the world by country. It deals with renewable water resources and concentrates mainly on the physical assessment of internal and external resources. It presents a picture of the state of the world's water resources that is not only the natural state but also the current situation, taking into account existing uses of water and their implications for countries sharing river basins.

Much remains to be done in order to obtain sound statistics on water resources, and particularly standardized data sets, at global level. This article presents some reflections in this sense. For example, more effort needs to be focussed on the assessment of the variability of water resources in space (basin level), in time (dry-year resources) and according to constraints (exploitable resources). Disaggregated information at river-basin level is particularly important in large countries with very diverse climatic conditions. National averages hide local differences and, for large countries, are of little use for evaluating the country's water situation.

In order to improve the comparability of water information at regional and global level, AQUASTAT has also been working on the development of global GIS-based data sets and modelling tools. The model developed was used for cross-checking the Africa data sets and showed that the combined use of country-based data and global water-balance modelling can enhance the overall reliability of the results. Field-based approaches (based on measurements) and modelling approaches are certainly complementary.

INTRODUCTION

Water has been a main issue on the international agenda for the last 30 years. At a global level, about 70% of the water withdrawals are directed towards agriculture and this is even over 90% in some developing regions. In view of the critical role of water in agricultural production in general, and food production in particular, and of the importance of agriculture in global water withdrawal, and in order to provide a basis for the discussion on increasing water scarcity and the future of irrigation in the world, the AQUASTAT programme compiles existing quantitative and qualitative information on water resources, water use and irrigation by country.

Developed since 1993 by the Land and Water Development Division of the Food and Agriculture Organization of the United Nations (FAO), AQUASTAT is the organization's global information system on water and agriculture with a focus on irrigation. Its aim is to provide users interested in global, regional and national analysis (such as policy-makers, decision-makers and researchers) with the most accurate, reliable, consistent and up-to-date information available on water resources and agricultural water management.

Global data sources often do not indicate the method used to compile and validate their datasets. The AQUASTAT publication "Review of world water resources by country" (FAO, 2003) presents concepts and methodology applied to compute country-level renewable water resources data. It presents and analyses key findings at both global and regional levels, and discusses the limitations of the approach and the information gaps that remain at country level. The survey gives priority to information available from countries. It makes no use of global water balance models. Although such method does not ensure homogeneity in the quality of information collected, it makes the best possible use of local knowledge. The study has devoted a particular attention to reducing the risk of double-counting for: (i) internal renewable water resources (IRWR) when assessing surface water and groundwater separately, and (ii) external renewable water resources (ERWR) when accounting for transboundary waters, border rivers or lakes. The approach followed in the study, as well as suggestions for improvement, will be described more in detailed below

TYPES OF RENEWABLE WATER RESOURCES

AQUASTAT gives the following definitions and assumptions on freshwater resources.

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Renewable and non-renewable water resources

Renewable water resources represent the long-term average annual flow of rivers (surface water) and recharge of aquifers (groundwater) generated from precipitation. They are computed on the basis of the water cycle.

Non-renewable water resources are groundwater bodies (deep aquifers) that have a negligible rate of recharge on the human time-scale and thus can be considered as non-renewable. While renewable water resources are expressed in flows, non-renewable water resources have to be expressed in quantity (stock).

Internal renewable water resources

IRWR is that part of the water resources, surface water and groundwater, generated from endogenous precipitation. The IRWR figures are the only water resources figures that can be added up for regional assessment.

Surface water flows can contribute to groundwater replenishment through seepage in the river bed. Aquifers can discharge into rivers and contribute to their base flow, the sole source of river flow during dry periods. Therefore, the respective flows of surface water and groundwater systems are not wholly additive. In AQUASTAT, the part of the country's water resources that is common to rivers and to aquifers is called overlap.

External renewable water resources

ERWR is the part of the country's renewable water resources that enters from upstream countries through rivers (external surface water) or aquifers (external groundwater). The total external water resources are the inflow from neighbouring countries (transboundary flow) and a part of the resources of shared lakes or border rivers.

In assessing the external flow of a country, a distinction has to be made between natural and actual incoming flow:

- Natural inflow is the average annual amount of water that would flow into a country in natural conditions, i.e. without human influence;
- Actual inflow is the average annual quantity of water entering the country, taking into account that part of the flow which is secured through treaties or agreements (in upstream and downstream countries) and possible water abstraction in upstream countries.

Natural and actual renewable water resources

Natural renewable water resources are the total amount of a country's water resources (IRWR and natural ERWR), which is generated through the hydrological cycle, without human influence. It includes both surface water and groundwater. The amount is expressed as a long-term average annual amount.

