WATER QUALITY CONSERVATION FOR SUSTAINABLE DEVELOPMENT

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I. Importance of water quality conservation

During the last twenty years public concern about the quality of available freshwater resources has been constantly increasing, due to the fact that ever more cases of serious pollution problems became known. Water - like soil and air - is no longer regarded as a practically inexhaustible resource which can be disposed of without prior consideration.

Although the total volume of water on earth has been estimated to be

1,400 millions cubic kilometers,

the amount of freshwater, easily accessible to human use is much smaller (Table 1). This amount, however, has been regarded as fairly constant, as it is constantly renewed via the hydrologic cycle of precipitation - percolation - evaporation - condensation - precipitation. The main concern of water management used to be the uneven distribution of freshwater over time and space (e.g. flooding and draughts), and therefore hydrologic monitoring was instituted rather early in most parts of the world with a view to planning of regulatory measures and for providing sufficient quantities of freshwater where and when it is needed.

With worldwide increasing population densities also water demand for various uses was constantly rising, and questions of water quantity management were given increasing priority. However, even a glance at table 1 reveals that not only accessibility but also quality determines the availability of water for human use; otherwise the enormous amount of water contained in the oceans would not be excluded because of its salinity.

Table 2 shows the different water uses. It can easily be seen that their requirements in terms of water quality are widely different, the most vital water uses (domestic use and food production) having the most exacting requirements. As table 3 shows, a large part of the world's population still has to live without these basic requirements being satisfactorily met.

Table 1: Global water resources

97.3% saline water (oceans)			
2.7% freshwater of which:	77.2% stored in glaciers and polar ice caps		
	22.4% soil moisture and groundwater of which:	65% below 750 m from the surface	
	0.35% in lakes and swamps		
	0.01% in streams	0.4% of freshwater (0.01% of all water)	
	0.04% in the athmosphere		

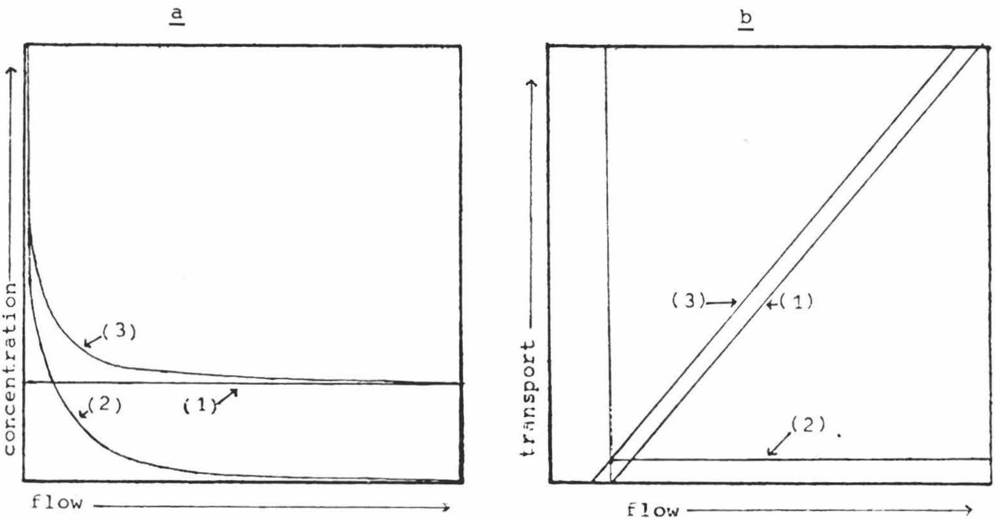
Table 2: Water uses

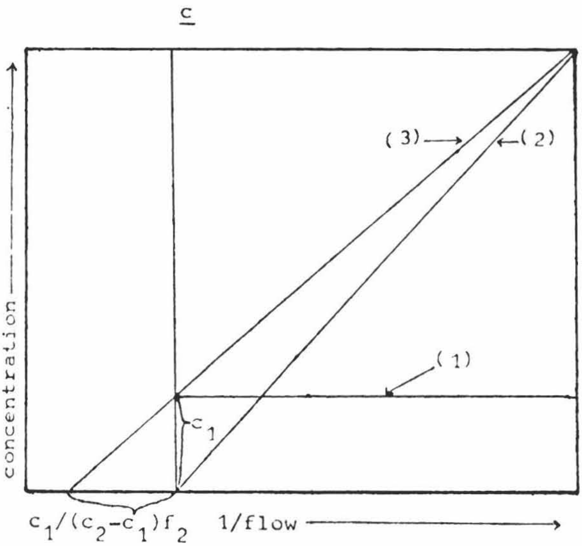
- domestic use
- agricultural use (about 80% of global consumption)
- industrial use
- preservation of fish and wildlife
- recreation and aesthetics
- hydroelectric power generation
- navigation
- waste disposal

