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Watershed Management and Rural Sanitation

Examples from different continents, perspectives for Latin America

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Editorial

The existence of water on Earth is vital to the existence of life on Earth. All known forms of life depend on water. But water does not only nourish ecosystems. It powers industry, grows food and makes human life possible. Thus, most human activities depend on the availability of water in appropriate quantity and quality, as well.

Civilization has historically flourished around rivers and major waterways. Such behavior guaranteed the continuous water supply and enabled the people to use rivers as traffic routes, as well. However, since most hydrological systems are characterized by a natural spatiotemporal variability, management of freshwater resources has always been an important task for civilization.

Population growth and industrialization in most parts of the earth have increased the pressure on the water resources in the last century, not only with regard to water quantity but also to water quality. On the one hand, water had to be provided for growing communities – for personal use, for food production and for industrial purposes. On the other hand, increasing amounts of wastewater were polluting the natural freshwater resources such as surface and groundwater. Agricultural areas have been extended, and production systems have been industrialized, often based on the uncontrolled use of agrochemicals.

Thus, due to population growth and excessive use of water resources, in many parts of the earth water is a scarce resource already today, in particular with respect to clean drinking water. Expected future change (e.g., in climate, demography, food production, industrial activities) might even aggravate this situation.

Integrated water resources management (IWRM) is a promising instrument from which many people and organizations believe that it can assist in solving some of these water related problems. Central elements of IWRM are cooperation (people, organizations, sectors), coordination (use of land and water resources, upstream vs. downstream issues), participation (stakeholder, actors), integration (water quality and quantity, surface and subsurface water) and capacity building.

IWRM aims at maximizing economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. Thus, IWRM aims high which is not easily to achieve. But, each part of the puzzle contributes to the whole picture, and each even disciplinary study on water related issues may gain more insight into the water related issues and solutions.

This third volume of the „*Mitteilungen des Forschungsinstituts Wasser und Umwelt*“ covers large parts of the above mentioned water related issues, focusing on Latin America. It consists of contributions to a DAAD expert seminar on the topic of “Rural sanitation and Watershed management”, held at Joao Pessoa in September 2009. The contributions range from drinking water supply to the discussion of the sanitation challenge, from the impact of agriculture to those of mining activities, from irrigation to reservoir operation. From a technical point of view, it covers the analysis of legal aspects, modeling issues and the interpretation of water quality related observations.

Due to a period of transition with respect to the direction of the Chair for Water Management at University Siegen it has taken more time than expected to finish this volume and publish the presentations of the expert seminar. However, we hope that this volume is still useful for the participants of the seminar for their every day work. We thank the authors for their contributions, the DAAD (German Academic Exchange Service) for the financial support enabling the organization of the expert seminar and, last but not least, the local organizers who took care of all practical questions during the seminar. Thanks a lot!

Siegen, June 2012

Prof. Dr. Helge Bormann

Participants from the Expert Seminar “Watershed Management and Rural Sanitation”

Contents

Water protection in the European Union and in Germany using the example of EC Water Framework Directive and the implementation in Germany

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Summary

In the past as well as even today, the status of European waters has been influenced by many anthropogenic activities. On the one hand, the waters have been used intensive for hundreds of years, e.g. for the agriculture for field irrigation, for the fishing industry, as waterways for the transport of goods (on their banks many important port cities arose), for energy generation and as a place of recreation. Rivers and streams absorb treated waste water. For many animals and plants, waters are a survival space that has to be protected. On the other hand, waters can be polluted by different substances from households, the industry, agriculture and runoff from impervious surfaces. As far as possible in Germany, the concentration of pollutants is restrained at the source, e.g. by closed loops or nearly closed loops at the industry, waste water treatment plants on the state of the art, ecological agriculture (it should be noted that also in Germany more explanatory work is required), and rainwater clarifying basins. This serves the purpose of pollutant retention up to partially the ultra trace level. Nevertheless, even in Germany water management has to be aligned, since in the past the primary focus was especially targeted at substance loads as well as on the water balance in terms of water quality. Today it is also necessary to assess the ecological water situation. Therefore, in Europe the protection of waters as a habitat for plants and animals (strengthening the variety of species) and as a drinking water resource is an important topic of environmental policy. The EU member states have committed themselves to reach the natural status of waters as close as possible by a common legislation and thus uniform requirements - the Water Framework Directive (WFD). This means that in Europe not only uniform goals were predetermined, but the WFD also includes deadlines which have to be met in order to reach the goals. Moreover, management plans as well as programs of measures which support the achievement of objectives are coordinated across administrative boundaries between all partners in the river basin district. In doing so, socio-economic consequences as well as environmental impacts of measure recommendations are also examined.

1 Introduction

In the European Union the water policy has been determined by a variety of water-related directives. However, only a few comprehensive connections existed between the directives. In order to protect the waters, it was necessary to develop an integrated water policy in the European Community. The introduction of the Water Framework Directive (Directive 2000/60/EC [1]), which came into force on the 22.12.2000, was the start for a common water pollution control policy in Europe. This signifies a coordinated management of waters within the river basins and across state and national borders; i.e. waters are not considered according to administrative boundaries, but according to so-called river basin districts. That implies a new orientation of the water protection policy as well as the water management in Europe. What makes this directive so special is the consistent implementation of a holistic view of waters; whereas the ecology of the water body is taken into account for the first time in order to assess the water status, in particular the biological parameters (typical animals and plants - the spectrum of species and the abundance). This view also includes an approach related to water body types as well as a combined approach of pollutant analysis (emission and immission) with regard to single substance and group parameters. The fundamental objective is to reach and to maintain a good ecological and chemical status of surface waters as well as a good quantitative and chemical status for the groundwater. For artificial waters and heavily modified waters, at least ecological potentials have to be developed; the aim is to reach a good ecological potential. Nevertheless, waters can only be labelled as heavily modified waters in case that it is proved that the modification can only be reversed under significant restrictions of the water use. The same applies to artificial waters, e.g. ship canals (Ministerium für Umwelt und Naturschutz, Landwirtschaft und Verbraucherschutz, NRW, Dez. 2008 [2]). The management of waters (surface waters and groundwater) which corresponds to WFD's objectives requires comprehensive information about water management-related basic data describing the actual state (course of waters, riverbed, bank structure, passability of the water bodies). This includes knowledge about pollution causes, existing water uses and the possibilities to improve the water status taking into account the existing use. The current deficits of waters which are assessed on the basis of the type-related reference status of waters and the chemical quality standards provide the basis of assessment. In Germany, the reference status was determined for each water body type. The directive coming into force, specific time requirements (deadlines) are associated during which the implementation into national law, the inventory, the monitoring programs, the management plans and the programs of measures have to be completed. Moreover, they determine by when the objective of a good water status has to be achieved. For the first time Europe-wide management plans are drawn up for waters; this includes the communication between actors at the regional level (water management, many direct and indirect water users, measure carriers, interest groups, the population in the river basins, such as the Rhine, Weser, Ems), between federal and state governments in Germany and the partners in Europe. According to the WFD, the measures for protection and the ecological development of waters have to be made as cost-effective as possible which means that reciprocal effects have to be taken into account, e.g. between surface waters and the groundwater or between measures for wastewater treatment and modifications of water body structures or water quality etc. Furthermore, water services should be cost-covering. Here environmental and resource costs have to be taken into consideration. Innovative approaches of the WFD are the transparent explanation of water uses, the intensive dialogue across regional and professional boundaries as well as the active participation of the public etc. (BMU, Gewässerschutz, die Europäische Wasserrahmenrichtlinie und ihre Umsetzung, Juli 2007 [3]; Ministerium für Klimaschutz, Umwelt, Landwirtschaft, Natur- und Verbraucherschutz NRW, Kernsätze der EU-Wasserrahmenrichtlinie [4]).

2 WFD’s objectives

By introducing the WFD in the European Union, a regulatory framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater was established. This framework was introduced in order to avoid and restrict their pollution, to foster their sustainable use, to protect their environment and to improve the condition of the aquatic ecosystems. Moreover, the condition of the terrestrial ecosystems as well as the condition of the wetlands directly depending on them should also be improved regarding their water balance. Further, the WFD was established in order to reduce the impacts of flooding and droughts. Primary aims of the WFD are the stepwise reduction of priority substances, to end the discharge of priority hazardous substances as well as the reduction of the pollution of ground waters (Article 1 WFD, 2000). Water quality should be protected and - if necessary - further improved to assure the population‘s water supply on the one hand, and to maintain or to improve environments for a varied fauna and flora on the other hand.