Actual renewable water resources are the sum of IRWR and actual ERWR, which take into consideration the quantity of flow reserved to upstream and downstream countries through formal or informal agreements or treaties and possible reduction of external flow due to upstream water abstraction. Actual ERWR vary with time and consumption patterns and, therefore, must be associated to a specific year.

Exploitable water resources

Not all natural freshwater, surface water or groundwater, is accessible for use. Exploitable water resources (manageable water resources or development potential) considers factors such as: the economic and environmental feasibility of storing floodwater behind dams or extracting groundwater, the physical possibility of catching water which naturally flows out to the sea, and the minimum flow requirements for navigation, environmental services, aquatic life, etc. In general, exploitable water resources are significantly smaller than natural water resources (Box 1).

BOX 1
Exploitable water resources in Lebanon

The case of Lebanon illustrates the difference between natural or actual water resources and exploitable water resources. About half of the country's water resources is hardly exploitable. The groundwater losses to the sea that are accounted for in the assessment of potential yield (about 0.7 km^3/year) come out as submarine springs. These resources are difficult to mobilize as the karstic channels in which the water flows are subject to mixing with saline water. Similarly, the floodwater running from the small catchments of the coastal mountains is lost to the sea with little possibility of putting it to beneficial use. Thus, out of the total water resources estimated at 4.8 km^3/year, exploitable water resources represent about 2.2-2.5 km^3/year.

Renewable exploitable water resources may be divided in three subcomponents: regular surface water, irregular surface water and regular groundwater.

Regular or permanent resources refer to the surface water or groundwater that is available with an occurrence of 90 percent of the time. In practice, it is equivalent to the low water flow of a river and the flow of groundwater that are often mixed. It includes the flow of groundwater not collected by watercourses flowing into the sea, enclosed lakes and areas of evaporation. It is the resource that is offered for withdrawal, diversion or groundwater extraction with a regular flow.

Irregular resources are equivalent to the variable component of water resources (e.g. floods) and, exceptionally, groundwater levels (flooding of karstic aquifers). It includes the seasonal and inter-annual variations, i.e. seasonal flow or flow during wet years. It is the flow that needs to be regulated.

In addition to renewable exploitable water resources (expressed in flow), there are also non-renewable exploitable water resources (expressed in quantity or stock). Their evaluation depends on long-term exploitation plans. Renewable and non-renewable exploitable water resources cannot be added up.

METHOD USED TO COMPUTE RENEWABLE WATER RESOURCES BY COUNTRY

The method used to assess renewable water resources by country was first described in FAO/BRGM (1996). It consists of a set of rules and guidelines leading to the calculation of the IRWR, the total renewable water resources (TRWR), and the country's dependency ratio.

The method is based on a water resources accounting approach. The TRWR of a country consist of the IRWR plus the external renewable water resources (ERWR). In order to calculate the ERWR, a distinction has been made between natural and actual ERWR. Since the TRWR are generally not equal to the amount of water available for use, where possible a compilation has been made of estimations of exploitable water resources per country and included in the country results.

The calculation of renewable water resources in AQUASTAT is based on long-term averages as available in existing, preferably national, literature.

The method consists of the following steps for each country:

1. Select the most accurate data sources;
2. Assess the IRWR;
3. Assess the natural and actual ERWR;
4. Assess the natural and actual TRWR;
5. Calculate the country's dependency on external water: the dependency ratio;
6. Ensure consistency between countries by cross-checking inflows and outflows between countries.

Assessing the internal renewable water resources

The IRWR are equal to the volume of average annual flow of surface water and groundwater generated from precipitation within the country (Equation 1):

$$IRWR = R + I - (Q_{OUT} - Q_{IN}) \qquad \text{(Equation 1)}$$

where:

R	=	surface runoff, which is the total volume of the long-term average annual flow of surface water generated by direct runoff from endogenous precipitation
I	=	groundwater recharge, generated from precipitation within the country
Q_{OUT}	=	groundwater drainage into rivers (typically, base flow of rivers)
Q_{IN}	=	seepage from rivers into aquifers

Although they are linked to the hydrological cycle, surface water and groundwater resources are often computed separately. Therefore, a simple addition of surface water and groundwater leads to an overestimation of the total amount of freshwater resources produced in a country. In AQUASTAT, the exchange between surface water and groundwater resource ($Q_{OUT} - Q_{IN}$) is called overlap. Box 2 illustrates the complexity of surface water and groundwater interdependency in humid and arid countries and the method used to compute overlap.

BOX 2

Surface water and groundwater interdependency or overlap

Summary of the approaches applied for estimating the overlap:

Humid areas

In humid areas, IRWR are assessed from available hydrographs (time-series data on measured surface water discharge). For areas where no measurements are available, data are extrapolated over space from areas where data are available. Where necessary, measured data are corrected to take into account water abstraction. In humid areas, the base flow of rivers consists mainly of drainage of groundwater reservoirs. Thus, estimates of surface water resources include a significant part of the groundwater resources. Therefore, the groundwater resources in humid areas have been assumed to be equal to the base flow of the rivers where data are available.