Table 3: Access to safe water supply in developing countries (according WHO survey, 1976)

urban population	75%
rural population	20%
overall share of adequately supplied persons	35%

Fig. 2: Model plots, illustrating flow dependence of transport and concentration for sources with different characteristics (a) flow dependence of concentration, (b) flow dependence of transport, (c) linearization of hyperbolic dilution curves





(1) Source of highly variable contribution to flow, but of constant concentration (e.g. surface run-off)
c1 = constant
T1 = C1f1

(2) Source of constant input to the system, diluted by surface run-off. (e.g. groundwater)
T2 = c2f2 = constant
c = T2/(f1+f2)

(3) A constant source (c2f2) diluted by a less concentrated source of highly variable flow (c1f1).
T3 = c2f2 + c1f1
c3 = T3/ (f1+f2)

However, different water uses do not only vary with regard to their qualitative and quantitative requirements but also with regard to the impacts they cause. In fact the relationship between water uses and water conditions may be regarded as a feedback system which only the natural self-purification mechanisms prevent from collapsing, if no regulatory measures such as wastewater treatment and treatment in water supply plants are introduced (Fig.1).

Fig. 1: <u>Relationship between water uses and water conditions</u>

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                 alter water conditions
                 ---------------------->
water uses                                  water conditions
                 <---------------------
                  determine possibility
                      of water uses
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II. <u>Preventive versus reactive conservation strategies</u>

From the foregoing paragraph it becomes evident that water quality conservation is a must not only to provide an adequate living standard to the majority of the world's population but also to allow sustainable agricultural and industrial development. At present this is regarded as a rather trivial statement, however general recognition of this fact is rather recent and based on painful experience. With view to large scale epidemics, decreasing fisheries, contamination of aquatic and agricultural products and salinization of irrigated lands, the necessity of ameliorative measures became urgent, and water quality aspects were given some priority.

Naturally most urgent cases attract most attention and have to be considered first; in other words: we are forced to follow a reactive strategy instead of spending sufficient time and efforts on early problem detection and prevention. Still, most water quality problems are not detected through evaluation of monitoring data but through the negative impacts they cause on water uses, i.e. at a rather late stage in the process of problem development. However, once a problem has reached an acute stage, efficient measures are time consuming and costly, whereas regulatory measures at an early stage of problem development may even represent economic savings.

Of course, those of us who are living in areas already affected by serious problems have little choice of where to focus their interest, but there are still large regions - especially in the developing part of the world - where prevention is viable a option.

In this context one argument has to be mentioned, because it has given rise to rather controversial discussions, namely that in developing countries development itself should be the priority target and should not be hampered by environmental considerations.

It is said that "the highly developed countries have used and exploited their resources to the fullest possible extent and got rich in the process. Although they are now ridden by environmental problems, people there have a high living standard and are not willing to accept a lower one for the sake of environment. It is hypocrisy, if such people advise against rapid resource development by introducing all sorts of enviromental concerns".

It cannot be denied that a purely protectionist attitude which may be termed hypocrisy exists, but in general a sound environmental programme is not opposed to development. Of course, every environmentalist will advise against development plans which drive at the complete exhaustion of the resoruce to be developed, but on a long range such projects neither benefit the economy of a country nor the living standards of its population. Furthermore, in most cases it is possible to device and alternative development scheme which yields sustainable benefits, if environmental considerations are included into development planning.

In fact, the ultimate target of a preventive water quality conservation strategy is to maintain suitable water quality for human uses by preventing excessive pollution, and not to protect water quality by preventing human uses. Thus, it aims at contributing to development and not at hampering it.