WFD‘s obligatory environmental aims until 2015 are illustrated in table 1: no deterioration of the surface water and groundwater condition as well as the protection, enhancement and rehabilitation of all water bodies. Reaching the “good status” by 2015, that is to reach a good ecological and chemical status for surface waters as well as a good ecological potential and a good chemical status in heavily modified or artificial waters (e.g. waterways respectively shipping canals) and the good chemical and quantitative status of groundwater. Regarding groundwater it is important to mention that the reversal of significant pollutant concentration is further required (Article 4, WFD, 2000 [1]; EC-Groundwater directive, Dec. 2006 [5]).

Table 1: Primary environmental objectives by 2015 (in exceptional cases by 2027). Source: Ministerium für Umwelt und Naturschutz, Landwirtschaft und Verbraucherschutz, NRW.

Water body		Ecology	Chemistry	Quantity
Natural	Deterioration prohibition; Requirement to achieve objective	Good ecological status	Good chemical status	No fundamental objective
Heavily modified water bodies (HMBW); artificial		Good ecological potential		
Groundwater	Deterioration prohibition	No fundamental objective	Good chemical status Trend reversal	Good quantitative status

The member states of the European Union have the obligation to approach the status of natural waters. Hence, “good status” is defined as a status which slightly differs from a “very good” status. If a body of water is in a very good status, it is predominantly anthropogenic unaffected.

Therefore, it is intended to develop stable cohabitations that are typical for the size of the corresponding water body (stream, river, transitional waters) or for the lake as well as for the respective natural environment. Referring to the varied use of water bodies, the good ecological status cannot be achieved at all points of the water body (e.g. in artificial and heavily modified water bodies), therefore exceptions to the rule are possible. In cases where the good ecological status cannot be restored or cannot be restored by proportionate means, the waters should be developed towards a good status (good ecological potential). At artificial and heavily modified water bodies, a separate designation can take place. The separate designation of heavily modified waters takes place at the end of a careful validation of possibilities for improvement. The requirements regarding the pollution load (chemical quality) remain unaffected by this aspect, i.e. they also pertain for water bodies which are classified as heavily modified (BMU, Gewässerschutz, die Europäische Wasserrahmen-richtlinie und ihre Umsetzung, Juli 2007 [3]). The deterioration prohibition should be comprehended in this way that concerning the ecological status or the ecological potential of the surface water bodies, it should not come to deterioration from a very good status to a good status or from a good status to a moderate status, respectively. Concerning the chemical status of waters (surface waters and groundwater) deterioration from a good into a moderate status should be avoided. The same pertains for the groundwater's quantitative status. From the achieving objectives precept follows that those measures and activities should be avoided which complicate the achievement of objectives or increase the distance to the objective (Wasserhaushaltsgesetz – neu - §§ 27, 30, 47 [6]).

3 Time schedule and work program for the achievement of objectives

The European Water Framework Directive particularly sets an ambitious timetable for the implementation of the specific objective to reach good status for all waters by the year 2015. The achievement of objectives includes several working steps which have to be carried out by the member states within the set time limit. After finishing each working step, a report has to be submitted to the EU commission. Regarding the different working steps, regulations and deadlines are set. Their results have to be presented to the public, and the public has the opportunity to comment on the issue.

In this paper, the most important steps will be explained briefly. An overview of the time schedule can be found in the annex (table A1). The first step was to transpose the WFD in national legislation until December 2003. Due to Germany's federal structure, the transposition into national legislation was coupled at the federal level with the amendment of the Federal Water Act, and at the national level with the amendment of the water laws as well as the ordinances of the 16 Länder. Another important step is the characterization of the river basins (inventory) (LAWA, Arbeitshilfe zur Umsetzung der WRRL, 2003 [7]).

3.1 Inventory (Characterization of the river basins)

Until the end of the year 2004, each member state should take a first inventory of the waters, i.e. characterization of the water bodies' inclusive pressures, impacts and economic analysis. The results of the inventory should be reported to the EU commissions. The surface water's and the groundwater's actual status should be captured by the inventory which provides the basis for further planning. Due to the fact that in Germany biological and chemical-physical investigation of waters, suspended solids, river structure, river sediments and living organisms in waters were started to be recorded in the area of water pollution control before the WFD had been introduced, the inventory could be taken on the basis of already existing data material and of available evaluation systems. Nevertheless, it should be noted that some data and information are missing, in particular with regard to the biological status of the waters, since the WFD is subjected to stricter requirements as this was the case before. As a consequence, complete data sets were not available. The content of the inventory was precisely determined by the WFD:

- *General description of surface waters and groundwaters (length and size of the catchment area, typecast of surface waters),*
- *Delimitation of water bodies,*
- *Determination of reference status for surface waters,*
- *Analysis of the chemical, biological and structural status of waters,*
- *Analysis of the quantitative status of the groundwater,*
- *Analysis of the pollution influence on waters,*
- *Description and review of the impacts which signify pressures for the waters,*
- *Preliminary designation of artificial and heavily modified water bodies,*
- *Economic analysis of water utilization,*
- *Register of protection areas,*
- *First economic analysis for cost recovery verification of water supply services.*

The achievement of the objectives for surface waters was assessed by three classes:

i) *Achievement of objectives probable,*

ii) *Achievement of objectives unclear,*

iii) *Achievement of objectives improbable.*

And for groundwater in two classes:

i) *Achievement of objectives probable,*

ii) *Achievement of objectives improbable.*

The summary report for inventory was submitted to the EU commission by the Federal environment ministry in March 2005. Due to the fact that not all information and the basis of assessment which was claimed according to WFD were available during the inventory, an intensive water monitoring was performed from 2006 to 2008. Moreover, conceptual specifications were worked out as a basis for further steps (Ministerium für Klimaschutz, Umwelt, Landwirtschat, Natur- und Verbraucherschutz, NRW, Bestandsaufnahme 2004 sowie Zeitplan und Arbeitsprogramm [8]; LAWA, Arbeitshilfe zur Umsetzung der WRRL, 2003 [7]).

3.2 Monitoring

One important objective of water monitoring is the identification and quantification of water pollution respectively modifications which accompany the water's wide variety of utilization. Further, water monitoring is needed for the identification of contamination sources, e.g. the discharge of substances from point or diffuse sources. It is important to recognize modifications at an early stage and hence to react adequately within the meaning of the preventive environmental protection, i.e. to ensure environmental protection as far as possible and to professionally justify necessary remediation measures. An emission-related as well as an immission-related monitoring are following because the monitoring of emissions alone is not sufficient for an effective water protection. The impacts of pollutant discharges can only be identified and assessed by a systematic investigation of the water body itself. The monitoring is guaranteed by a combination of continuous measurements, random samples and investigations undertaken in systematic intervals. Explicit objectives of monitoring are:

- *Determining ecological and chemical status of surface water bodies,*
- *Determining chemical and quantitative status of groundwaters,*
- *Establishing a reliable basis for measure planning as well as pursuance of report duties,*
- *Identifying causes in case of loadings,*
- *Success control for the measure program.*

The monitoring programs are mandatory in order to evaluate the surface water’s and groundwater’s status in total. This is a very demanding task and requires a high degree of expertise. On the basis of the correlation of surface waters to the type of water bodies and fish water bodies as well as on the basis of the inventory results, monitoring programs were established for the first monitoring cycle in the period of 2005 until 2008. They were established for waters with a catchment area of > 10 km² as well as for canals, lakes > 50 ha and dams. A distinction is drawn between overview monitoring points, operational monitoring points and investigative monitoring points (see table 2). For instance small water bodies are investigated within the scope of an investigative monitoring, inter alia in that case, if it turns out that they represent significant loadings for larger water bodies in which they are flow in. In Germany normally, measuring programs were generated independent of the fact whether the particular water body is considered to be natural, heavily modified or artificial. Regarding the overview monitoring as well as the operational monitoring, measuring points were defined at representative water sections (WFD, Annex V, 2000 [1], GewBEÜ-V, February 2006 [9]).