Semi-arid areas

In semi-arid areas, IRWR are generated mainly from flash-flood events. The groundwater resources are obtained from rainfall infiltration estimates or from analyses of measured groundwater levels/heads in aquifers. The surface water resources are estimated through flash-flood discharge measurements or estimates. Care should be taken to ensure the correct assessment of the part of surface water flows that recharges the aquifers in order to avoid overestimation of the total water resources.

Very arid and coastal areas

In coastal or very arid areas, a large part of the groundwater aquifers is not drained by the rivers and overlap is therefore relatively small.

In almost all countries, a part of the IRWR has to be estimated by modelling using rainfall data (spatial or temporal extrapolation of measured hydrological data), but the models used should be well adapted to the regional hydro-climatological conditions.

Measured runoff corresponds to actual flow, influenced by utilization and human consumption. These measurements together with estimates of the water consumption (and its evolution in time) should be used in order to calculate the long-term average annual runoff, which is part of the IRWR. Also in this case, the use of models might be useful to estimate the average natural annual flow, but on the condition that the parameters of these models have been calibrated in some elementary basins where the runoff has not yet been influenced by abstractions.

Assessing external renewable water resources

The ERWR are equal to the volume of average annual flow of rivers and groundwater entering a country from neighbouring countries (Equation 2):

$$ERWR_{NATURAL} = SW_{IN} + SW_{PR} + SW_{PL} + GW_{IN} \quad \text{(Equation 2)}$$

where:

SW_{IN} = surface water entering the country
SW_{PR} = accounted flow of border rivers
SW_{PL} = accounted part of shared lakes
GW_{IN} = groundwater entering the country

AQUASTAT makes a distinction between natural and actual ERWR. The actual ERWR take into account the quantity of flow reserved by upstream (incoming flow) and/or downstream (outflow) countries through formal or informal agreements or treaties, and possible water abstraction occurring in the upstream country. Therefore, the actual ERWR may vary with time. In extreme cases, the value may be negative when the flow reserved to downstream countries is more than the incoming flow (Equation 3).

$$ERWR_{ACTUAL} = SW^1_{IN} + SW^2_{IN} + SW_{PR} + SW_{PL} - SW_{OUT} + GW_{IN} \quad \text{(Equation 3)}$$

where:

SW^1_{IN} = volume of surface water entering the country which is not submitted to treaties

SW^2_{IN} = volume of surface water entering the country which is secured through treaties
SW_{PR} = accounted flow of border rivers
SW_{PL} = accounted part of shared lakes
SW_{OUT} = volume of surface water leaving the country which is reserved by treaties for downstream countries
GW_{IN} = groundwater entering the country

Box 3 describes the rules used in AQUASTAT to calculate the different components of the water resources. They are neither absolute nor universal. They have been selected to represent all the situations in the most realistic way possible. Figure 1 presents the standard computation sheet, in which as an example these rules have been applied for Myanmar.

Assessing total renewable water resources

The TRWR are the sum of the IRWR and the ERWR. As with the ERWR, a distinction has been made between the natural and actual TRWR (Equations 4 and 5):

$$TRWR_{NATURAL} = IRWR + ERWR_{NATURAL} \quad \text{(Equation 4)}$$

where:

IRWR = internal renewable water resources (Equation 1)
$ERWR_{NATURAL}$ = natural external renewable water resources (Equation 2)

$$TRWR_{ACTUAL} = IRWR + ERWR_{ACTUAL} \quad \text{(Equation 5)}$$

where:

IRWR = internal renewable water resources (Equation 1)
$ERWR_{ACTUAL}$ = actual external renewable water resources (Equation 3)

BOX 3
Rules applied for computing ERWR

Surface water entering the country (SW_{IN})

The mean annual flow measured or estimated at the border of the transboundary river is accounted for as an external resource for the downstream country. It is not deducted from the resources of the donor country except in the case of an agreed apportionment, i.e. a treaty between the countries. Because of the existence of bilateral and multilateral agreements and upstream water consumption, two categories of external water resources are differentiated:

- Natural flow corresponding to long-term average flow not affected by or before being affected by upstream consumption.
- Actual flow corresponding to a given period which takes into account water abstraction from upstream, be it through an agreement or from a factual situation, and/or agreed or accepted commitments towards downstream countries.

A particular case is the situation where part of the runoff entering the country originates in the country itself after it has entered and exited a neighbouring country. In such a case, and where the information is available, this flow is deducted from the incoming flow to avoid double counting. Therefore, net inflows are considered over the country borders.