III. Point sources and non-point sources of pollution

Effluentes from large human settlements and from industrial plants are obviously pollution sources. Everybody working in the field of environmental water chemistry would not need actual measurementes to risk a fairly qualified guess about river water quality below a point where such effluents are discharged untreated, and - in most cases - would also be able to suggest adequate treatment measures. If a factory is newly installed, decisions on the production process also determine the amount, concentration and composition starts, it would be possible to elaborate a corresponding waste treatment scheme, and - ideally - provide waste treatment from the very beginning. Also, if production and waste treatment are planned and considered simultaneously, it may be possible to match the specific requirements to such a degree that economic benefits instead of additional treatment costs result (e.g. biogas, a product of anaerobic treatment, may be used as an additional energy source; stabilization ponds may eventually be used for aquaculture of water vegetables and fish, etc).

If a factory is already discharging untreated wastes over a period of time, a monitoring station may be needed - not to recognize the problem which is only too evident - but to reinforce water legislation, call for treatment measures and supervise the results.

All these cases have in common that - with our present state of knowledge - it is possible to anticipate problems without conducting long term investigations, and to suggest solutions even though it may not be easy to enforce them. The situation is, however, much more complicated, if we have to deal with non-point source pollution which is the prevailing type of pollution in rural areas. Non-point source pollution reaches a river via surface run-off or via groundwater contribution to river flow. It may be a direct result of human activities, but it may also be a consequence of environmental changes which have been triggered unintentionally. In such a case, the chain - or better the network - of mechanisms which have contributed to water quality deterioration cannot be easily detected, although we may already be confronted with a full blown problem. In other cases the origin of a problem may be evident - e. g. eutrophication through run-off from agricultural lands where too much fertilizer is applied - but ameliorative measures are difficult to design and to reinforce. Wastewater treatment cannot be applied, as there is no definite source of wastewater which could be treated.

In other words: our knowledge about the mechanisms of non-point source pollution as well as our possibilities to anticipate problems and interfere with them are much smaller than in cases of point source pollution. This admittedly difficult situation is discouraging many scientists from tackling the problem.

On the other hand, it is especially in the rural areas where the importance of early problem detection and quality conservation in surface waters is high:

- small scattered settlements or frams cannot easily be supplied with safe freshwater from supply plants, and people often have to rely on untreated surface water for domestic use. (This situation is reflected in table 3), and

- food (vegetables, meat, milk, freshwater fish, etc) is produced in rural areas, and its quality and quantity depends on the quality of available surface water.

Admittedly, in most rural areas, affected only or mainly by non-point source pollution, acute water quality problems are still localized and not widely spread. However, population density (and consequently water demand and pollution) is worlwide on the rise, and for many areas the possibility to chose a preventive instead of a reactive water quality conservation strategy may be lost in the near future.

IV. Attempting a preventive water quality conservation strategy

1. Water quality monitoring

Obviously, in order to detect water quality problems at the earliest possible stage, it is necessary to know the actual water conditions and their changes over time. This knowledge cannot be obtained by random checks, as the data obtained will be influenced by too many unknown factors to lend themselves to conclusive evaluation. Therefore, conducting regular monitoring operations is prerequisite to obtaining a conclusive picture on water conditions. Such operations include:

- a set of sampling stations, chosen to reflect the typical environmental conditions in the drainage area (e.g. geology, topography, land use, population density, development potential and development plans),

- a set of relevant parameters (e.g. conservative ions, indicators for: organic pollution, eutrophication, eventual specific problems) to be measured according to defined analytical methods, in order to render intercomparable results,

- a regular sampling frequency, determined by seasonal changes in rainfall and stream flow (e.g. monthly sampling to cover dry and wet season conditions), and

- a functional infrastructure which allows punctual sampling, rapid transport of samples to the analytical centre(s), facilities for reliable and punctual analysis of incoming samples, and data recording.

As, in general, at least one annual cycle of measurements is needed to cover seasonal changes in temperature and/or stream flow, detection of long term changes and trends requires a monitoring period of (at least) several years. Ideally, such operations should be instituted on a permanent level.

2. Data evaluation within a system context

Even the design of water quality monitoring network (e.g. the selection of representative sampling stations and parameters to be measured) requires inputs from other fields than water chemistry, namely information on surface configuration, soils, agriculture, forestry etc. For the evaluation of collected data such information is even more important. A search for significant trends and changes on a purely statistical basis would require more data than one could reasonably hope to collect within ten years of monthly sampling, and detection of courses and mechanisms of such changes would be almost imposible. Thus, the evaluation process would not be sensitive enough for early problem detection.