On a longer part, such a water section has the physical, chemical, hydrological and hydro-morphological conditions which are typical for the corresponding water body and the relevant quality component; these include e.g. flow velocity, flow behaviour, shadowing, riparian buffer stripes, uses on banks and in the surrounding area, structural conditions, substrate composition (WFD, Annex V, 2000 [1}, GewBEÜ-V, February 2006 [9]).

In North Rhine-Westphalia (NRW), for example, measuring programs are attuned between the state office for nature, environment and consumer protection North Rhine-Westphalia, cooperating institutions as well as the relevant district governments. The measuring programs were coordinated in sub catchment areas. In Germany, criteria for the typecast of water bodies, criteria for the selection of measuring points, investigation and evaluation methods as well as rules for the assessment of the water body’s status are specified in the monitoring guidelines section A to section D (Leitfaden Monitoring Oberflächengewässer, August 2009 [10]).

Table 2: Overview about WFD's types of monitoring. Source: GewBEÜ-V, February 2006, http://www.watersee.net/files/fyrom/4_EU_WFD.pdf.

For surface waters three types of monitoring are required by the WFD:	
Surveillance	to help validate risk assessments and detect long-term trends
Operational	focuses on water bodies which do not meet good status and on the main pressures they face – pollution where this is the main problem, water flow where extraction creates risks.
Investigative	when a further information about surface water bodies is needed that cannot be obtained via operational monitoring, including information on accidents and decide what action is needed
For each surface water body, the Competent Authorities will co-ordinate the assessment of areas as appropriate, including: Biology (plankton/phytobenthos, macrophytes, invertebrates and fish); Hydromorphology; Physico-chemistry (including pollutants); Priority and priority-hazardous substances	
For groundwaters, the monitoring requirements cover:	
Groundwater resources through a water level monitoring network	
Surveillance and operational monitoring of chemical status	
In addition to these main types of monitoring, Member States need to carry out more detailed analysis in areas that are protected for drinking water or for natural habitats and species	

3.2.1 Surveillance monitoring

Surveillance monitoring stations represent a catchment area of 500 – 2.500 km² as well as > 2.500 km². They are determined according to annex 5 of the WFD as well as to annex 6 of the GewBEÜ-V. Surveillance monitoring stations are important for the balancing of pollutant loads as well as for the recognition of long-term trends. They should provide consistent and comparable conclusions regarding the water status. Moreover, they serve to check and complete the inventory results and they are an instrument for the control of supraregional, river basin wide measures. A distinction is made between monitoring stations of level A which are elements of the consideration at the river basin level and monitoring stations of level B which are relevant at the level of the sub-basin area or working area, respectively.

The measuring points of level A are located at the main water system of the river basin districts; the measurement results are, inter alia, relevant for the A-report. The measuring programs at the measuring stations are coordinated at the river basin level. Measuring stations which are located at the national borders are – if possible - examined together with the neighbor concerned. As far as possible and necessary, the measuring points at the A-level are equipped with fixed measuring stations and automatic composite sample collectors in order to identify chemical components which are relevant for the monitoring as well as general chemico-physical components in addition. Samples have to be taken where no automatic measuring station is available. Moreover, the biological quality components are determined over the length of waters. Apart from this, a precise determination of the discharge quantity by means of gauges has to be ensured (Leitfaden Monitoring Oberflächengewässer, August 2009 [10]).

The measuring points at the B-level serve for condensing information about the water status in the sub-basin areas (working areas). They were established in order to further differentiate the loads and their sources. For some parameters a trend observation is carried out or ensured, respectively, by a routine and permanent measuring frequency. For other parameters a valid load estimate is made. On the B-level the establishment of fixed measuring stations is renounced. Water sampling and freight investigation ensued by spot tests, for biological quality components sections of measurements are defined. Both are based on technical and practical considerations. The measuring ranges for the investigated biocenosis should give a representative image of the ecological status. Together with the chemical results, they should be used for mutual interpretation (Leitfaden Monitoring Oberflächengewässer, August 2009 [10]).

Altogether, the concept of surveillance monitoring is a flexible and integrated monitoring approach, that is, *Länder*-specific, national and international measuring programs are considered together in order to gain a coherent and comprehensive overview of the waters situation. It contains a staged approach in order to gain knowledge. Surveillance monitoring is completed by aggregated information from the operational monitoring or by screening studies at the large stations of alarm monitoring for example. The measuring frequencies is shown in table A2 on surveillance monitoring in the annex, the mentioned measuring frequencies represent a minimum requirement.

3.2.2 Operational monitoring

The operational measuring points of flowing waters are arranged in such a way that they represent and reliably illustrate the status of a water body or a group of water bodies This applies to flowing waters with a catchment area of > 10 km² and lakes with areas of > 50 ha, respectively. Operational monitoring includes artificial and heavily modified waters as well as waters in protected areas, with additional requirements regarding the monitoring to some extent. Operational monitoring provides the fundamental basis for the status classification of the water bodies compared to the "good status" and compared to a less stringent management objective, respectively, or to the "good ecological potential". In order to be able to address different questions in an efficient and technically correct way, the operational monitoring stations are load-oriented and therefore arranged in a flexible manner of time and space. Hence, for the examination of individual quality components, different monitoring points and regions under investigation, respectively, have to be selected within a water body depending on suitability. The determination of representative monitoring stations always has to take into account the local conditions. The operational monitoring is reduced to the investigation of quality components which are indicative for existing loads, loads that have to be examined or deficits in the water bodies. In the case that a load is clearly indicated by different parameters and/or quality components, the parameter or the quality component, respectively, which characterizes the status of water bodies best and most significant is investigated, i.e. the parameter or the quality component which reacts most sensitive to changes of the respective load situation. Aspects which are related to the particular case always have to be taken into consideration like the overlapping of different water body related loads or aspects. Further, attention has to be paid to the fact that substance loads have another spatial impact as structural deficits. Therefore it may be necessary to identify loads at different measuring points with different measuring frequencies in different seasons. The operational monitoring is supplemented by modeling, expert conclusions and detailed information from the investigative monitoring, in particular in case of overlapping loads. Regarding the establishment of monitoring programs all load types have to be principally considered and have to be checked with respect to possible impacts (Leitfaden Monitoring Oberflächengewässer, August 2009 [10]). The measuring frequencies and investigation periods are shown in table A3 on the operational monitoring in the annex. The mentioned measuring frequencies represent a minimum requirement.

The monitoring is principally carried out at water bodies or at groups of water bodies for which the inventory has shown "achievement of objectives improbable" or “achievement of objectives unclear”, the chemical status was classified as “not good” or for which further defined management objectives are not reached. One element of success control is the continuous updating of the status assessment which ensures the compliance of the deterioration prohibition and the precept of achieving objectives for example. The first monitoring cycle had to be finished by the middle of 2008 and the data and knowledge deficits in the inventory had to be completed (Bewirtschaftungsplan für die nordrhein-westfälischen Anteile von Rhein, Weser, Ems und Maas 2010 - 2015, September 2009 [11]).

3.2.3 Investigative monitoring with the example of NRW

The investigative monitoring is planned for the monitoring of waters < 10 km², inter alia, if this is required in the exercise of the management responsibility after dutiful consideration of the water authorities as well as within the scope of other water management execution. Moreover, the investigative monitoring is used for the creation of profiles of bathing waters according to the bathing water directive (directive 2006/7/EG) as well as for priority programs with the aim of expert statement which can be transferred to the whole region of NRW. The investigative monitoring also serves for the monitoring or cause study, respectively, according to the GewBEÜ-V and the water quality ordinance (GewQV). Investigations of flowing waters which are carried out for the purpose of cause and consequence clarification in relation with environmental alarm events according to the environmental alarm directive (Sep. 2008), are ascertained with the investigative monitoring → alarm monitoring (Bewirtschaftungsplan für die nordrhein-westfälischen Anteile von Rhein, Weser, Ems und Maas 2010 - 2015, September 2009 [11], Verordnung über Qualitätsziele für bestimmte gefährliche Stoffe und zur Verringerung der Gewässerverschmutzung durch Programme (Gewässerqualitätsverordnung – GewQV), Februar 2006 [12], Grundsätze zum Umgang mit Schadens- oder Gefahrenfällen im Bereich des Umweltschutzes „Umweltalarm-Richtlinie“ [13]).

