The «stocks» and «flows» language

UN Statistics Division

6 June 2011

We speak the language of our particular discipline, our specific field of expertise. Inter-disciplinary work is sometimes similar to building the Babel tower.

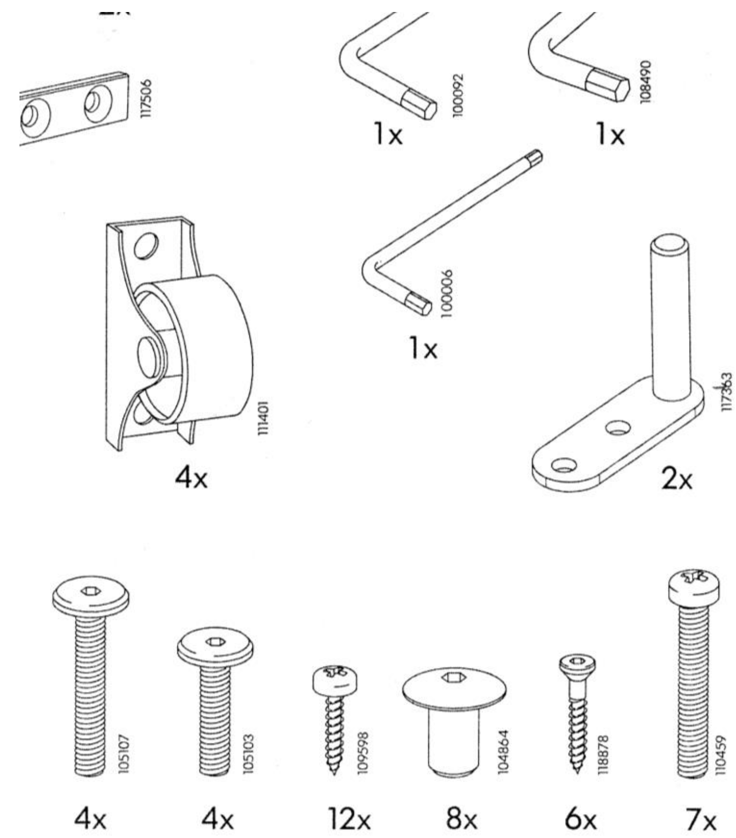
"When I use a word," Humpty Dumpty said, in a rather a scornful tone, "it means just what I choose it to mean—neither more nor less."

"The question is," said Alice, "whether you *can* make words mean so many different things."

"The question is," said Humpty Dumpty, "which is to be master——that's all."

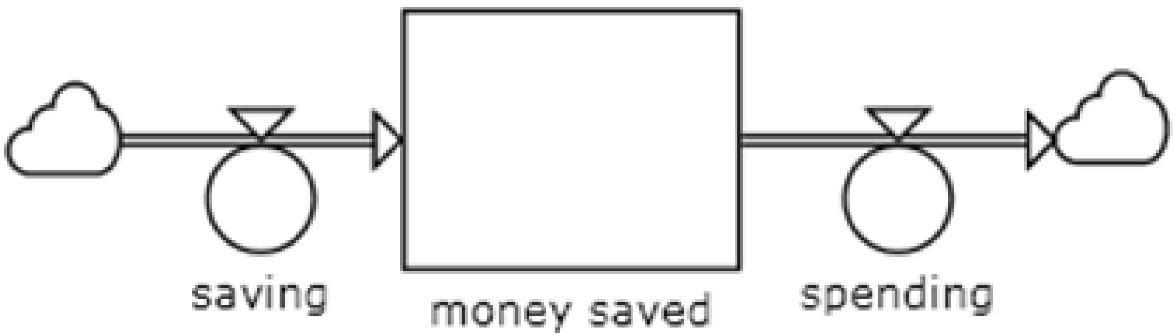
This presentation concentrates on concepts, rather than words. It reviews the basic building blocks of water accounts from a system's perspective.

Esperanto was developed hoping (Mr. Hope) to increase understanding between nations and cultures. Perhaps there is a need for practical approaches that promote common understanding with small training investments.



The solution of environmental problems requires simple intuitive languages that can help build shared visions. Correct coding and standardization is also required.

The language of "stocks" and "flows" is useful to talk about dynamic processes. A sentence has a noun and a verb. The "stocks" are like the nouns and the "flows" are like the verbs. For example: by saving I increase money saved; by spending I decrease money saved.

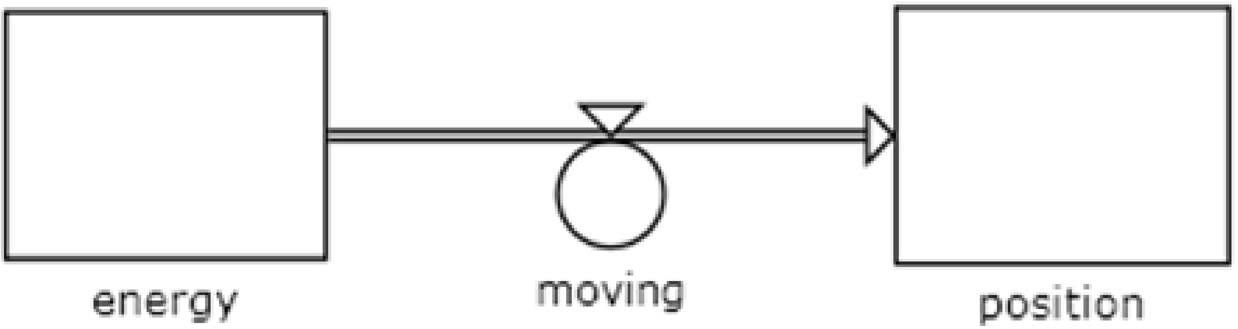


The example above can be expressed as follows in mathematical terms.

$$\frac{\partial Money}{\partial t} = saving(t) - spending(t)$$

With these simple elements it is possible to describe the dynamics of complex systems.

The following example refers to a closed system (there are no clouds). The example tells us that by moving the energy stored is depleted, but at the same time the position is changed.