Flow in border rivers (SW_{PR})

As a general rule, 50 percent of the river flow is assigned to each of the bordering countries. Several situations exist:

- Where the river exclusively borders the countries without entering any of the adjacent countries nor exiting from them, the incoming resources are estimated on the basis of the river runoff in the upstream part of the border section. Where the runoff increases substantially from upstream to downstream, the downstream figure is used after subtraction of the part of the runoff generated by the country itself.
- Where the source of the river is in one of the two countries, the rule applies only for the other country. For the originating country, 50 percent of the contribution from the other country could similarly be considered as external resources where known.
- Where the river enters one of the two countries after having divided the two countries, it is considered a transboundary river for the receiving country and all the runoff at the entry point in that country is considered as an external resource. The 50-percent rule applies for the other country.
- Where a treaty exists between the adjacent countries of a river system, the rules applied are those defined in the treaty.

Shared lakes (SW_{PL})

- Where the lake has an outlet into a river (e.g. Lake Victoria enters the Nile River in Uganda), all the runoff at the entrance of the river is accounted for as external resources for the receiving country.

- For all the other countries, an equal share of this runoff can be considered as external resources, after having subtracted the country contribution to the lake. Where this results in a negative value, the external resources are considered to be zero for the country in question. Where the river forms the border between two countries, the rule described above for border rivers applies.
- For lakes without an outlet, the global runoff entering the lake is estimated and shared equally between the adjacent countries, after having deducted the part contributed from the country. Where this results in a negative value, the external resources are considered to be zero for the country in question.
- Artificial lakes have not been accounted for as the flow reduction is an impact of water development and not a natural phenomenon.

Surface water leaving the country (SW_{OUT})

The computation of actual ERWR considers the outflow of surface water only in the case of an agreed apportionment between the upstream and downstream countries.

Groundwater entering the country (GW_{IN})

The mean annual estimated groundwater flow entering the country is accounted for as an external resource.

Groundwater leaving the country (GW_{OUT})

The computation of ERWR does not consider outflow of groundwater.

FIGURE 1
The AQUASTAT computation sheet
Computation of renewable water resources by country (in km^3/year, average)

Country: Myanmar

INTERNAL RENEWABLE WATER RESOURCES (IRWR)

		Source IPCC		Area country					
Precipitation		2091	mm/yr	67658000	ha			1414.593	km3/yr
Water resources produced internally in a 10th frequency dry year									(?)
Surface water produced internally (R)	a	874.600		(1)					
Groundwater produced internally (I)	b	156.000		WRI					
Overlap (Q_{IN}-Q_{OUT})						150.000	c		(2) estimated
Total internal renewable water resources		1030.600 (=a+b)			-	150.000 (=c)	=	**880.600** (d=a+b-c)	

EXTERNAL RENEWABLE WATER RESOURCES

		Natural	Actual				Notes
Surface water							
Surface water entering the country (SW_{IN})	e	128.186					(3) Inflows : 20 from India, 68.74 (Yuan Yiang) and 31.29 (Lancang) from China + 8.156 from Thailand
Inflow not sumitted to treaties			128.186	f			
Inflow submitted to treaties							
Inflow secured through treaties			0.000	g			
Accounted inflow		128.186 (h=e)	128.186 (i=f+g)				
Flow in border rivers (SW_{PR})							
Total flow of border rivers		73.630	73.630				Mekong
Accounted flow of border rivers	j	36.815	36.815	k			
Shared lakes (SW_{PL})							
Accounted part of shared lakes	l	0.000	0.000	m			
Surface water leaving the country (SW_{OUT})	n	54.415					(4) Contribution of Myanmar to Mekong, outflow to Laos + half the inflow from China
Outflow not submitted to treaties							
Outflow submitted to treaties							
Flow to be reserved by treaties					(o)		
Surface water: total external (natural)	p=h+l+j	165.001					
Surface water: total external (actual)	q=m+k+f+g		165.001	-	(r=o)	= 165.001 (a1=q-r)	
Groundwater							
Groundwater entering the country (GW_{IN})	s					(a2)	
Groundwater leaving the country (GW_{OUT})	t			u			
Total							
Total external water resources (natural)	v=p+s	165.001			w=v	165.001	
Total external water resources (actual)					x=a1+a2	**165.001**	

TOTAL RENEWABLE WATER RESOURCES (TRWR) — Total

		Natural	Actual	
Surface water : total	y=a+p	1039.601	1039.601	aa=a+a1
Groundwater : total	z=b+s	156.000	156.000	bb=b+a2
Overlap	c	150.000	150.000	c
Water resources: total	wn=y+z-c	**1045.601**	**1045.601**	wa=aa+bb-c
Dependency ratio			**15.78** %	=100*(q+a2)/(q+a2+d)