The investigative monitoring is carried out, if environmental quality standards are exceeded and the reasons for this are unknown and the source of loads have to be further determined, respectively. This would be the case if the significance of single contributions cannot be differentiated due to overlapping loads or the loads of the operational monitoring cannot be clarified. The investigative monitoring also serves for the clarification of data deficits or in order to investigate the effect and the impact of accidental pollution. Monitoring for investigative purposes cannot be planned longer-term in advance, since the measurement is always tailored to the concrete issue on a case-by-case basis, i.e. the parameters to be monitored, the frequency of monitoring as well as the monitoring points have to be determined on a case-by-case basis. The investigative monitoring also serves the purpose to examine the requirements which should ensure the waters compatibility concerning the utilization which are placed by the water authorities when the water permits are issued. It should be noted that emissions from diffuse sources also constitute a water use, but contrary to the point sources (waste water treatment plant, hydropower plant, etc.), they do not have reference to facilities (Bewirtschaftungsplan für die nordrhein-westfälischen Anteile von Rhein, Weser, Ems und Maas 2010 - 2015, September 2009 [11]). The monitoring of bathing waters, ship canals, lakes and dams will not be explicitly explained here. The topic of alarm monitoring should be briefly explained in the following.

Alarm monitoring: Within the scope of the real-time water monitoring, relevant organic compounds are measured and evaluated daily. On the Rhine for example, temporary loads that occur wavelike are frequently noticed by continuous measurements. The monitoring ensured both by means of fixed monitoring stations along the Rhine and by laboratory ships (see figure 1). The analysis methods and the sample techniques are continuously improved and adapted. Via the international warning and alarm plan Rhine of the ICPR (International Commission for the Protection of the Rhine) jerky loads that were noticed are immediately after the measurement forwarded to the downstream users. Amongst others, this serves especially for the water companies which can prepare for the pollution and implement adaptation measures. Moreover, messages about pollutant waves that have been noticed are internally forwarded to the relevant district government and to the river police. In the case that the pollutant wave is coming from upstream, the upstream residents are also informed in order to investigate the causes (Grundsätze zum Umgang mit Schadens- oder Gefahrenfällen im Bereich des Umweltschutzes „Umweltalarm-Richtlinie“ [13], LANUV Fachbericht 13, 2009 [14]).

Figure 1: Laboratory ship Max Prüss; Source: Landesamt für Natur, Umwelt und Verbraucherschutz NRW.

3.2.4 Monitoring of groundwater with the example of NRW

According to WFD’s article 7, the Member States shall identify within each river basin district: „*all bodies of water used for the abstraction of water intended for human consumption providing more than 10 m³ a day as an average or serving more than 50 persons, and those bodies of water intended for such future use*”. The member states shall monitor, “*in accordance with Annex V, those bodies of water which according to Annex V, provide more than 100 m³ a day as an average*” (Article 7 WFD [1]).

In Germany, all groundwater bodies were investigated. The monitoring network for groundwater monitoring has already existed for decades. Therefore, the measuring points could mainly be used from available points of measurement for the monitoring according to the WFD. The measuring points for the chemical monitoring represent the parts of the land use in the catchment area of the groundwater body. Information regarding the expansion of measuring points, the series of measurements (normally 30-year time period for quantitative monitoring points) as well as the preferably representative location are available in the daughter directive groundwater 2006/118/EC. Moreover, in the guideline “Monitoring Groundwater, 2008“ information regarding the selection of measuring points can be found. For each measuring point a measuring point characteristic has to be prepared. This paper contains information about the geo-hydrological position in the flow system, the land use, the annular variation, etc. Besides, the measuring points must correspond to the state of the art (Leitfaden Monitoring Grundwasser, März 2008 [15], CIS Guidance Document No. 15, Guidance on Groundwater Monitoring, 2007 [16]).

The quantitative status as well as the chemical status of the groundwater is investigated. The measuring points are designed nationwide and region wide, therefore, also available in drinking water protection areas and other protected areas. According to the legislations for protected areas, these areas are additionally monitored separately. In drinking water protection areas, for example, raw water measuring points and drinking water measuring points are available (EU-WRRL, 2000 [1]; GewBEÜ-V, Februar 2006 [9]).

Monitoring network – quantitative status

The density of the measuring net and the measuring frequency have to acquire the short- and long-term variations of each groundwater body as well as the groundwater recharge. In NRW, 1515 measuring points exist for quantitative monitoring (see figure 2). The measuring frequency is selected in such a way that a reliable conclusion about the quantitative status is ensured. Normally, a monthly measurement is made. Measuring points with a lower frequency are also added (up to half-yearly). This implies that long-standing measurement series are available and that a good basis for the validation of the measurement series is provided (Bewirtschaftungsplan für die nordrhein-westfälischen Anteile von Rhein, Weser, Ems und Maas 2010 - 2015, September 2009 [11]).

In order to investigate transboundary flow directions and flow rates (also across international borders), not only a sufficient number of measuring points had to be established, but also further data like geometry and permeability of the aquifer had to be determined. The quantitative status of the groundwater body is assessed by the groundwater level or the groundwater level hydrograph, respectively. If the result of the monitoring has revealed that the good quantitative status cannot be reached or the achievement of the objective is at risk, a balancing of the groundwater quantity is required (LAWA Arbeitshilfe zur Umsetzung der EG-Wasserrahmenrichtlinie, 2003 [7]; Leitfaden Monitoring Grundwasser, März 2008 [15]).

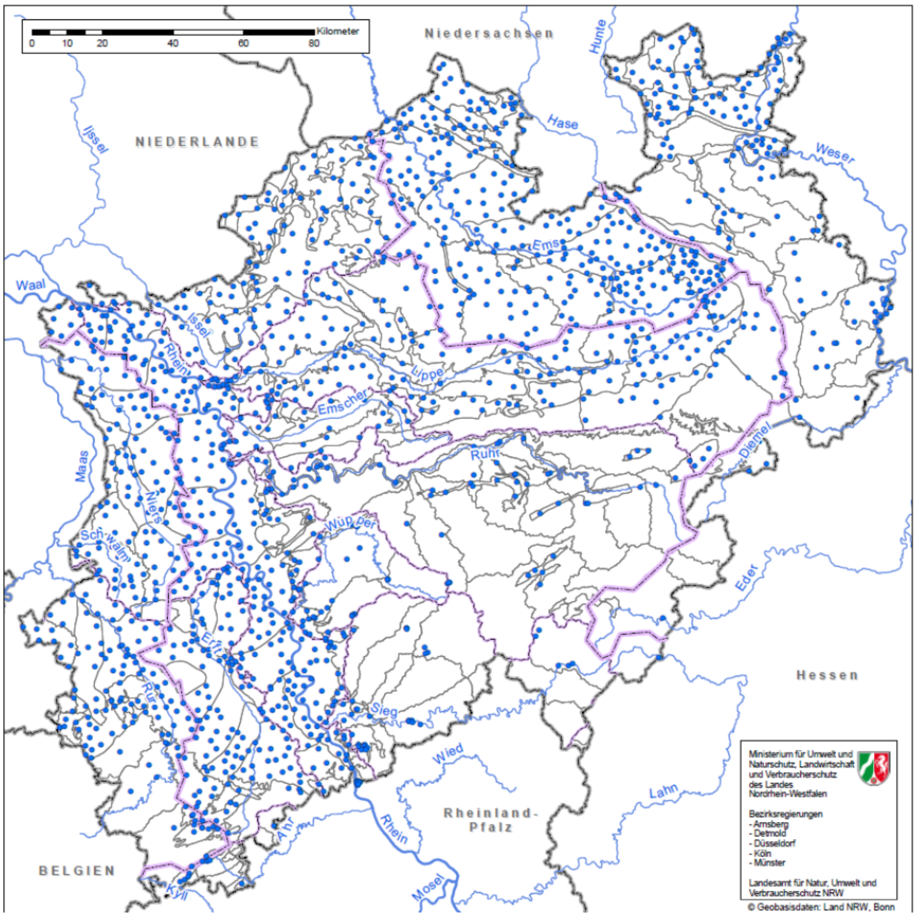

Figure 2: Monitoring network for the quantitative status, the blue dots are the measuring points; Source: Ministerium für Umwelt und Natur, Landwirtschaft und Verbraucherschutz, NRW, Sept. 2008.