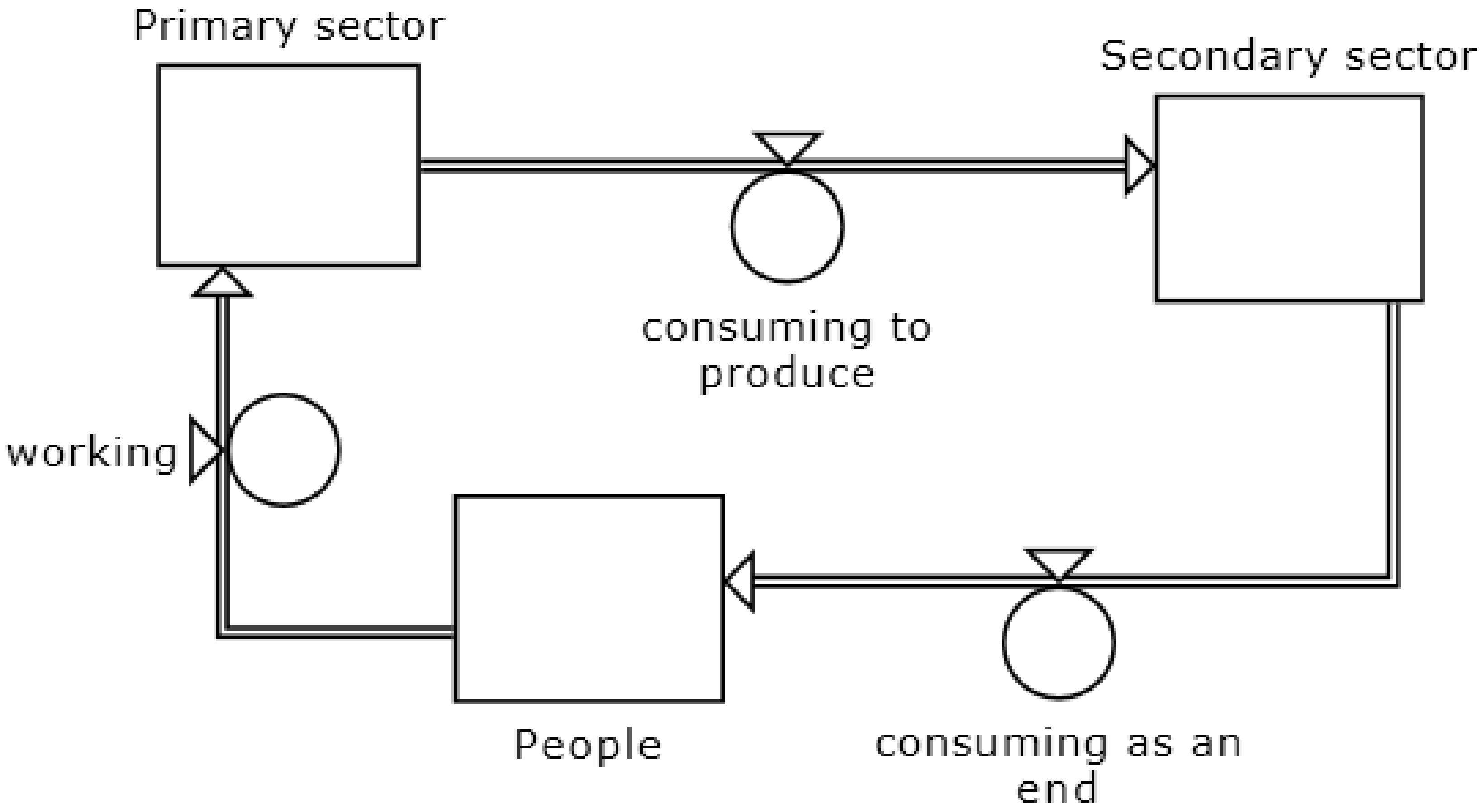


The example above can be expressed as follows in mathematical terms.

$$\frac{\partial Energy}{\partial t} = -moving(t) \qquad \frac{\partial Position}{\partial t} = moving(t)$$

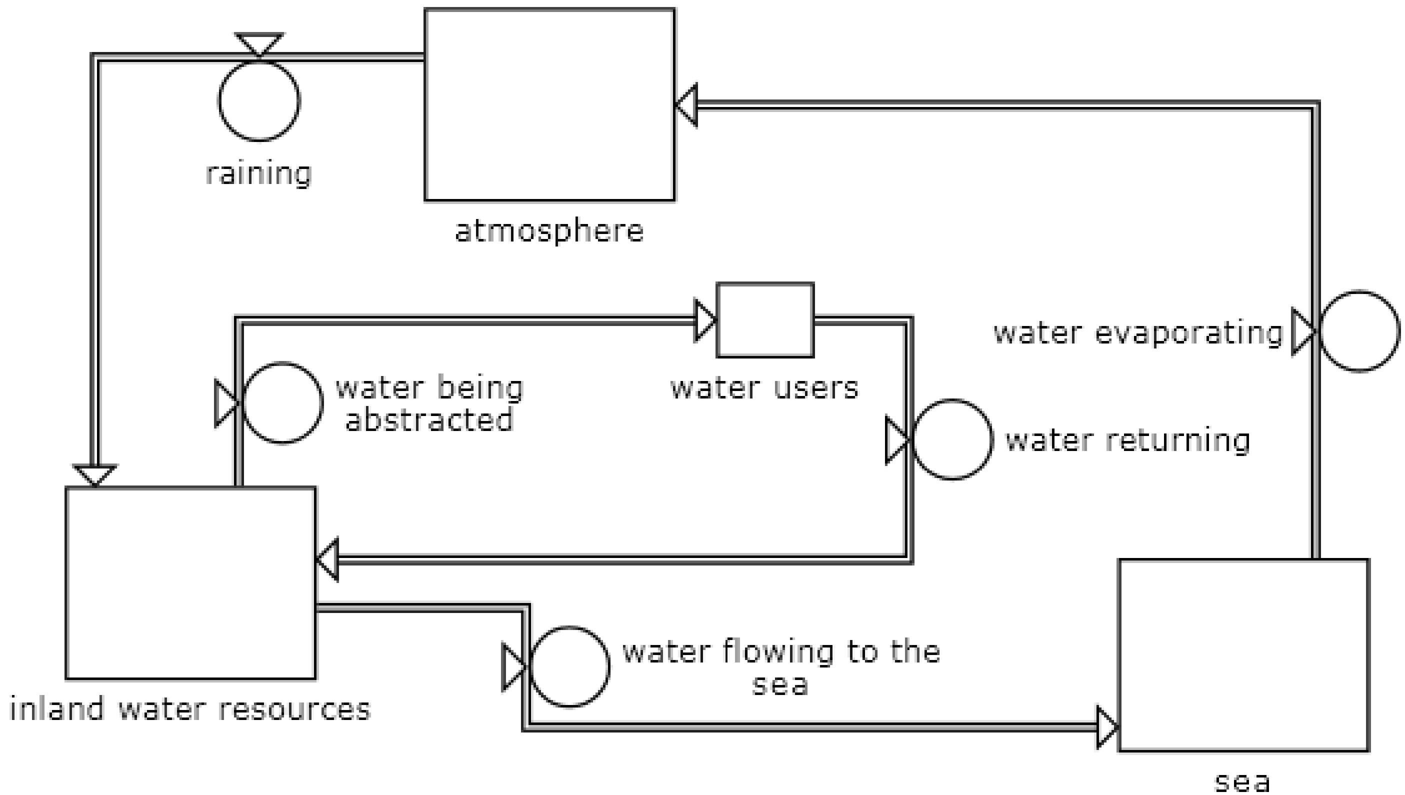
The equations shown above can be solved by integration of the function that describes the movement. Everything has to be expressed in the same measuring units.

In a similar way the transactions in a society can be described. Even though the example is very simple, more detail can be added to communicate useful information for decision making.



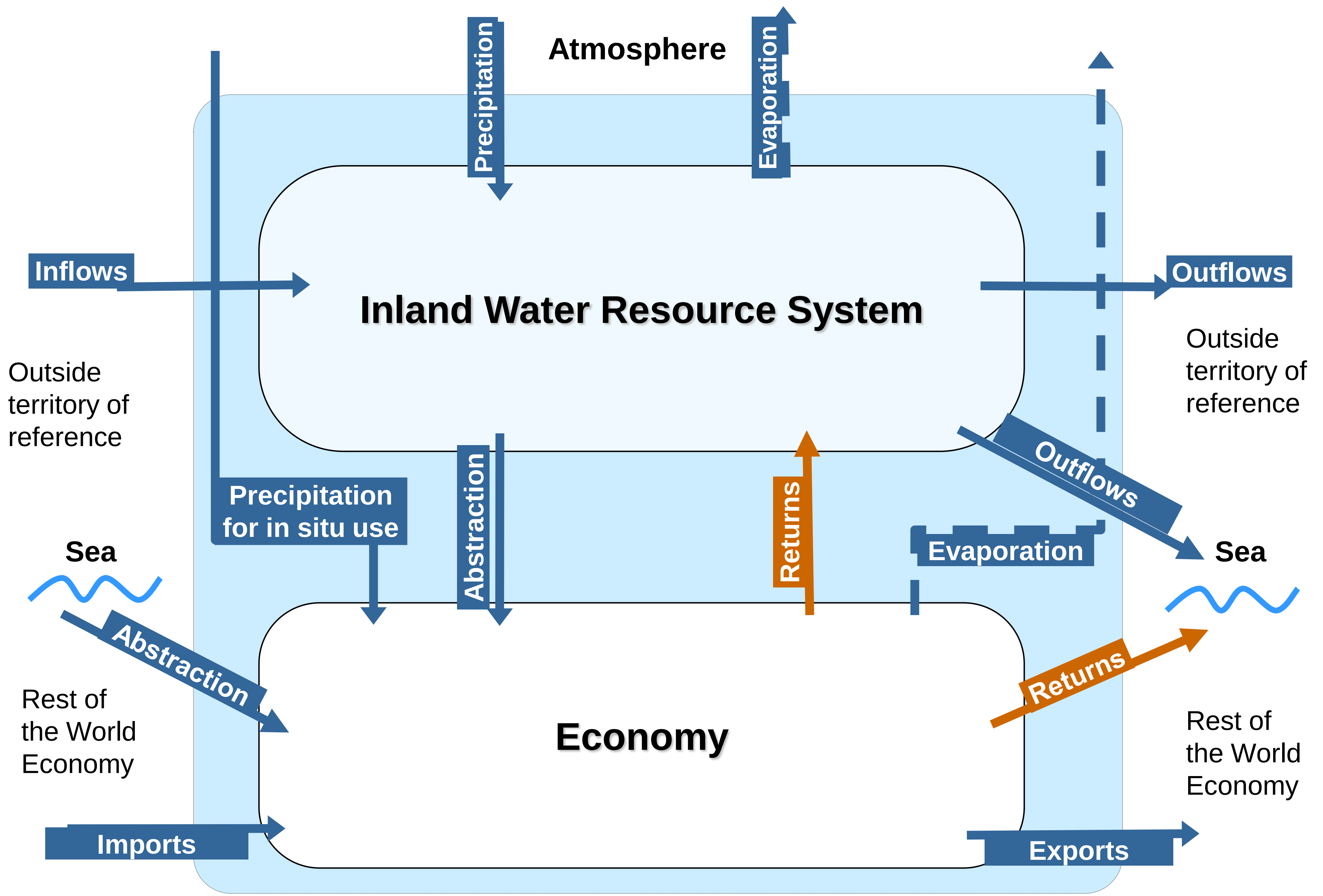
All the flows and stocks have to be expressed in the same measuring units. One way of achieving this is using monetary units calculated with uniform criteria.