EXPLOITABLE WATER RESOURCES **(4)**

Regular renewable surface water	bb			
Irregular renewable surface water	cc			
Regular renewable groundwater	dd			
Exploitable water resources: Total	=bb+cc+dd	-		
Non renewable resources			**on Nb of years**	

Notes
(1) total discharge of Myanmar rivers (1002.8) minus inflow from other countries (128.2)
(2) Overlap between surface and ground water = less than 100% of groundwater recharge; most of the groundwater is drained by the rivers and becomes the low flow of water courses. Some groundwater flows out into the sea.
(3) Inflows : 20 from India, 68.74 (Yuan Yiang) and 31.29 (Lancang) from China + 8.156 from Thailand
(4) No data available on exploitable resources

Source
Renewable water resources data : FAO/AQUASTAT, 1999
Precipitation IPCC (2002)

Calculation of the dependency ratio

In order to compare how different countries depend on external water resources, the dependency ratio is calculated. The dependency ratio of a country is an indicator expressing the part of the water resources originating outside the country (Equations 6 and 7). It does not consider the possible allocation of water to downstream countries (SW_{OUT} in Equation 3).

$$\text{Dependency ratio} = IWR/(IRWR+IWR) \times 100 \text{ percent} \qquad \text{(Equation 6)}$$

$$IWR = SW^1_{IN} + SW^2_{IN} + SW_{PR} + SW_{PL} + GW_{IN} \qquad \text{(Equation 7)}$$

where:

IRWR	=	internal renewable water resources (Equation 1)
IWR	=	total volume of incoming water resources from neighbouring countries
SW^1_{IN}	=	volume of surface water entering the country which is not submitted to treaties
SW^2_{IN}	=	volume of surface water entering the country which is secured through treaties
SW_{PR}	=	accounted flow of border rivers
SW_{PL}	=	accounted part of shared lakes
GW_{IN}	=	groundwater entering the country

This indicator may theoretically vary between 0 and 100 percent. A country with a dependency ratio equal to zero does not receive any water from neighbouring countries. A country with a dependency ratio equal to 100 percent receives all its water from outside without producing any.

Transboundary flows

When examining flows of water between countries, cross-checking of transboundary flows is important. AQUASTAT uses matrices showing exchanges between upstream and downstream countries in order to compare inflow and outflow values and to ensure the overall consistency of the computation of country water resources. Matrices allow for a more detailed representation of the flows between countries and avoid double counting of transboundary (external) flows (they do not consider border rivers), as explained in Box 3. An example of such a matrix is given in Figure 2.

THE POTENTIAL OF MODELS FOR GLOBAL WATER RESOURCES ASSESSMENT

In AQUASTAT, the water resources assessment at country level was mainly based on hydrological information on the main rivers extrapolated to areas where direct measurements were not available. Although all efforts were made to present a standard framework for water resources computation, the methodology used (relying on country information) does not ensure consistency in water resources assessment from one country to another.

In order to overcome this problem and improve the comparability of water information at regional and global levels, AQUASTAT has also been working on the development of global GIS-based data sets and modelling tools. A water balance model has been developed and implemented on Africa (FAO, 2001). Available information on Africa was processed through a continental GIS-based model to provide a comprehensive picture of the different elements of the water balance at continent scale. This approach makes best use of scattered information and enables extrapolation of point data or data available at country level to develop a credible picture of the situation of the continent's water use and its impact on water resources. It has also the advantage of presenting a homogenous methodology for computing the water balance across the continent.

The model used is simple and performed entirely within the GIS environment. It makes the best possible use of available information, be it regional coverage of the main climate elements of the water balance (precipitation and crop water requirements), soil properties, or irrigation. The model consists of two parts. A vertical soil-water balance model, performed monthly for every grid cell (10 km x 10 km), computes the part of precipitation that does not return to the atmosphere through evapotranspiration. This water, termed surplus in the study, is then routed through the landscape in the rivers by the horizontal part of the model. In GIS, this is performed by generating a grid-based hydrological network based on an available digital elevation model.