Al least one other data set, namely hydrological and/or meteorological data, should be available for evaluation of water quality data. Dilution consequent on rainfall or concentration during a long dry period of mainly evaporation account for many concentration changes, and in many cases a thorough evaluation of the quality/quantity relationship already allows conclusions on how pollutants reach a river. Ideally for every sample taken at a certain station a corresponding flow value should be available; where a hydrologic network already exists, water quality monitoring stations will often be chosen to coincide with hydrologic stations.

Where this is not possible, installation of a gauge and water level recording, or even collection of meteorologic data from the closest available station would give valuable information. In addition, all available information on natural resources, resource uses and eventual problems in the drainage area should be considered as potentially relevant. In short: water quality data should be evalluated in the context of the overall environmental system.

The following example shows a problem which could be detected at a rather early stage, although it was not directly due to human activities but rather to natural conditions in a specific area. It, therefore, arose somewhat unexpectedly and needed a multidisciplinary effort to be fully understood:

The problem may be summarily described as salinization of surface waters and surface soils on a plateau of 100-200 m elevation, characterized by flat to gently rolling plains. Surface configuration and soil properties in this area are suitable for agricultural use, although rainfall distribution is erratic and irrigation water has to be provided even during the rainy season, in order to ensure a good harvest. Thus, irrigation development was considered to be of high priority, and the area became the focus of large scale irrigation development projects, including dam construction and water storage in reservoirs.

In this context, of course, the quality of irrigation water is of high importance, and therefore water quality data were screened with view to this question. It showed that during the dry season the NaCl concentration of river water at some few sampling stations approached the level at which salt becomes toxic to rice plants (1g/L). From the point of view of irrigation planning this did not seem to be an acutely critical situation, as such conditions occurred only at extreme low flow and seemed to be confined to a few places only. However, it attracted attention to salinity questions, and therefore salt concentrations and their flow dependence were examined in more detail. This evaluation showed that in all rivers of the area - even in those where NaCl - concentrations never reached extraordinary values - salt concentrations decreased with flow whereas salt transport increased with flow.

This pattern indicated that salt reached the river in two different ways:

- as salt transport increases with flow, surface run-off which determines the high seasonal variations of stream flow must be carrying salt to the river. This salt can only originate from surface soils in the drainage area.

- as salt concentration decreases with flow, there must be a higly concentrated salt source of more or less constant flow contribution which is diluted by surface run-off.

This was assumed to be seepage of saline groundwater.

On the basis of these assumptions, a mathematical model was formulated which allows to calculate NaCl concentrations as a result of flow and two site specific parameters, to be determined through regression analysis (Fig. 2, Table 4). As can be seen from Fig. 3, the data calculated according to this model corresponded fairly well to the actually measured data.

Concurrently to this evaluation, exercise all available information on salinity in the area was collected and a soil survey and geological survey was conducted. It was known that the whole area is underlain by geological salt deposits, but these had been considered previously to lie at too great a depth to be of influence on surface conditions. Some heavily salt affected, barren patches of surface soil had been regarded as a completely independent phenomenon, due to evaporation of flood water in poorly drained depressions over hundreds of years. Even the existence of saline wells in the area had not been considered of importance, and had never been evaluated in the overall context. Now, considering all available information in a system context, reevaluation of previous assumptions apperared necessary. In fact, the findings from the new soil survey explained satisfactorily the existence of saline soil patches and saline wells, and also validated the results of water quality data evaluation.

To briefly summarize these findings:

- Salt bearing bed rock can be encontered close enough to the surface to be exposed by erosion; in many cases it had been exposed already.

- Water which percolates the salt bearing geological formation becomes saline. The brine may seep out at the footslope of hills but may also travel large distances under ground, if an impermeable clay layer prevents it from rising to the surface. Shallow saline aquifers are frequent in the area. Where the capping clay layer is disrupted or thin enough for capillary rise to reach the surface a saline spot will form.

Thus, it became evident that salinity phenomena which appeared localized and irrelevant to irrigation development, as long as they were regarded separately, are in fact closely interrelated (Fig. 4) and can be interpreted as the first indicators of a potentially serious salinity problem. Careless irrigation development may trigger the problem, as changes in the water balance of the area - especially fluctuations of the shallow groundwater table - have an important influence on salinization.