The most frequent effects on the quantitative status are: i) Abstraction for the drinking water supply, process water supply, irrigation and sprinkling, ii) water table drawdown in correlation with mining, iii) groundwater recharges. Whereby, a deliberately made artificial groundwater recharge does not signify a load regarding the quantitative status contrary to a long-term water abstraction, since the recharge has the objective to stabilize the groundwater balance and to reduce the overstress caused by the abstraction. Nevertheless, the enrichment represents interference in the quantitative status. Therefore it has to be named, but it must not be further investigated, as far as negative effects like water logging, for example, are avoided (LAWA Arbeitshilfe zur Umsetzung der EG-Wasserrahmenrichtlinie, 2003 [7]; Leitfaden Monitoring Grundwasser, März 2008 [15]).

Monitoring of the chemical status

The monitoring of the chemical status is carried out by means of surveillance monitoring points and – if necessary – by an operational monitoring. The measuring stations have to be arranged and operated in such a way that a long-term rise of pollutant concentrations, caused by anthropogenic activities, as well as a trend reversal as a result of measures can be recognized and assessed. The density of the measurement network is based upon the type and the structure as well as the water management utilization of the groundwater body which has to be assessed (utilization like agriculture, forest, extensive land use, areas of settlement and industrial areas). The measuring stations have to be representative. At the selected measuring stations samples are taken and analyzed regularly, whereby the measurement frequency is based on the characteristic of the measuring point/station (Leitfaden Monitoring Grundwasser, März 2008 [15]).

Surveillance monitoring

In NRW, 1003 surveillance monitoring points exist. At the measuring stations limit values or threshold values, respectively, are checked for their compliance. The so-called basic parameters are measured; i.e. the standard parameters (oxygen, pH-value, conductivity, nitrate and ammonium) and the major ions (sodium, potassium, iron, manganese, sulphate, chloride, magnesium, calcium and hydrogen carbonate). The parameters are investigated once a year at all measuring stations (Leitfaden Monitoring Grundwasser, März 2008 [15]). Furthermore, pesticides (PSM) are monitored at the surveillance measuring points. Concerning the pesticides, the monitoring is carried out in a rotating manner so that in the regular cycle of the management plan – every 6 years – all measuring points are at least examined once for pesticides. In other words, every year 1/6 of the measuring points are analyzed for relevant substances. In NRW this procedure is possible due to the fact that long-term measurement series exist so that the recognition of loads and trends is given. In addition to the parameters mentioned before, threshold values of further parameters are investigated every six years at the measuring stations of surveillance monitoring according to the daughter directive on groundwater (2006/118/EC, annex II [5]) if they are not included in the annually basic monitoring. The parameters for surveillance monitoring are given in table 3.

Table 3: Parameter and monitoring frequency of the surveillance monitoring groundwater. Source: Ministerium für Umwelt und Natur, Landwirtschaft und Verbraucherschutz, NRW**.**

Parameters	Monitoring frequency
Oxygen, pH-value, conductivity, nitrate, ammonium, sodium, potassium, calcium, magnesium, iron, manganese, sulphate, chorine, hydrogen-carbonate	annually
Pesticides, arsenic, cadmium, lead, mercury, nickel, tetra-chloroethylene, trichloroethylene; if necessary area specific parameter	every six years

Operational monitoring

The operational monitoring is carried out at groundwater bodies which had shown the result “achievement of objectives improbable” in the inventory. The monitoring serves for the analysis of the chemical status and for the analysis of long-term trends of anthropogenic activity. Moreover, the results of the operational monitoring provide the basis for the measure planning. Therefore, the measurement network has to provide reliable conclusions. The monitoring is performed once a year. Basic parameters as well as area-specific parameters (if necessary) and additionally the parameters which lead to the result “achievement of objectives improbable” are investigated (see table 4). Furthermore, the emission-related considerations of the groundwater-relevant point source contaminated sites are relevant which are made on the basis of plums. The operational network encompasses 1365 measuring points in NRW (701 are simultaneously used for surveillance monitoring). The whole chemical measuring network (surveillance and operational) has 1667 measuring points in NRW.

Table 4: Parameter and monitoring frequency of the operational monitoring groundwater. Source: Ministerium für Umwelt und Natur, Landwirtschaft und Verbraucherschutz, NRW**.**

Parameter	Monitoring rota
Oxygen, pH-value, conductivity, nitrate, ammonium, sodium, potassium, calcium, magnesium, iron, manganese, sulphate, chorine, hydrogen-carbonate and parameter with the result “achievement of objectives improbable”; if necessary area specific parameter	annually

The selection of measuring points was made on the basis of the land use in the catchment area of the groundwater body, i.e. each measuring point is clearly assigned to a characteristic land use (Bewirtschaftungsplan für die nordrhein-westfälischen Anteile von Rhein, Weser, Ems und Maas 2010 - 2015, September 2009 [11]). It should be noted that the amount of the measuring points within a land use corresponds to the ratio of this land use on the entire area of the groundwater body. In the case that the land use of the whole groundwater body area accounts for 75% agriculture and 25% forest, nine existing measuring points picture the groundwater status under agricultural use and three existing measuring points picture the status under forest use, for example. The chemical measuring network groundwater in NRW (surveillance and operational) is shown in figure 3.

Figure 3: Monitoring network for the chemical status; green dots – surveillance monitoring, purple dots – operational monitoring, orange dots – surveillance and operational monitoring. Source: Ministerium für Umwelt und Natur, Landwirtschaft und Verbraucherschutz, NRW, Sept. 2008.

3.3 Public participation

A central claim of the WFD is public information, consultation and participation whereby the public includes the users of the waters. Article 14 of the WFD requires an active involvement of all interested parties in the planning and implementation of measures, i.e. in the development, review and updating of the river basin management plans. Moreover, a consultation regarding the different intermediate stages of the implementation process takes place. In the CIS guideline No. 8, 2003h, the terms „active involvement“ and „interested parties“ are explained in more detail. In NRW, interest groups representing the “broader public” are also involved according to the “SUP- Richtlinie (2001/42/EG)”, Article 2 (4) and according to the Aarhus convention. They should and could actively contribute to the planning process by discussing issues and proposing solutions. The insights gained by this procedure are considered in the river basin management plan, in the program of measures and in the planning entity profiles. In addition, the documentation of the planning process and of the planning output is made available by the computer-based data capture tool „water body profiles“. The issues and proposals (water body profiles) which worked out at the district government level are brought together and evaluated at the Länder level (German states). According to the WFD, public consultation regarding specific documents represents a lower level of active participation. The public consultation is provided with formal specifications and serves the function to gain information and opinions (Bewirtschaftungsplan für die nordrhein-westfälischen Anteile von Rhein, Weser, Ems und Maas 2010 - 2015, September 2009 [11]; CIS Guidance Document No 8, Public Participation [17]; SUP-Richtlinie 2001/42/EG, Prüfung der Umweltauswirkungen bestimmter Pläne und Programme [18]).

One important instrument of public participation is the transparent information of the population, stakeholders and the municipal decision makers in order to create awareness for the importance of management objectives and to achieve an early acceptance for the program of measures. Decisions should be understood, appreciated and reliable. With increasing concretization of the planning, the public participation was progressively deepened, since the reference to the public and the complexity of planning processes are increasing. From the inventory over the setting up of monitoring programs right up to the development of the river basin management plans as well as the measure programs, the circle of participants was expanded continuously, for example by “round tables” in the regions and/or other interest groups (see figure 4). The participation process was carried out with the instruments of core working groups, working groups, bilateral discussions, symposia, and regional forums on the *Länder* level as well as for the individual sub-catchments (Bewirtschaftungsplan für die nordrhein-westfälischen Anteile von Rhein, Weser, Ems und Maas 2010 - 2015, September 2009 [11]; CIS Guidance Document No 8, Public Participation [17]).

In order to involve the different actors, a steering committee (under the direction of MUNLV) and national subject-specific working groups were set up in NRW. The steering committee is responsible for the central control and determines relevant key points for the implementation process. In the steering committee, actor groups are represented that cover all main bodies which are affected by WFD’s implementation.