In a similar way the water cycle can be described. It is possible to consider that it is a closed system where the law of mass conservation has to hold. For simplicity not all the flows are shown.

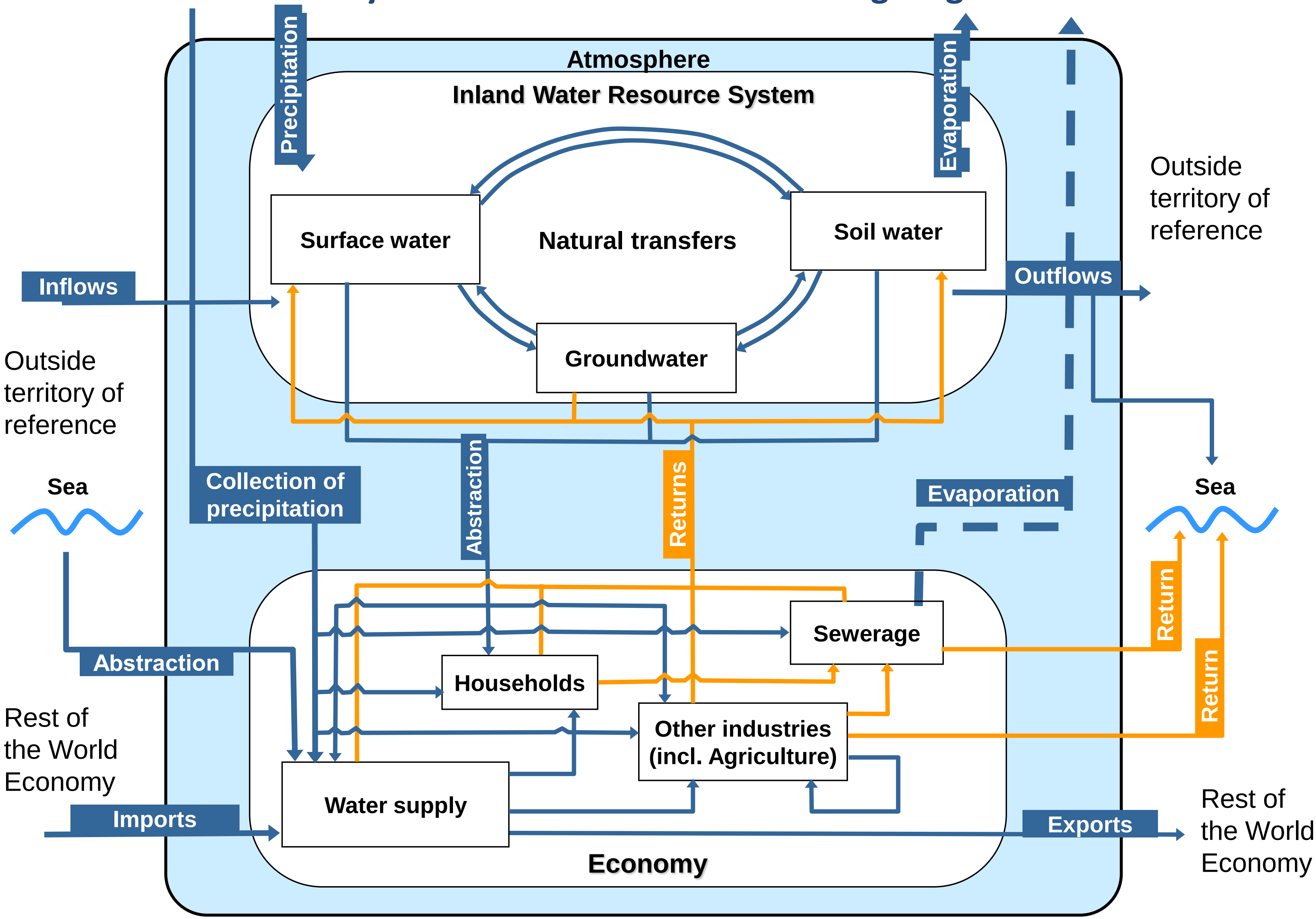


Due to the complexities associated with measuring the atmospheric and oceanic stocks, it is more practical to use an <u>open system</u> model (with clouds showing the boundaries)

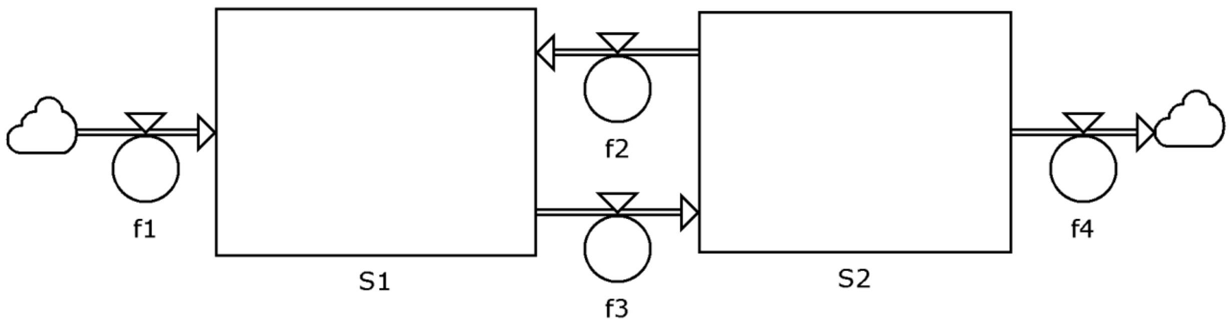
SEEA-Water is based on a stock-flow model comprising two main subsystems: the inland water resource system and the economy.