FIGURE 2

Matrix of transboundary water exchange between the Eastern European countries of the Former Soviet Union in km^3/year

		r	e	c	e	i	v	i	n	g	
	COUNTRIES	**BELARUS**	**MOLDOVA**	**UKRAINE ***	**LATVIA**	**LITHUANIA**	**RUSSIAN FED.**	**POLAND**	**HUNGARY**	**ROUMANIA**	**TOTAL**
e	**BELARUS**			Dnepr 19.300 Pripyat (of 12.700 which 5.8 orig. in Ukraine)	Daugava (W. Dvina) 14.300	Nemunas 6.800 Tributaries 2.500	0.000	Bug (border) 2.5 of which 0.2 orig. in Belarus not counted			
				32.000	14.300	9.300	0.000	0.000			**55.600**
m	**MOLDOVA**			Dnestr (of which 9.2 orig. in Ukraine) 9.840 Other 0.110							
				9.950							**9.950**
i	**UKRAINE**	Pripyat 5.800	Dnestr 9.200 Prut (border) =2.90/2= 1.450				Northern Don 3.900	Bug 1.800 San 0.100	Cisa 6.500	Prut (border) =2.90/2= 1.450	
		5.800	10.650				3.900	1.900	6.500	1.450	**30.200**
	LATVIA	0.000				0.000	Velika 0.670				
t		0.000				0.000	0.670				**0.670**
	LITHUANIA	0.000			Lielupe 2.000 Daugava 0.500 Venta 1.300 W. Coast 0.210		Nemunas 0.840 Pregel 0.010	0.000			
		0.000			4.010		0.850	0.000			**4.860**
t	**RUSSIAN FED.**	Dnepr 7.700 W. Dvina 7.200		Northern Don 1.200 Desna ?	0.000	Nemunas (border) not counted		0.000			
		14.900		1.200	0.000	0.000		0.000			**16.100**
i	**POLAND**	Neman 0.100 Bug (border 2.3/2) not counted		0.000		Nemunas 0.040	Pregel 1.990		x ?		
		0.100		0.000		0.040	1.990				**2.130**
n	**HUNGARY**			0.000							
				0.000						0.000	**0.000**
9	**ROUMANIA**		0.000	Danube (border) (of which 6.5+ 2.9 orig. in Ukr) =126/2= 63.000							
			0.000	63.000					0.000		**63.000**
	T O T A L	**20.800**	**10.650**	**106.150**	**14.300**	**9.340**	**5.890**	**1.900**	**6.500**	**1.450**	

* : Ukraine receiving: from Europe: 106.150 km^3/year. Table water resources: 86.450 km^3/year. Difference: 19.7 = 5.8 (Pripyat) + 9.2 (Dnestre) + (2.9+6.5)/2 (border Prut and Cisa).

Crop water requirements were calculated using the modified Penman-Monteith method (FAO, 1998). They were calculated for each grid cell on a monthly time step and compared with the actual evapotranspiration, ETa(m), resulting from the soil-water balance model. The difference was then multiplied by the cropping intensity to obtain a monthly grid of irrigation water requirements. The model was calibrated as far as possible against measured natural river-flow data.

The modelling exercise showed how it may be necessary to obtain estimates of water resources from models where national data are absent or unreliable. The model is a useful tool for checking the overall results of the study and for pinpointing possible errors. The model was used to cross-check the Africa data sets. Where there were clear inconsistencies, the country water balances were reviewed and modified as necessary. Therefore, the combined use of country-based data and global water-balance modelling can enhance the overall reliability of the results.

ASSESSMENT OF THE RESULTS AND REFLECTIONS

Country information

The option chosen for this study was to rely on country information. This was based on the assumption that no regional information can be more accurate than studies carried out at country level. However, there are a number of difficulties when dealing with national sources:

- In most cases, a critical analysis of the available information is necessary to ensure consistency between the different data collected for a country and a river basin;
- Gathering data from different sources highlights similarities between the different sources, but also contradictions, and errors in data transcription. Such discrepancies could probably be explained by country experts and may be due to different aggregations and accounting methods;
- Very little information exists on water resources in humid Africa;
- In arid and semi-arid climates, abundant literature exists as water plays an important role in economic development. However, access to information on water resources is sometimes restricted for strategic reasons;
- The accuracy and reliability of information vary significantly between regions, countries and types of data. No consistency can be ensured at regional level on the duration and dates of the period of reference.

Natural water resources

Physical natural renewable water resources are essentially expressed in quantity over time, in general mean annual flow, which is equal to the total runoff of the water balance of the area considered. The figure is based on the integration of the results of measurements, extrapolations and/or modelling. This hydrological approach is not perfect: the flow actually measured is not always natural or equivalent to the flow generated, the “upstream” approach (calculating the inflow, often based on calculated effective rainfall) and the “downstream” approach (measuring or estimating the outflow) are not always converging, etc. In order to be able to compare data and regional syntheses, it is important to make an effort to harmonize these different hydrological approaches used and to include metadata on methods used, validity of the results, etc (Margat, 2000). As an example, calculating the natural water resources based on measured or estimated outflow is suitable in humid zones. However it is not a correct method to be used in arid zones where part (or total, in the case of closed basins) of the flow generated is lost by evaporation. Upstream of this evaporation zone it is after all an exploitable resource and the calculations in arid zones should take this into consideration. In such cases, surface water resources should be assessed by measuring the runoff upstream of the major loss areas, where they reach their maximum value.