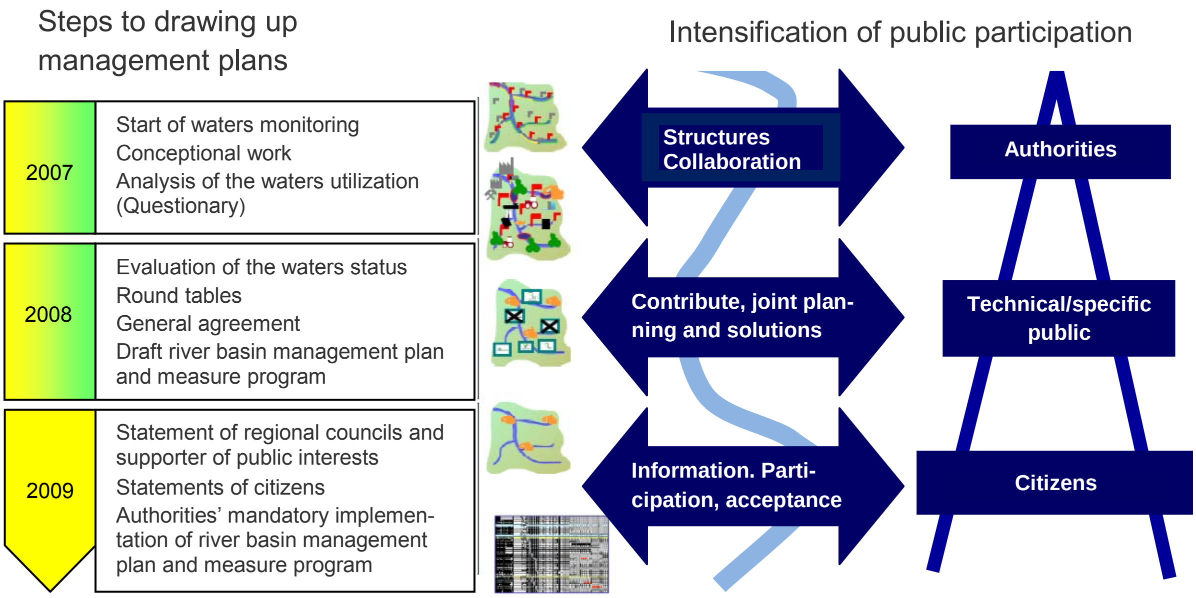

Figure 4: Participating groups within the scope of the river basin management planning Source: Ministerium für Umwelt und Naturschutz, Landwirtschaft und Verbraucherschutz (MUNLV)**.**

The working groups deal with the technical-related design of the measure and river basin management planning. Depending on the work progress, they were adapted to the requirements, merged together or completed. The institutions in the working group range from the district water associations, the leading municipal associations, the chamber of agriculture and the associations of agriculture, gardening, foresters and landowners over umbrella organizations of the water and soil associations, representatives of industry (e.g., BDI, VCI, IHK) right up to the accepted nature protection associations, the fisheries associations and the representatives of specific water utilization (hydropower, mills, water supply, mining, shipping). The core working groups (actor groups and regionally responsible authorities) coordinate the regional work process and basic interim results. In addition, they undertake a multiplier function vis-à-vis the groups which are represented by them, and they coordinate the results achieved at the level of the planning entities within the respective sub catchment area (Bewirtschaftungsplan für die nordrhein-westfälischen Anteile von Rhein, Weser, Ems und Maas 2010 - 2015, September 2009 [11]).

Apart from the active public participation, the WFD also prescribes a public consultation by article 14. Thereby, obtaining statements is based on two main ways. The first classical way is the display of relevant documents in the state ministry (MUNLV), district governments, districts and district-free cities. The second way is a website for online participation. The public information took place in the conventional way by the planning entity profiles as well as by the generally understandable explanatory reports enriched with photos and illustrations as well as by press releases, press handouts and press reports. On the internet, access to the following documents is provided: i) Consultation documents for downloading and the opportunity to deliver an statement online ii) Background documents and information about current dates and events (www.flussgebiete.nrw.de), iii) Important data in geographic information systems (map tool; www.elwasims.nrw.de). The map tool visualizes all important information (current) regarding the surface water and groundwater monitoring, existing contaminants and protection areas. With the help of water body profiles, data about the monitoring results, management objectives, general conditions and measures for each water body can be obtained in a tabular form. Furthermore, calendars, poster and flyer were created in order to raise awareness. Photographic competitions dealing with the topic of “streams and rivers” were carried out, and information films were also made available. These activities were accompanied by school projects, exhibitions or the realization of environment days of the cities and the communities.

3.4 Reporting duty and presentation of the results

According to the WFD, the member states have a regular reporting duty to the EU commission. The reporting duty serves an EU wide exchange of waters data as well as for mutual information. Due to the reporting duty, the investigations on the waters are made comparable. In Germany, the Federal Environment Agency is responsible for the transfer of the waters data (chemical, biological, bacteriological as well as chemical-physical data).

WFD’s objectives apply to all water bodies. The reporting duty to the EU commission concerns for larger waters, i.e. for:

- *All streams and rivers with a catchment area which is larger than 10 km²,*
- *All lakes respectively stagnant waters with a water surface of more than 50 ha,*
- *All transitional waters with a catchment area which is larger than 10 km²*
- *Coastal waters up to a line of one nautical mile seaward from the baseline,*
- *All groundwater bodies.*

The reporting duty is of a formal nature. However, the reports have to be expressive in a way that they permit the EU commission to check if the method of the member states is in accordance with the guidelines. Further, the EU commission has to assess the coherence of the procedure in international river basins on the basis of the reports. Since the test process is very complex due to the multitude of river basins, the EU commission has introduced a so-called “reporting system“. This system was developed in accordance with the EU Water Directors. It is called “Water Information System Europe (WISE)“. The information system works with databases. Hence, the requirements for the data input are structured in a way that the member states are able to enter necessary information accordingly. It should be noted that the data input is limited. Although the data satisfy the requirements of the EU commission, for example as control function, they do not meet the requirements which are expected from a clear and understandable information with the aim of public participation, for example to planning of measures programs. Therefore, the EU reporting system runs parallel to the reporting system within the member states. It is important to ensure that the contents of the EU system in no way conflicts with the national reporting forms. Reports were and will be provided on the following dates:

- *June 2004: 1. List of the river basin districts and responsible authorities,*
- *March 2005: Status report of the bodies of water,*
- *March 2007: Report about necessary monitoring programs ,*

- *March 2010: First management plan including a summary of the program of measures,*
- *December 2012: Report on the progress achieved by the measures,*
- *March 2013: Update of the inventory which does not have to be reported to the EU commission,*
- *March 2016: Second management plan including a summary of the program of measures (Bewirtschaftungsplan für die nordrhein-westfälischen Anteile von Rhein, Weser, Ems und Maas 2010 - 2015, September 2009 [11]).*

The EU commission uses the data which are entered in WISE in order to undertake analysis, draw up statistics, write reports to the EU parliament and control implementation steps of the WFD in the member states. Further, the data are published by the EU commission via the internet. Thus, there is currently a first statement about WFD's implementation in Europe available. In Germany, the data are computerized via the portal called "Wasserblick" in WISE. The portal „Wasserblick" is operated by the Federal Institute of Hydrology (BFG). Aggregated data on the water quality in Germany, for example, are made available to the public (Bewirtschaftungsplan für die nordrhein-westfälischen Anteile von Rhein, Weser, Ems und Maas 2010 - 2015, September 2009 [11]; CIS Guidance Document No. 21, Guidance for reporting [19]).