The problem described above is rather unusual, and thus the results obtained are valid and useful only for the area concerned. Nevertheless, this example seemed suitable to illustrate the advantages of data evaluation in a system context, for the following reasons:

- The problematic compound (NaCl) was not introduced to the water by human activities, it could not even be regarded as a direct consequence of agricultural development. Thus, without considering the specific geology of the area, NaCl concentration could not be expected to be an especially important parameter. It is doubtful whether simple screening of water quality data or even comparison to a comprehensive list of quality standards could have revealed the problem at such an early stage, if evaluation had not been carried out with view to already existing development plans.

- Salinization of soils in connection with irrigation development is not uncommon, but the mechanisms involved are normally of different nature (i.e. evaporation of irrigation water results in salt accumulation in poorly drained fields). Knowledge of these "normal" mechanisms had been drawn upon to explain the existence of saline spots. This preconceived explanation, however, almost prevented detection of the true mechanisms of soil salinization in this specific case. It proved untenable as soon as other system components (geology, hydrogeology, hydrology, water quality) were considered simultaneously with soils.

3. Incorporation of environmental aspects into development planning

Early detection of potential problems and mechanisms of problem development will not lead to water quality conservation, if the knowledge is not used to elaborate a corresponding action plan which - in case of non-point source pollution - includes management measures in the drainage basin. Elaboration of such a plan will be a multidisciplinary effort, as all system components involved in the problem have to be considered simultaneously. If knowledge on potential environmental problems is only obtained and used to assess preconceived develpment projects (for instance in form of an Environmental Impact Assessment, EIA), this will often lead to rejection of development projects and thus strengthen the unproductive dispute "environment versus development".

Following up on the example given earlier, one can imagine that a large scale irrigation project, incluiding dam construction for water storage, a delineated irrigation area and a conveyance system had already been designed in some detail and were only awaiting the results of an obligatory EIA for construction to start. At this stage, the irrigation project would already have received large inputs of work and funds, as detailed topographical and geological surveys have to be conducted from an engineering point of view, irrigation engineers have to design the conveyance system, and eventually even a resettlement study for people living in the future reservoir area is necesary.

Thus, the general expectation would be for the project to go ahead as soon as posible, the EIA being regarded as a bothersome formality. At this stage, the perception that hydrostatic pressure from the huge waterbody in the reservoir might drive the saline groundwater to the surface, and that the irrigation area might become barren instead of productive would be received rather reluctantly. The best possible outcome of such a situation would be avoidance of an environmental disaster by stopping the irrigation project altogether, writing off previous investments.

However, if it is still possible to decide for several small storage tanks instead of a large one, and to incorporate knowledge of potential salinity problems into the siting of these tanks instead of a large one, and to incorporate knowledge of potential salinity problems into the siting of these tanks as well as into the management of the irrigation areas, agricultural development can be achieved on a sustainable basis. At the same time, surface water salinity can be kept at a tolerable level, which - in turn - will benefit irrigation development and all other water uses.

Thus, it seems to be mainly a question of timely co-operation whether accordance or confrontation between environment and development issues will be achieved. For a preventive water quality conservation policy in areas of mainly non-point source pollution such co-operation is indispensable, as non-point source pollution can only be regulated by managemente measures in the drainage basin and not by water treatment.

V. Conclusions

Efforts to maintain suitable water quality in surface waters, generally focus on water bodies which are already endangered by obvious pollution sources. Much less attention is paid to those water sources which appear comparatively unspoilt, as they receive only or mainly non-point source pollution. As detection of non-point source pollution and its mechanisms normally requires long term monitoring activities and careful data evaluation, such programmes are often postponed in favour of more urgent cases.

However, from and economic as well as from a technical point of view, timely prevention of acutely critical situations (i.e. a preventive strategy) is more rewarding than institution of amelioratory measures after a problem has become acute (i.e. a reactive strategy).

Although non-point source pollution poses specific difficulties to early problem detection and regulatory interference, water quality conservation can be achieved, if the strategy is based on multidisciplinary co-operation from the very beginning. This relates also - and especially - to co-operation with development planners and decision makers, as sustainable development relies on maintainance of suitable resources, freshwater being one of the most vital resources.