The details of each subsystem are shown in the following diagram



The following simple example shows how the stock flow models can be transformed into a matrix



The equations can be arranged as a matrix

Therefore, for a time step:

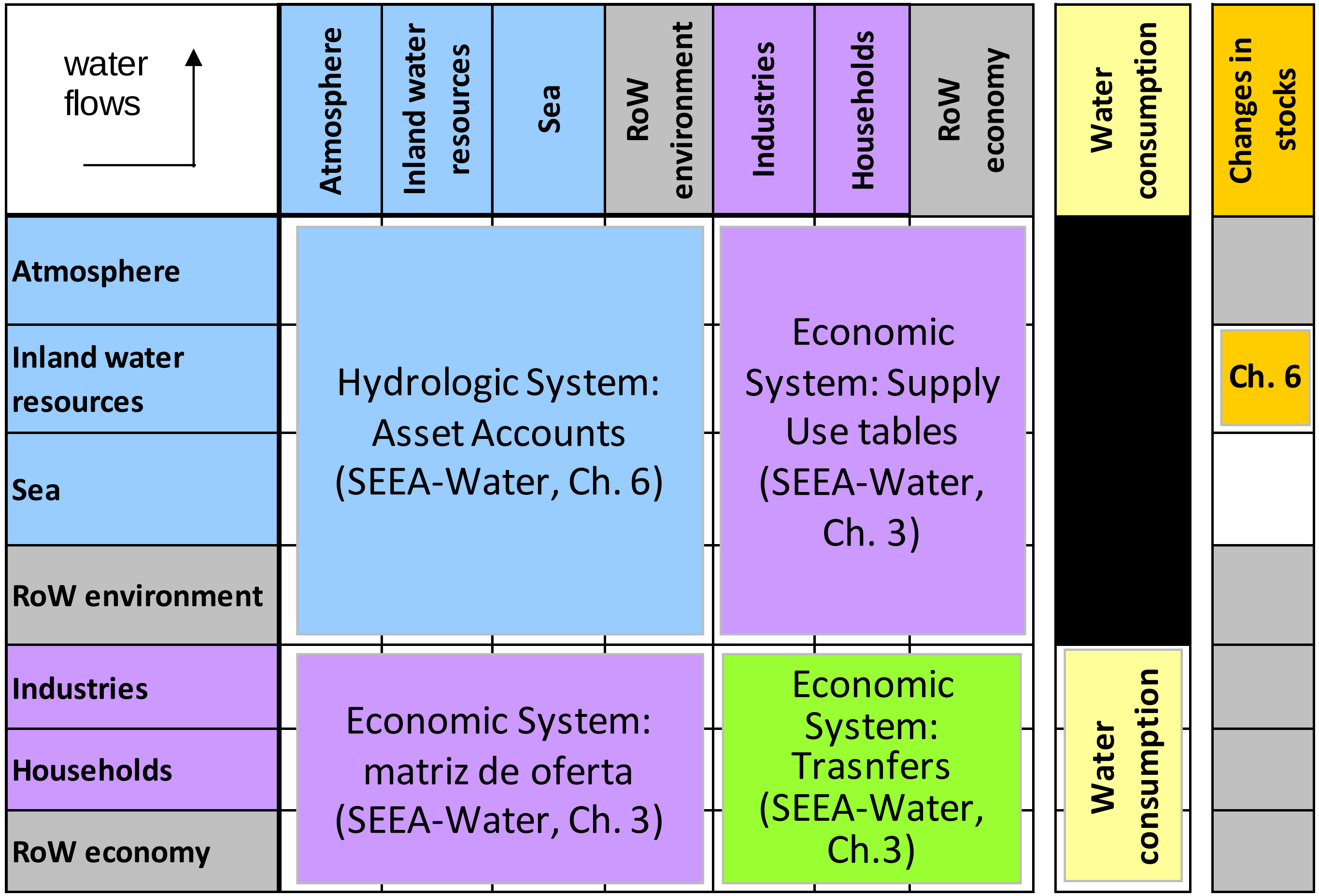
$\Delta S1 = f1+f2-f3$

$\Delta S2 = f3-f2-f4$

	Out	S1	S2	ΣR	ΣC	Δ
Out	0	f1	0	$\Sigma R1$	$\Sigma C1$	
S1	0	0	f3	$\Sigma R2$	$\Sigma C2$	$\Delta S1$
S2	f4	f2	0	$\Sigma R3$	$\Sigma C3$	$\Delta S2$
ΣC	$\Sigma C1$	$\Sigma C2$	$\Sigma C3$			

Diagrams and matrices are equivalent. Diagrams are easier to understand, but become messy with all the details.

The flows described in the diagrams can be transformed into a «hypermatrix», in which the law of conservation of mass has to hold (all rows should be equal to all columns, except when there are changes in the stocks)

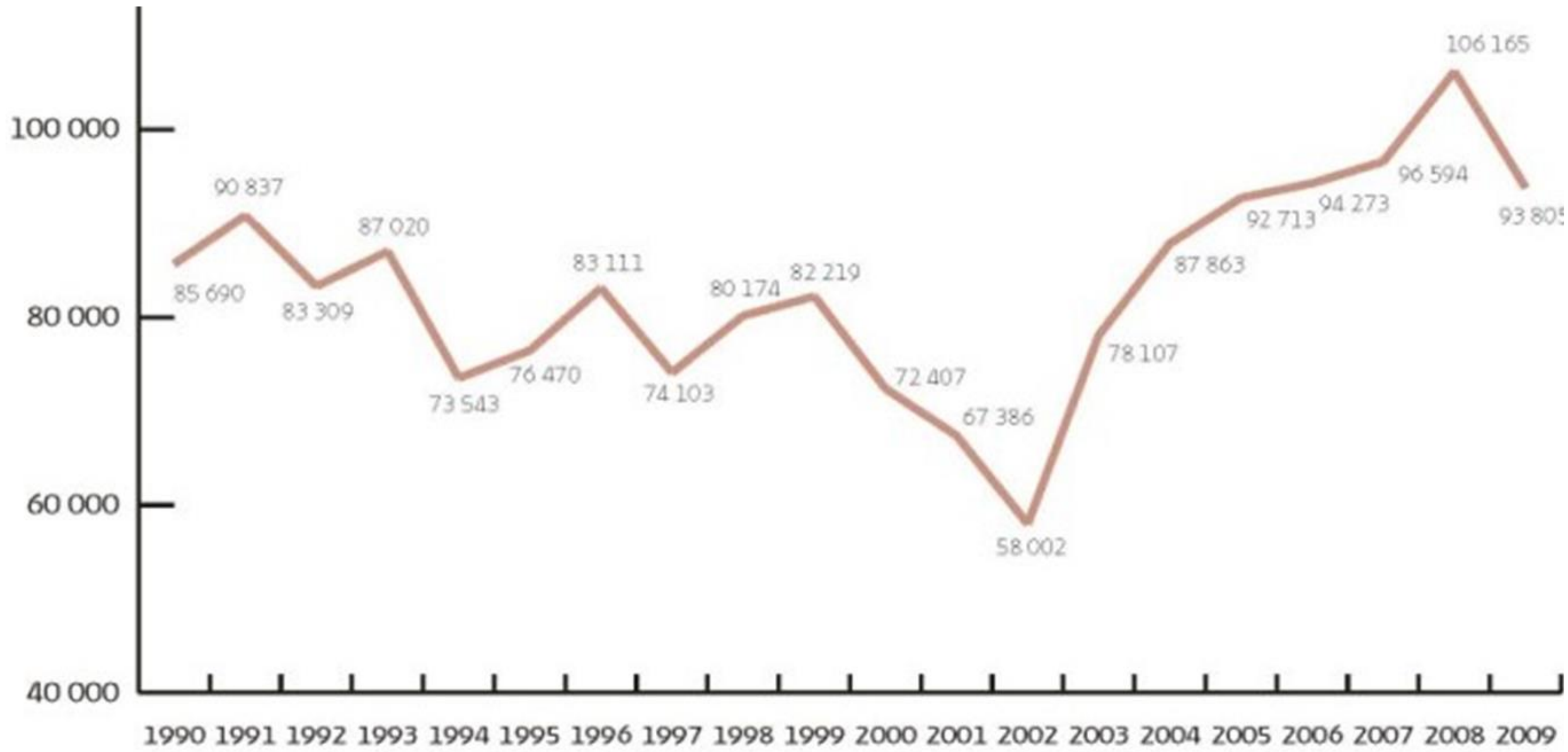


It is relatively simple to compile the standard SEEA-Water tables with the hypermatrix.

Each cell of the hypermatrix describes a specific concept.