Statistics on natural renewable water resources face three problems:

- *Time reference:* Providing average annual data as such is not sufficient. The data have to be accompanied by metadata (on reference period, dates, etc.) and by expressions on variability. Especially for “guaranteed” flow data, having a certain frequency of occurrence, details should be given, such as for example “annual flow in a dry year of a tenth frequency” or “flow with an occurrence of 90% of the time”. Thus, an effort to improve and homogenize the inter-annual variability is necessary, especially by better unifying the reference periods used for the calculation of averages and frequency;

- *Spatial reference:* Whatever area is chosen (country, hydrographical basin, region), global statistics can hide a very large spatial variability and should be completed with maps. Country level data may give an idea of the water situation in a country, but they hide the local diversity, particularly in large countries. Contrary to basin data, country level data also require a distinction to be made between internal resources and external resources (in relation to the country boundary). In order to improve water statistics for large countries, they should thus describe internal variations: by basins and/or by regions with contrasting climatic and physiographic conditions;
- *Water quality:* Generally, quantitative water resources statistics implicitly refer to freshwater resources (without however giving a universal definition). Should data on brackish water or saltwater be systematically collected, as done in certain countries, including source? Should a subdivision of water resources be given according to different water quality classes? This is difficult to realize since the water quality concept is linked to standards used, a multitude of criteria and variables, and as such it is not possible to have one global definition. Also, the water quality class may change during its flow.

Surface water and groundwater resources

While this dichotomy is classical in water resources statistics, it expresses two ways of water access and management (which is suitable for water supply and water use statistics for each water use sector) rather than a separation between two independent and additive resources. In reality, groundwater and surface water resources are heavily interdependent at a continental level as well as at country level (Margat, 1998).

The approaches used to separately estimate their values for an entire country are not coherent. Data on runoff of a basin (surface water) and on groundwater recharge (groundwater) neglect the exchanges, in both directions, between aquifers and rivers. In order to avoid the double-counting, the “overlap” concept has been introduced (Equation 1).

While this correction is useful for the estimation of the total water resources of a country, it does not allow for a separate evaluation of the surface water and groundwater resources in such a way that they become additive. This distinction is not necessary for the natural resources as such. However, it becomes important when evaluating exploitable water resources, which takes into consideration the conditions of access to and mobilization of the resources dependent on the water demand. For this, instead of subdividing, in a rather arbitrary manner, the natural resources in surface water resources and groundwater resources, it seems easier and more useful to distinguish:

- permanent and regular surface water and groundwater resources, allowing for simple diversion or collection structures;
- irregular (mainly surface water) resources, the capture of which would need regulating structures.

Exploitable water resources

The concept of “natural resources”, quantified on an exclusively hydrological basis, is without doubt necessary. However, it is not sufficient as such because water resources are a physical-economical concept. Consequently, it is more realistic to quantify “exploitable” or “manageable” water resources, as a function of three criteria:

- technical-economic criteria: affordable cost of development and exploitation;
- environmental criteria: exclusion of water that needs to be conserved for nature;
- geopolitical criteria: sharing of water between countries

Of course, the above criteria may vary as a function of the relative abundance of the natural resource or the demand and as such don’t facilitate a unique evaluation. However, it is desirable to obtain a minimum of consensus between the countries of each large region in the world, making the criteria used for the estimation of their exploitable water resources more explicit, so that it is possible to establish actual water resources statistics that are comparable and respond better to the demands.

The concept of exploitable water resources is in particular applicable to non-renewable resources, such as groundwater stocks of which mining is possible without having an impact on the renewable resources around. Comparative statistics on theses resources should mention the evaluation criteria used and the planned duration of exploitation. Care should be taken not to mix up the evaluation of exploitable stocks with annual production at a given date, which sometimes is added up to renewable resources (confusion between resources and uses).

Green water

In addition to statistics on conventional (natural and actual) water resources, the so-called "blue water", it might be worthwhile to estimate "green water", especially that part which guarantees rainfed agriculture. While these resources can be compared with the blue water they should, however, not be added up. Green water can be considered more or less equal to the actual evapotranspiration of cultivated, non-irrigated land (Box 5).

BOX 5
Blue water and green water

Rainfall may either flow on the surface or underground. It may finally reach the sea or it may return to the atmosphere, evaporated or transpired/consumed by the vegetation (two universal paths of the water cycle). In general, only the first type is considered 'water resources' offered by nature to humans. This is especially the point of view of hydrologists, who measure or assess them, and of developers. They consider evaporation as 'losses' (although they are only lost for runoff). The use of words such as efficient rainfall or useful rainfall is significant in this regard. However, from an ecological point of view, it is excessive to judge such 'water resources' as useless because they maintain soil moisture and nourish natural and cultivated vegetation in rainfed systems.