In NRW and in the other 15 *Länder* different operative reporting levels are distinguished:

- *A-reports cover the river basins such as the Rhine, Weser, and Ems. These reports are of supra-regional importance and coarse scale, together with the reports from the sub catchment areas; they provide a general overview on the most important supra-regional management questions in the river basin districts. The A-reports are submitted to the EU commission in the form of a „general report". The specific management planning is described in the reports of the different Länder.*
- *B-reports are reports on the level of the catchment areas, like the Lower Rhine, Middle Rhine, Main, Moselle, and Saar. On the basis of the C-report, B-reports contain a more detailed depiction which also addresses aspects of the catchment area like regional management questions. It relates to the level of aggregation; partial reports are submitted which serve as the basis for the A-report.*
- *C-Reports represent the lowest reporting level and serve as the basis of all reports. They are based on the level of the sub catchment areas (like the Sieg, Lippe, and Ruhr) or on the level of the planning units, respectively. On this level, all data and information for the description of the waters are collected in detail. Moreover, they are completed and assessed by local knowledge. A documentation of the water management basics is carried out which provides the basis for the future water management and the water management enforcement, respectively. For the first time, all data which are relevant for a water resources planning can be considered and assessed in the context. The reports also serve for the information of the public.*

The statements between the reporting levels may not have discrepancies. The planning unit profiles also belong to the reports. In order to illustrate the water status, a map has to be generated for each river basin district. One can distinguish between thematic maps that are component-related maps, for:

- *Macrozoobenthos; macrophytes; phytoplankton, the fish fauna,*
- *Relevant substances for the planning units,*
- *General chemical and physical parameters or*
- *Aggregate substances according to appropriate substance groups.*

In addition, there are maps for the integral consideration, like the overall assessment:

- *Ecological status biology,*
- *Ecological status chemistry,*
- *Overall ecological status,*
- *Chemical status.*

For each surface water body, the display is arranged according to the color coding from the evaluation. In the case that the good status or the good ecological potential is not achieved in a surface water body and if this can be traced back to the fact that one or more environmental quality norms for specific synthetic and non-synthetic pollutants cannot be met, the water body is marked by a black dot (GewBEÜ-V, 2006, Annex 4 [9]).

Maps also have to be generated for the status of the groundwater. Here, maps for the quantitative status as well as for the chemical status were created. Concerning the chemical status, component-related respectively pollution-related maps as well as a map for the purpose of a total evaluation are available. The color coding of the groundwater status is similar to the status of the evaluation.

3.5 Management planning and programs of measures

According to WFD's article 13, a management plan has to be generated for each river basin in Europe. This should be especially strived for international river basins, but at least for the national part of a river basin district a coherent management plan has to be drawn up. It is also possible to complete the management plans which are generated at the river basin level by detailed plans in the lower levels - in a sub-catchment, for example. In order to be able to prepare supraregional river basin reports, several conservations and coordination actions were and are required. It had to be ensured that the implementation of the WFD is consistent and harmonized beyond the borders as well as comparable. This is important due to the fact that there are different partners as well as different load situations in the different river basin districts in Europe. With regard to the current status of the waters and the programs of measures which are derived from the current status of the waters, normally no significant differences exist at the borders because at the borders comparable natural and cultural landscapes continue. Differences are within the larger river basin districts such as the Rhine in terms of the natural regions (e.g. from the Alps to the North Sea) and land use (e.g. metropolitan areas, agriculture, industry, mining) since water resources management is different in these areas. Correspondingly, programs of measures arise for the achievement of objectives according to the WFD which are adapted to the respective situation. In order to clarify the management issues and to develop measure programs regarding the Rhine, the experiences of the ICPR (International Commission for the Protection of the Rhine) could be used. Where no international water exists in Germany, administrative agreements were concluded for the coordination of the management planning and the drawing up of measure programs, so as to organize themselves into the river basin commission like the River Basin Commission Weser - RBC Weser (Bewirtschaftungsplan für die nordrhein-westfälischen Anteile von Rhein, Weser, Ems und Maas 2010 - 2015, September 2009 [11]).

In addition to the general description of the river basin district, the management plan contains information on:

- *The essential requirements of the EC Water Framework Directive,*
- *Specific requirements with regard to certain protected areas and protective goods, respectively, like the monument conservation,*
- *The monitoring programs to assess the current water status,*
- *The status of surface waters and the groundwater,*
- *Loadings of waters and their causes,*
- *The management objectives for the particular water bodies and the program of measures for achieving the objectives,*
- *The economic analysis of water uses,*
- *The measures for public information and participation, and about*
- *Responsible authorities as well as regulatory proceedings which accompany the implementation of the program of measures (Bewirtschaftungsplan für die nordrhein-westfälischen Anteile von Rhein, Weser, Ems und Maas 2010 - 2015, September 2009 [11]).*

The program of measures, the planning unit profiles and the reports of the national and international river basin districts supplement the management plan. The reports on the river basin districts describe the goals which are relevant for the whole river basin. The planning unit profiles provide information on the status of the water bodies and the groups of water bodies of surface waters and the groundwater, i.e. on the loadings, the management objectives as well as on planned measures. The program of measures stated in the profiles provides the framework for detailed planning and the implementation of measures. In order to plan and realize the measures, a cooperation between the water users, agriculture and forestry, the industry, water management authorities, water associations, cities and municipalities, the natural conservation and the fisheries associations is required. This means that for an efficient and effective implementation of measures, the relevant authorities as well as the persons concerned have to be involved timely in the planning process. Further, the issues of landscaping, regional planning, spatial planning, agricultural legislation, monument conservation had to be incorporated. Thus a structured work is required and in order to ensure this, extensive conceptual specifications were developed in NRW in advance. The measures for ecological water development contribute to the stabilization of typical biocoenoses in waters. Thus, they can be better adapted to climate change (Bewirtschaftungsplan für die nordrhein-westfälischen Anteile von Rhein, Weser, Ems und Maas 2010 - 2015, September 2009 [11]).

In NRW, the quality of surface waters is ensured at a high level due to the fact that the state of the art regarding the waste water draw-off and the waste water treatment is introduced to the greatest possible extent. Wherever necessary, the concepts for disposal of rainwater should be supplemented up to the year 2012. Those who have the duty of wastewater disposal (thus also road construction authorities) are asked to present corresponding examinations and planning's. According to § 7a federal water law (WHG), industry and trade have always been committed to apply the state of the art and to reduce pollutant discharges in waters.

Due to erosion, localized flatting or the discharge of nutrients (in particular phosphorus) and pesticides, agriculture contributes to the pollution of waters. The discharge of nutrients was reduced by distance requirements, riparian strips and river bank strips in accordance with state water law (LWG, 2010). Concerning pesticides, farmers are trained adequately. Moreover, the discharge is reduced by suitable retention facilities (preventive measures such as collecting and treating wash water for atomizer and machines, reducing the dosage, weather dependent period for the application, planted riparian strips, alignment of the crop rows, artificial wetlands) as well as by technical progress. In order that native species of animals and plants can find their habitat in waters, waters should have – apart from the good water quality - the typical structure and preferably the passability for fish and microbes. In NRW the focus of the measures lies in the field of surface water ecology, i.e. in the improvement of the passability of water bodies as well as of the water body structure. The essential requirements on the measures to improve the ecological passability like for example fish passage facilities for up and downstream fish migration (e.g. fish ladders, fish pass, rough ramps) or similar aspects are fixed in the "Durchgängigkeitserlass" of the January 2009. The heading "passability for fishes" also includes measures for the protection of fish at water withdrawal facilities or at power plants. The measures for the passability for fishes also contribute to the success of the migratory fish program and to the implementation of the council regulation EC 1100/2007 of European eel. In order to take account of the aspect of the production of renewable energy from hydropower, particular decisions are made on the basis of the passability regulation -„Durchgängigkeitserlass" - (Landes Wassergesetz, NRW, 2010 [20]; Durchgängigkeit der Gewässer an Querbauwerken und Wasserkraftanlagen „Durchgängigkeitserlass", Januar 2009 [21]; Handbuch Querbauwerke, 2005 [22]-; COUNCIL REGULATION (EC) No 1100/2007 of European eel [23]; Bewirtschaftungsplan für die nordrhein-westfälischen Anteile von Rhein, Weser, Ems und Maas 2010 - 2015, September 2009 [11]).