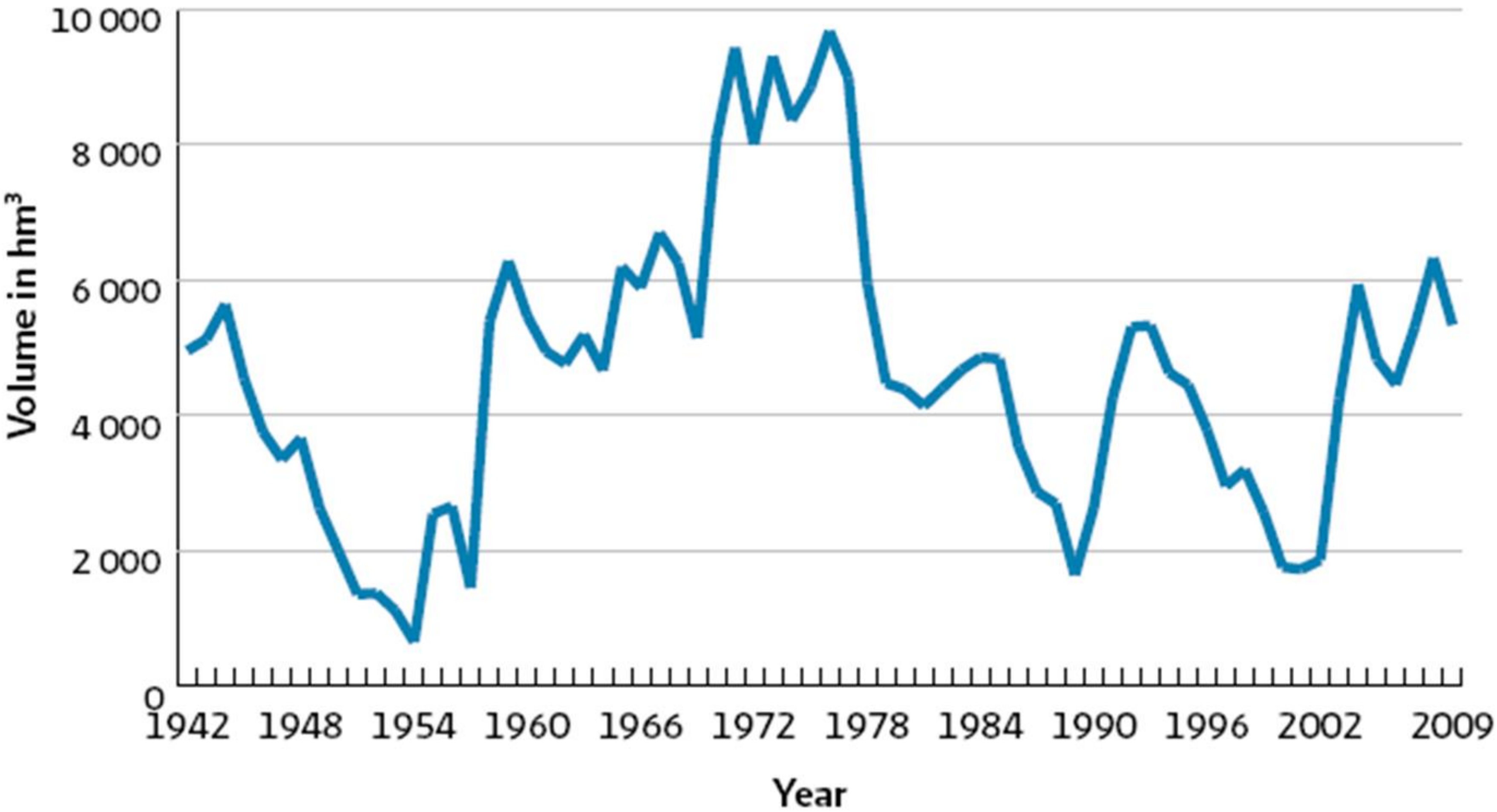
water flows ↑	Atmosphere	Inland water resources	RoW Environment	Industries	Households	RoW Economy	Water Consumption
Atmosphere		Precipitation					
Inland water resources	Evapo-transpiration	Runoff and aquifer recharge	Out-flows	Abstraction or withdrawal			
Rest of the World Environment (RoW)		Inflows					
Industries		Returns		Water supplied from one industry to another	Water supplied to households	Exports	Water consum-ption
Households				Wastewater to sewers			Water consum-ption
Rest of the World Economy (RoW)		Imports					

Example: stocks of water in artificial reservoirs in Mexico, 1990-2009. In millions of cubic meters.



Dry years are recorded in the stock time series.

Example: stocks of water in Chapala lake, Mexico, 1942-2009. In millions of cubic meters.



Longer time series can help in the identification of cycles.

Using the right units to improve understanding. International standards.

USE	DO NOT USE
hm^3 = cubic hectometers = 1 000 000 m^3	Mm^3 remember that the prefix is affected by the exponent. This is a huge unit.
The prefixes milli (m), centi (c), hecto (h), etc are written in lower case.	Gm3 is even a larger unit.
The prefixes mega (M), giga (G), tera (T), etc are written in upper case.	1,000,000. Do not use commas to separate thousands. The comma is confused with the decimal point. Use spaces.
Watts (W), Newtons (N), etc are written in upper case.	
Meter (m) is written in lower case, without a dot.	
Flows are rates, therefore are expressed per unit of time. USD/year, m^3/s, TWh/year	

Thank you!

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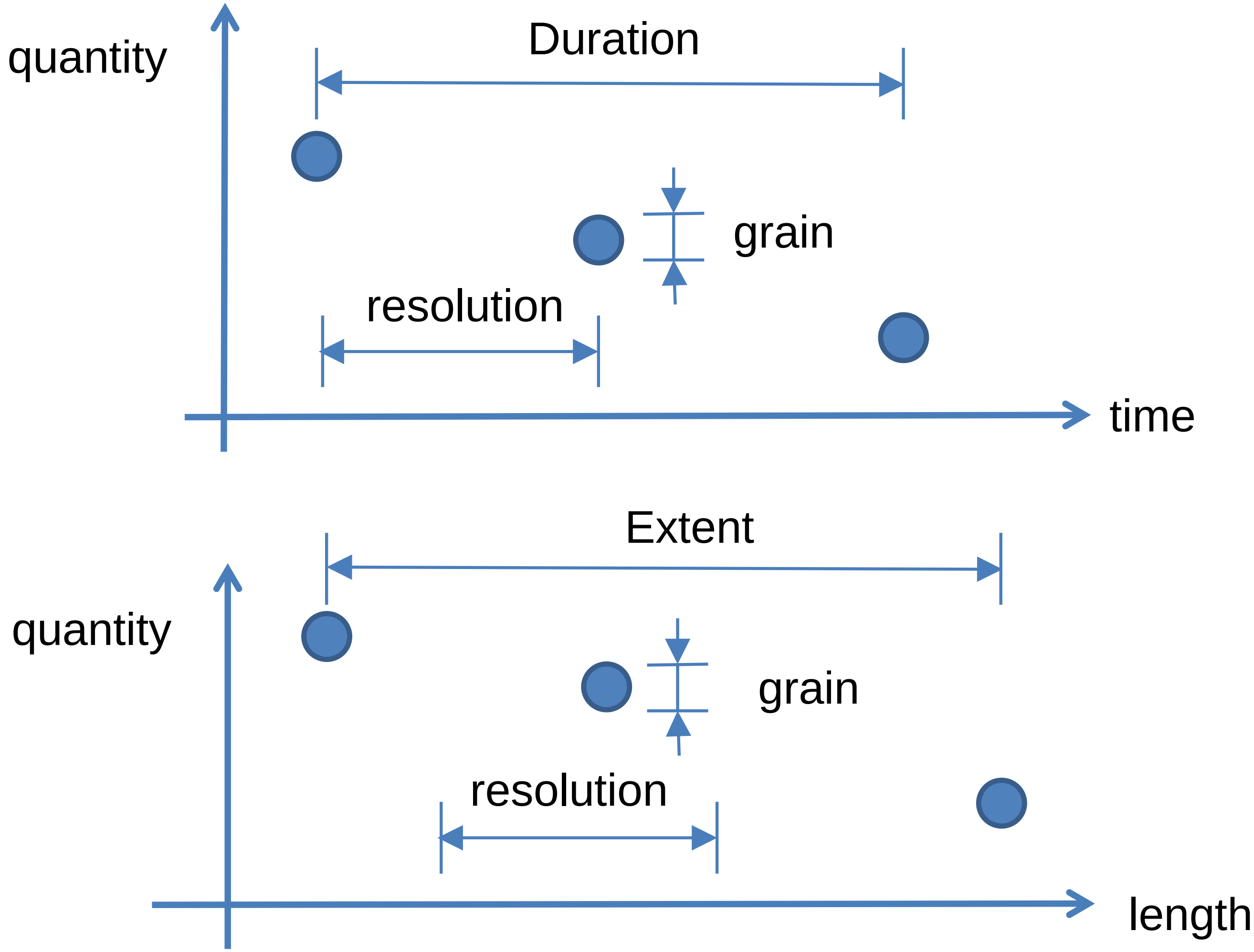
The concept of scale is very important for measuring and interpretation of results..