Both hydrologists and agronomists distinguish two types of water: blue water and green water. They cannot be summed but contribute to the water potentialities of a country:

- Blue water is the source of supply. It is equivalent to the natural water resources (surface water and groundwater runoff).
- Green water is the rainwater directly used and evaporated/transpired by non-irrigated agriculture, pastures and forests.

In theory, green water can be assessed as it corresponds (as a maximum) to the volume of the actual evapotranspiration or to the runoff deficits of each catchment. However, such a global calculation is meaningless for local flows that cannot be aggregated by groups of surface units as can be done for blue water. Comparing the difference between the green water and the theoretical needs of the crops is an average indicator for the irrigation needs.

Secondary and non-conventional sources of water

While actual renewable water resources are known as primary water resources, which means available for first use, secondary resources refers to the return of primary water in the system, thus becoming available again for exploitation. In fact, it is an interaction between resources and utilization in a same area, without increasing the natural resource. Statistics on secondary resources can be useful for the complete comparison between resources and utilization. Box 4 shows the specific case of the assessment of exploitable water resources in Egypt, considering both primary and secondary resources. These secondary water resources can be considered as a type of non-conventional sources of water.

BOX 4
Assessing exploitable water resources in Egypt

This box presents water availability by sources of water and water use in Egypt in the year 2000. The actual primary resource corresponds to the TRWR (58.3 km^3/year). If this estimation alone were to be compared with actual water withdrawal (68.3 km^3/year) it would indicate a heavy overexploitation. However, it is not the case here because return flow and infiltration from agricultural fields (secondary use) represent significant elements in the country's water balance.

Water input	**million m^3/yr**	**Water use**	**million m^3/yr**
Renewable surface water resources	56 000	Agriculture	59 000
Renewable groundwater resources	2 300	Domestic	5 300
Reuse of agricultural drainage water (return flow to rivers)	4 840	Industry	4 000
Reuse of groundwater (seepage from agriculture)	6 127		
Reused treated wastewater	2 971		
Desalinated water	100		
Use of fossil groundwater (non-renewable water)	825		
Total	**73 163**	**Total**	**68 300**
		Navigation + hydropower	4 000

With increasing pressure on natural freshwater in parts of the world, other non-conventional sources of water are growing in importance, which are accounted for separately from natural renewable water resources. They include:

- The production of freshwater by desalination of brackish water or saltwater;
- The reuse of urban or industrial wastewaters (with or without treatment), which increases the overall efficiency of use of water (extracted from primary sources).

In both cases statistical data should make a clear distinction between:

- The potential production (capacity) as a function of the installed equipment at a given date (year);
- The actual production, which needs to be put in the statistics on water supply and water use, also at a given date.

Another type of non-conventional water to consider is the inter-basin water transfer. Examples are the High Lands Water Project in Southern Africa, which transports water through tunnels from Lesotho to the area of Johannesburg in South Africa, or the importation of water in Israel from water importation from Turkey, via tankers or Medusa bags.

Additional reflections

The adaptation of "water statistics" to information needs should be well targeted. Always the question should be asked for whom and for what use (local, national, international) they are intended.

Likewise, it is advisable to regionalize the efforts to improve water statistics as a function of the needs, which are far from uniform in the world.

REFERENCES

FAO. 1995. *Water resources of African countries: a review*. Rome. 35 pp.

FAO. 1997. *Water resources in the Near East region: a review*. Rome. 35 pp.

FAO. 1998. *Crop evapotranspiration – guidelines for computing crop water requirements*. By R.G. Allan, L.S. Pereira, D. Raes & M. Smith. FAO Irrigation and Drainage Paper No. 56. Rome. 299 pp.

FAO. 2001. *Atlas of water resources and irrigation in Africa*. FAO Land and Water Digital Media Series No. 13. Rome.

FAO. 2003. *Review of world water resources by country*. Water Report No. 23. Rome. 110 pp.

FAO/BRGM. 1996. *Les ressources en eau: Manuels & méthodes nº 28*. Par: Jean Margat. Rome. 148 pp.

Margat, Jean. 1998. *Conséquences de l'interdépendance des eaux de surface et eaux souterraines sur l'évaluation des ressources en eau.* UNESCO/PHI International conference: Water: a looming crisis? Paris, June 1998. 5 pp.

Margat, Jean. 1999. *Evaluation des ressources en eau exploitables*. Aide-mémoire dérivé d'une note pour UN/DAES. Août 1999.

Margat, Jean. 2000. *Quelles données hydrologiques pertinentes pour évaluer les ressources en eau des pays méditerranéens ?* Séminaire international: hydrologie des régions méditerranéennes, Montpellier 11-13 octobre 2000. 7 pp.