Table 4: <u>Dependence of salt concentration and salt transport on flow</u> (theoretical deduction)

$$c3 = \frac{c1f1 + c2f2}{(f1 + f2)} \qquad\qquad c3 = \frac{T}{f}$$

$$= \frac{c1(f1+f2) - c1f2 + c2f2}{(f1 + f2)} \qquad\qquad f = f1 + f2$$

$$T = c1f1 + c2f2$$

$$= c1 + f2(c2 - c1)\,\frac{1}{(f1 + f2)}$$

linear regression : $y = c3$; $x = 1/f$

intercept: $c1$

slope: $f2\ (c2 - c1)$

$$T = c3\ (f1 + f2)$$

$$= f2\ (c2 - c1) + c1\ (f1 + f2)$$

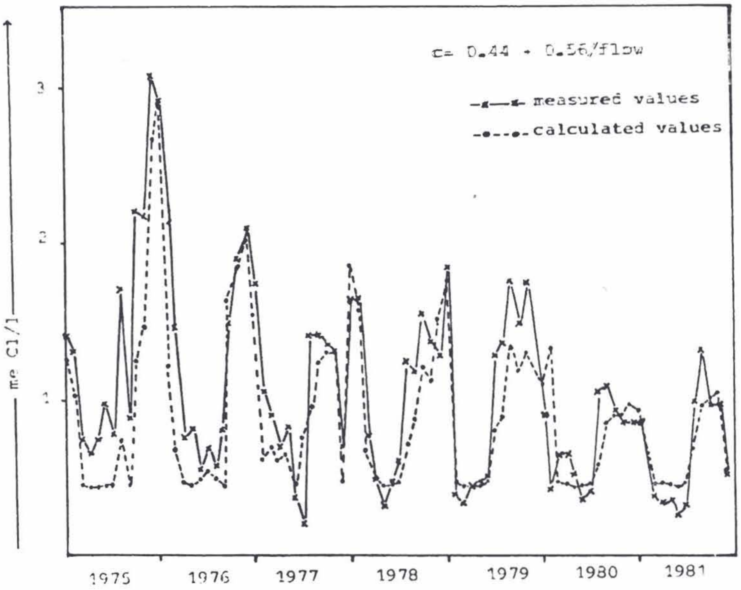
linear regression : $y = T$; $x = f$

intercept: $f2\ (c2 - c1)$

slope: $c1$

c1: concentration of surface run-off ($\doteq$ constant)
c2: concentration of groundwater ($\doteq$ constant)
c3: concentration of river water
f : stream flow
f1: flow contribution of surface runoff
f2: flow contribution of groundwater ($\doteq$ constant)
T : Transport

Fig. 3: Comparison between measured and calculated Cl concentrations for two different river stations



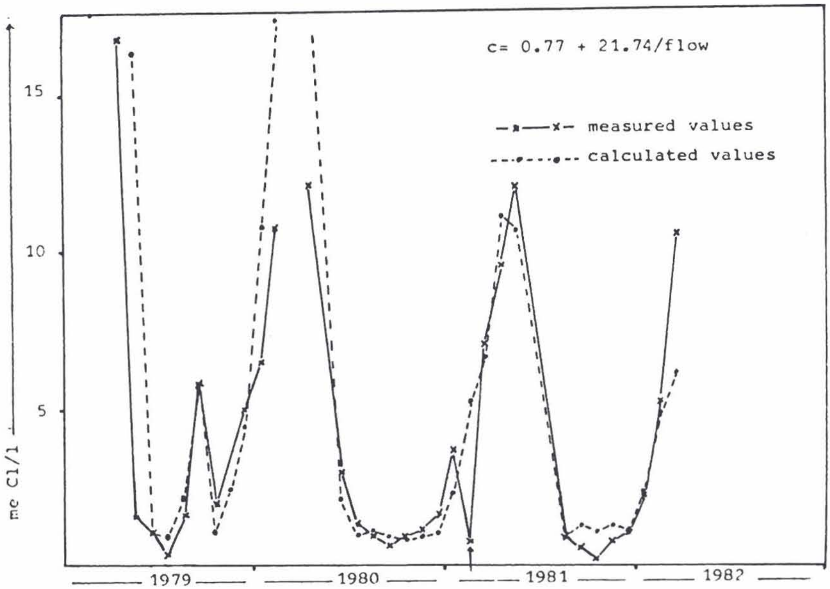


Fig.4: A schematic view of the system components and their interrelationship