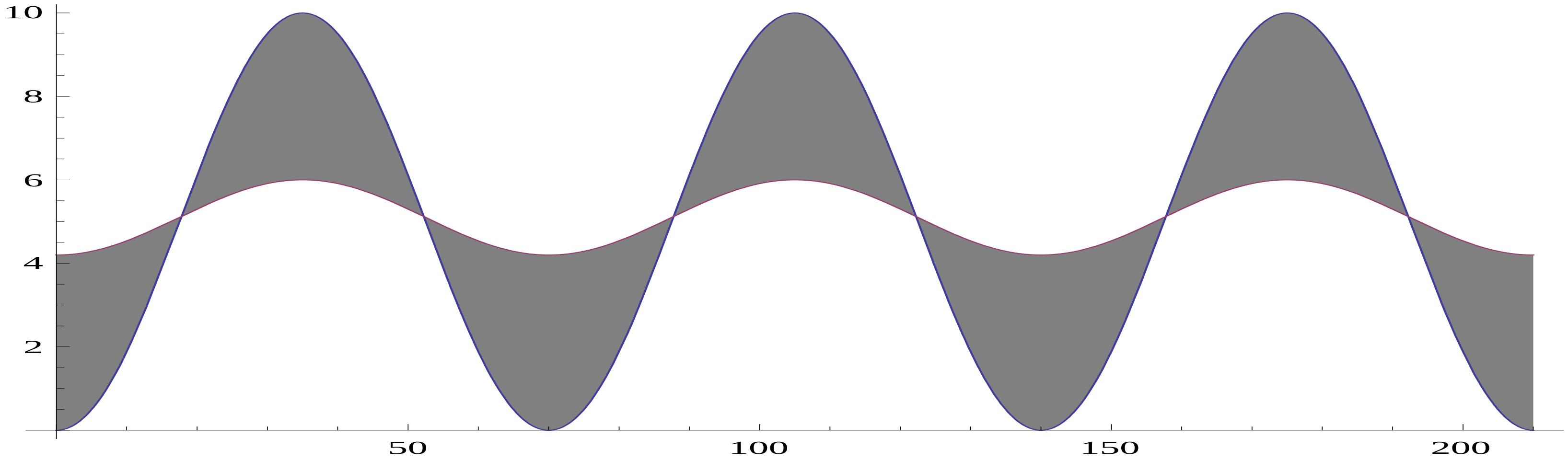
Time scale

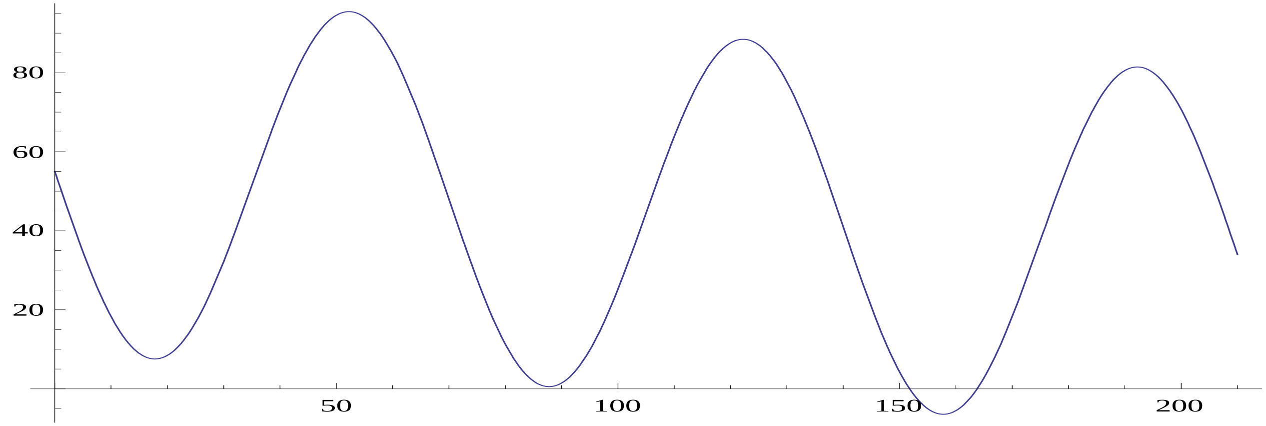
Space scale



The selection of the time and space scales of observation depend on the type of phenomena being studied.

The following example shows a cyclic behavior through time, which is only visible using the right scale of time.





For water management sometimes an annual resolution might be insufficient, requiring monthly measurements. Geographically the resolution at the level of nation might be insufficient, requiring studies at river basin level or even at sub-basin level.

Example of a simple dynamic system. A snapshot shows stocks (states), but not flows (change). It is possible to see the position of the vehicles, but it is impossible to know if they are moving.

A collection of several snapshots can provide information about the changes in the system, so that future situations are predicted.

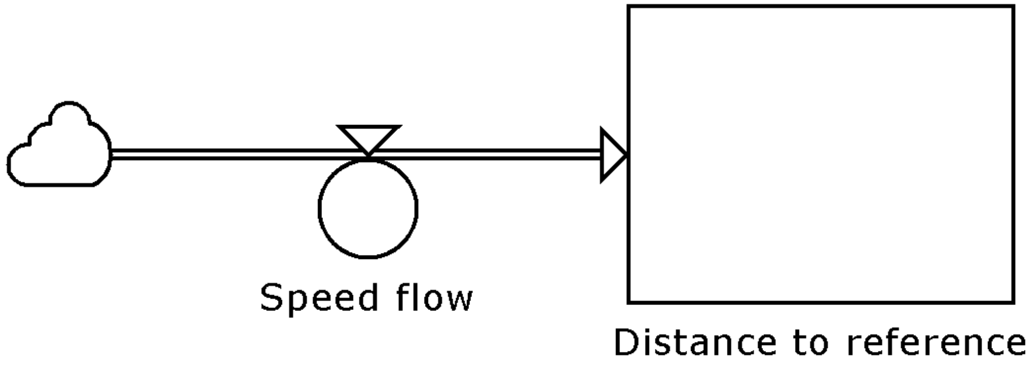
If the shutter speed of the camera is lower than the speed of the cars, then movement is "captured". The following picture is actually an overlapping of several images.

Shutter speed is analogous to time step in system dynamics. Depending on the time step different dynamics are captured (or not captured).

Sometimes change is imperceptible in "short" time periods. The mountain in the picture is also moving (it's changing), except that the movement happens in geologic times.

Depending on the problem, time steps can be of one hour, one day, one month, one year, or even several years. Statisticians have to take «pictures» that capture the <u>relevant</u> elements for present and future <u>users</u>.

This simple model can help us to predict the position of one of the cars in one of the previous pictures:

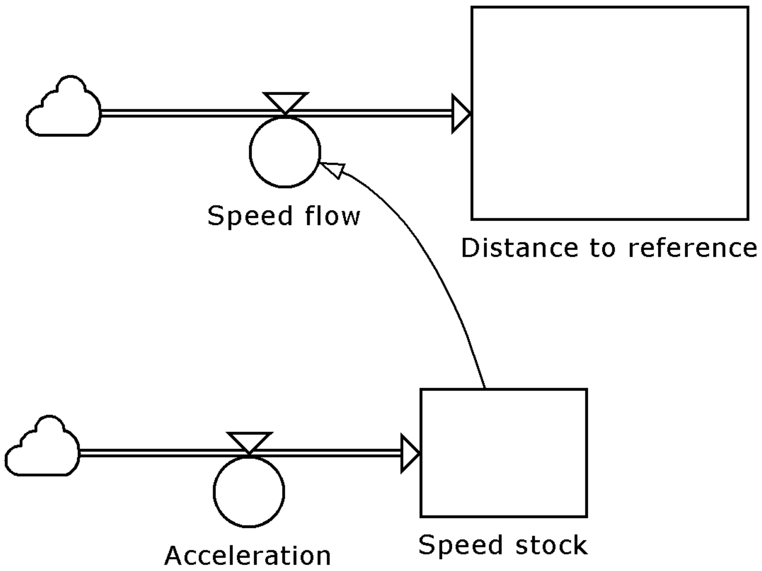


The solution is simply:

$$Dist_t = Dist_0 + \int_0^t (Speed)dt$$

The position of the car is a function of its speed, which is a function of time.

A more complex model can be elaborated. In this case the speed of the car is modeled as accumulated acceleration, which makes Newton's law more explicit; therefore the model might be more useful



The solution is then:

$$Dist_t = Dist_0 + \iint_0^t (Accel)dtdt$$

More complicated models can be built. The solution will be a system of differential equations. Numerical solutions solve for finite time steps.

Water is used in very large quantities. See comparisons (orders of magnitude worldwide):

• Diamonds abstracted in one year	26 tons/year
• Oil produced in one year	5 000 000 000 tons/year
• Maize produced in one year	800 000 000 tons/year
• Water turbinated in hydroelectric plants	20 000 000 000 000 tons/year
• Water abstracted for agriculture	2 500 000 000 000 tons/year
• Water abstracted to supply cities	400 000 000 000 tons/year

Water is much more abundant than other natural resources. Water is bulky and therefore cannot be moved as far as other resources. Water is mainly a local issue.

In the case of water, the concepts of stocks and flows are easily transferred and understood.

The main governing law is the conservation of mass, within the economic and inland water susbsystems. Therefore:

$$Stock\ economy = Init\ Stock\ economy + \int_0^t (net\ inflows\ economy)dt$$

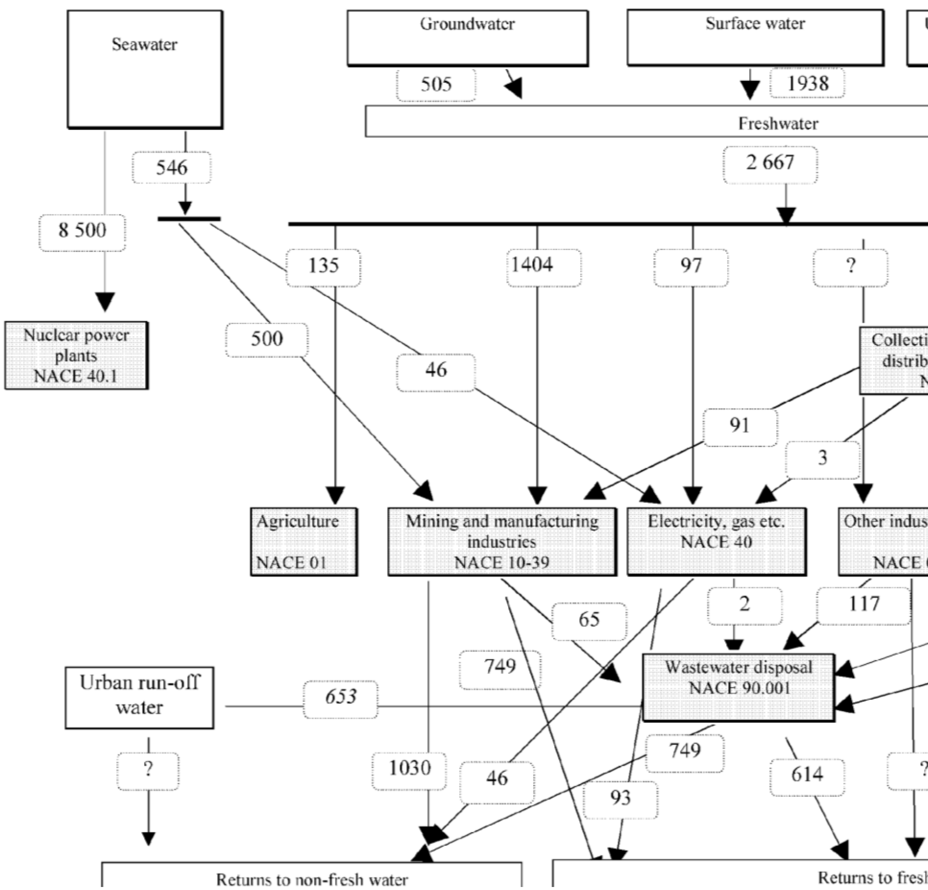
$$Stock\ Inland\ Waters = Init\ Stock\ Inland\ Waters\ + \int_0^t (net\ inflows\ inland\ waters)dt$$

Since water is a bulky commodity stocks in the economic subsystem are negligible, therefore it is assumed that stocks in the economy = 0, initial stock = 0

Based on this laws it is possible to derive a system of equations. NOTE: the conservation of mass includes all liquid flows within the boundaries of the model AND water leaving the boundaries (e.g. evaporation, discharges to the sea, AND “consumption”)

The different specialists can work together assembling stock and flow diagrams. The concepts are easily understood due to the flowing nature of water.

Figure 1 Flow of water in the Swedish technosphere



There are strict rules that have to be followed when assembling a stock flow model. There are specialized software packages to help in the task.

Minimum water-management-relevant breakdown

Economy

#	Industry code	Remarks
1	ISIC 1-3 irrigated	Agriculture. Usually the largest user and consumer.
2	ISIC 1-3 rainfed	Agriculture. Green water.
3	ISIC 36 not for city water supply	Could be associations of irrigators
4	ISIC 36 for city networks	
5	ISIC 37	Sewers. Separate urban runoff
6	ISIC 35 cooling	Cooling sometimes is excluded due to its low consumption
7	ISIC 35 hydroelectricity	A major user, usually considered separate for not being consumptive.
8	Other ISIC	All the industries not listed before
9	Households	

Inland water resources and boundaries

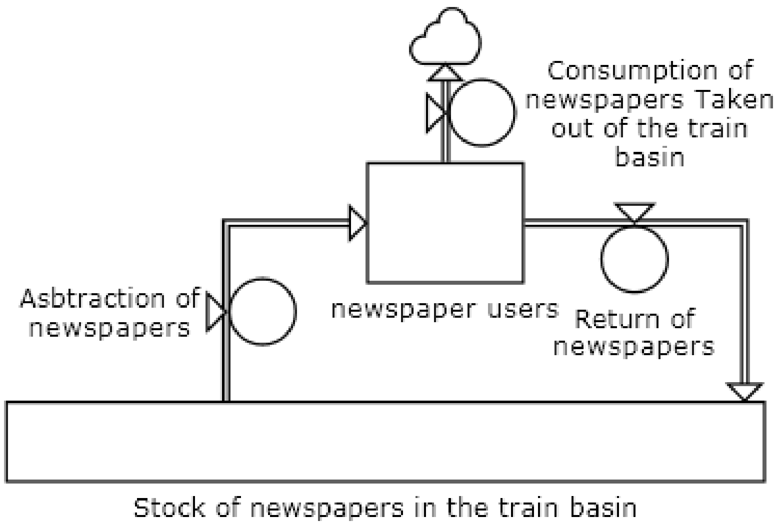
#	Medium	Remarks
1	Atmosphere	Precipitation and evaporation
2	Soil water	Not measured
3	Surface Water	Levels in lakes are constantly measured
4	Ground water	
5	Sea	
6	RoW	Measured when treaties exist

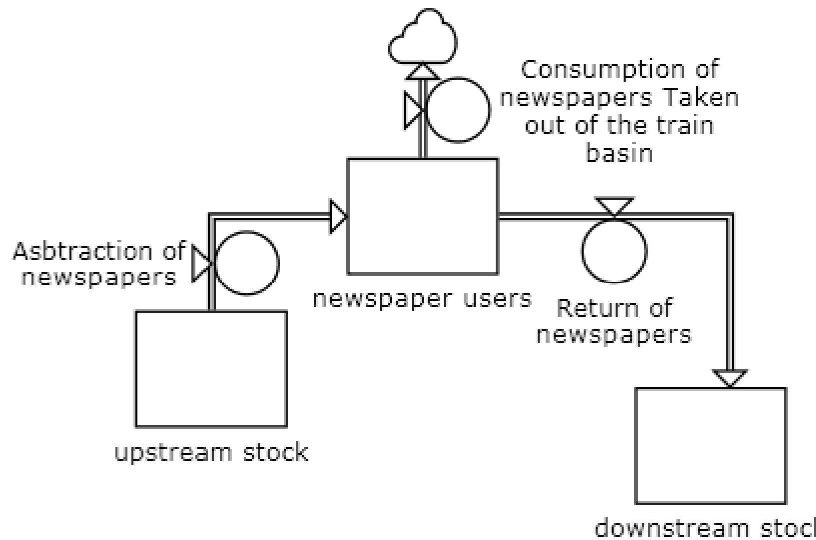
The "hypermatrix" would have (9+6)*(9+6) = 225 cells. Only about 46 data items are highly relevant

Location in space and time determine value. In the <u>same river basin</u> upstream water has a much higher value than downstream water.

Newspapers "Upstream" of the "train" basin

Newspapers "Downstream" of the "train" basin

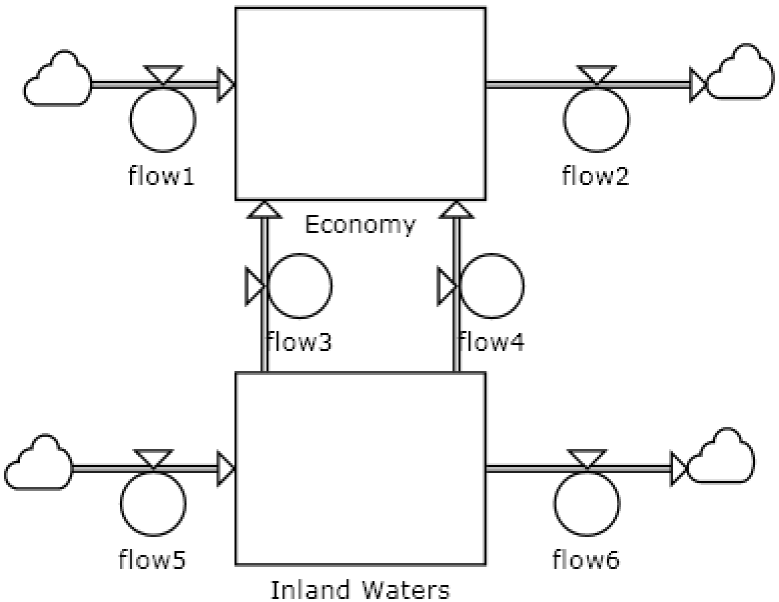




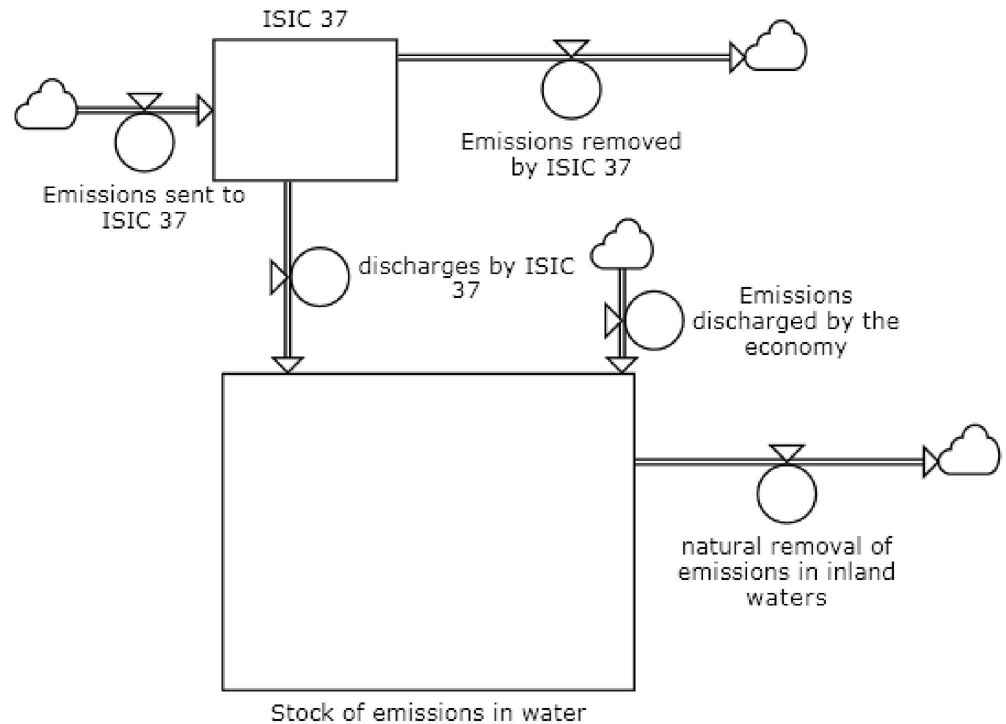
<u>Within a river basin</u> it is important to make a separation between upstream and downstream flows and stocks.

Besides quantitative aspects of water it is important to examine waterborne emissions. In the case of emissions the equations for conservation of mass are not very useful.

Quantitative model



Emissions model



Similar diagrams and matrices can be elaborated for emission accounts. NOTE: stocks in the quantitative model are usually assets. In the emissions model they are liabilities.

Hipermatriz de instituciones

	Atmósfera	Rec Híd	Mar	RoW	Agricultura	Agua y Saneamiento	Manufactura	Energía
Atmósfera								
Recursos Hídricos						SENPLADES	INEC	CELEC EP
Mar								
RoW								
Agricultura								
Agua y Saneamiento								
Manufactura								
Energía eléctrica								

Ejemplos de indicadores publicados por el ente regulador de las empresas de agua potable, alcantarillado y saneamiento en el Reino Unido (Ofwat)

Table 13 Major components of distribution input in England and Wales

	2001-02	2002-03	2003-04	2004-05
Water delivered to:				
Metered households	1,295	1,437	1,608	1,727
Metered non-households	3,712	3,656	3,677	3,609
Unmetered households	7,327	7,206	7,264	6,973
Unmetered non-households	159	169	155	147
Water taken unbilled	206	230	233	242
Total water delivered:	12,699	12,698	12,936	12,698
Of which estimated supply pipe leakage	888	1,000	1,024	1,024
Of which estimated meter under-registration	213	208	215	214
Distribution operational use	100	101	96	96
Distribution losses	2,527	2,606	2,625	2,584
Distribution input:	15,326	15,404	15,658	15,378
Of which total leakage	3,414	3,605	3,649	3,608

Ejemplos de indicadores publicados por el ente regulador de las empresas de agua potable, alcantarillado y saneamiento en el Reino Unido (Ofwat)

Table 15 Company estimates of metered household consumption (l/head/d)[1]

	2001-02	2002-03	2003-04	2004-05
Water and sewerage companies				
Anglian	119	123	127	125
Dŵr Cymru	132	140	122	121
Northumbrian – North East	128	128	146	143
Northumbrian – Essex & Suffolk	141	142	152	152
Severn Trent	134	132	135	133
South West	123	138	142	141
Southern	151	148	149	140
Thames	150	149	154	153
United Utilities	136	128	132	129
Wessex	129	129	135	138
Yorkshire	138	137	138	140
WaSC average	**134**	**135**	**138**	**136**