Regarding groundwater, significant rising trends in terms of chemical pollution are only observed in very few cases in NRW. In the past this was reached by agricultural and horticultural measures taken for the reduction of the discharge of nutrients and pesticides in the groundwater. Future measures which will be adduced concern the implementation of the fertilizer ordinance and of the plant conservation legislation. Special requirements in drinking water abstraction areas are added. In these areas, transboundary water cooperation carries out a variety of measures on the spot for the reduction of the discharge of nutrients and pesticides. The water cooperation works on a voluntary basis. The State of NRW offers for interested parties a specific consulting concept on the basis of the experiences of the water cooperation. For groundwater bodies which are affected by contaminated sites, the good status should be reached by the year 2027 by area rehabilitation (off-site-treatment, in-site-treatment, on-site-treatment), the removal of wild landfills, and encapsulation. In light of WFD's requirements, the good quantitative status of the groundwater is reached almost everywhere in NRW except from areas where mining activities still exist (brown-coal surface mining or lime exploitation) since they show deficits. Here less stringent environmental objectives are set since the good quantitative status cannot be reached by the year 2027. The environmental damage (inter alia wetlands and water supply) is limited by appropriate reduction measures (technical compensatory measures like artificial infiltration of treated dewatering water into the dry out aquifer or into wetlands depending on groundwater, respectively; in addition, river bed sills should be implemented in order to reduce the flow velocity of the water discharged in the river and to hold up the water level widespread by that measure). The groundwater balance is a highly complex system and it is more than the sum of its parts. Against this background, the ecological effectiveness of these measures is controversial. Furthermore, the monitoring programs are comprehensively established in order to be able to control and readjust measures permanently (Bewirtschaftungsplan für die nordrhein-westfälischen Anteile von Rhein, Weser, Ems und Maas 2010 - 2015, September 2009 [11]).

4 General description of river basins

The categorization as well as the typecast is an essential precondition for the assessment of surface waters. In general, the categories flowing waters, lakes, transitional and coastal waters are distinguished. The approach of the integrated, type-specific assessment of surface waters takes into account that waters of the same category can differ, e.g. in respect to the substrate properties, the flow velocity, the physico-chemical properties (temperature, pH-value, conductivity, oxygen content) which leads in turn to the development of different communities of the aquatic organisms (biocoenosis). Consequently, water types are defined for each category of waters. In order to ensure a consistent approach with respect to the typecast, it has been derived by the Federal-Länder Working Group on Water (LAWA) for flowing waters in Germany.

4.1 River basin types (Flowing waters types)

A natural water body has typical, regionally distinct different structures and runoff which form the framework conditions for a characteristic colonization of plants and animals. Therefore, a typology has been derived in accordance with certain criteria on the basis of the flowing water landscapes and hydro-geological conditions. Further, it makes distinctions according to the life requirements of the different biological quality components. Hence, the German typology of flowing waters was methodologically developed “top down” in an initial step, from the geomorphologic basics of the landscape down to the individual types.

In the WFD, the characteristics of the waters are already taken into consideration in the designation of so-called eco-regions. An eco-region is a superior natural environments unit. In Germany, seven eco-regions can be distinguished. NRW has a share in four eco-regions – the Central Uplands, the Western Uplands, the Central Lowland and the Western Lowland. A further subdivision takes place in flowing water landscapes which the waters are assigned according to the different natural environment conditions (geology, geomorphology). In NRW, for example, 10 different flowing water landscapes are distinguished which are again differentiated inter alia according to the river bed substrate, the flow behavior and the runoff characteristics in river basin types/flowing water types. Exemplary landscapes are lowland areas as sand areas, weathering areas and river terraces, loess regions, lowland areas as well as uplands areas such as siliceous bedrock, foreland of the siliceous bedrock, volcanic areas, weak carbonate mountain, shell limestone areas and karstified limestone areas. For this purpose, the WFD has provided two methods which stand for election: System A (eco-region, altitude, catchment size, geology of the natural environment) and system B which is more complex due to its data (eco-region, altitude, catchment size, geology of the natural environment, latitude and longitude, composition of the river bed substrate). In WFD’s implementation, the types of flowing waters provide the basis for the creation of the "Waters Type Map Germany" for example, but also for the determination of the reference status of a water body (reference condition) as well as for the development of biological evaluation methods. The waters typology has to be taken into account in the planning and realisation process of the monitoring since different variants of investigation and evaluation methods partially apply to the different water body types. The different types are also relevant for the planning of measures because the planning objectives have to orientate towards these water body types (WFD, Annex II and Annex XI [1]; Blaue Richtlinie, NRW, März 2010 [24]).

In Germany, 25 flowing waters types are principally distinguished. In the Alpine eco-region and in the eco-region of the Alpine foothills, four types can be found, at the Uplands eight types and in the North German Lowland nine types. Moreover, there are four flowing waters types which are disseminated in different eco-regions. These are so-called “eco-region independent types”. For all types of flowing waters, profiles are available which have the function to illustrate the different types of water bodies (ideal-typical characteristics) and their properties as well as to serve as a general basis for understanding. The profiles include the morphological description of the different types of waters, the water condition (geological categories – siliceous, carbonate, organic), physic-chemical conductance, a short description of the characteristic of the discharge respectively the hydrology as well as the biocenotic characterization. Moreover, in the annex of the profiles all relevant information for the general description of evaluation methods regarding the quality components are brought together. The profiles make a contribution to the description of the reference conditions, but they cannot be used as a sole basis for a biocoenotic evaluation system (Umwelt Bundes Amt, Begleittext Teil A, April 2008 [25]).

In addition to the flowing waters types which particularly take into account the habitat requirements of the makrozoobenthos and the aquatic flora, fish waters types have been derived according to the natural habitats of the fish type communities. Fishes are more mobile and have other habitat demands as the microbes (makrozoobenthos). In Germany, the description and differentiation of fish waters types are based on the historical abundance of fish on the one hand and on the knowledge about the demands regarding the habitat of the different fish species on the other hand. The fish waters types are also described in the profiles. Altogether, 38 waters types could be distinguished regarding the fish fauna in NRW. These waters types are called "fish waters types”. (Bewirtschaftungsplan für die nordrhein-westfälischen Anteile von Rhein, Weser, Ems und

Maas 2010 - 2015, September 2009 [11]; Erarbeitung von Instrumenten zur gewässerökologischen Beurteilung der Fischfauna, 2007 [26]).

4.2 Reference conditions

According to WFD's requirements regarding biological quality elements, a so-called reference condition has to be defined for each type of water body. The reference condition is by definition a water status in which no or only minor anthropogenic impacts can be identified. The reference status/condition is often referred to as a "guiding principle", whereas the guiding principle describes the present potentially natural water status. That is, the guiding principle describes the water status on the basis of knowledge about the function of the river ecosystem. The description of the reference condition includes the chemical- physical and hydromorphological situation as well as the species communities living under natural conditions in the waters (see the waters-type profile and fish waters-type profile mentioned in chapter 4.1). The reference condition serves as benchmark for the very good status of water bodies in the evaluation of the current status of waters. The background is that the different degradation levels should be measured by a comparable benchmark. It is necessary to ensure that the scale of assessment starts at a defined zero point for all water types independent of the intensity of the existing use (Bewirtschaftungsplan für die nordrhein-westfälischen Anteile von Rhein, Weser, Ems und Maas 2010 - 2015, September 2009 [11]).

Only irreversible anthropogenic changes on surface waters will be taken into account when determining the reference condition. For the assessment, strict guidelines are followed, e.g. waterway construction, buildings, and land use. It shall be deemed to be a reversible encroachment what theoretically is to restore. Cost-benefit considerations or realization chances for the implementation of measures are *a priori* not relevant here. In ideal situations, the reference condition can be derived from real existing waters. Is this impossible due to intensive uses (none available reference waters), the reference condition can be derived by using the best found characteristics, historical data, expert knowledge or modelling of the very good status. Rules for the derivation of the reference condition can be found in the CIS guideline No 10, 2003. The same applies to the different fish-waters-types. With respect to heavily modified and artificial water bodies, reference conditions cannot be derived. As a benchmark for these waters, the maximum ecological potential can be used for evaluation (Bewirtschaftungsplan für die nordrhein-westfälischen Anteile von Rhein, Weser, Ems und Maas 2010 - 2015, September 2009 [11]; CIS Guidance Document No 10, Rivers and Lakes – Typology, Reference conditions and Classification Systems, 2003 [27]).

The achievement of water's very good status respectively the reference conditions is in particular *not* WFD's objective. As the general quality objective are intended to reach the „good status" as well as the „good ecological potential". It should be noted, however, that a general deterioration prohibition is valid since explicit waters in a "very good status" must be protected in particular against the deterioration to a „good status" by means of appropriate measures, even if the WFD aims at reaching the „good status"(Bewirtschaftungsplan für die nordrhein-westfälischen Anteile von Rhein, Weser, Ems und Maas 2010 - 2015, September 2009 [11]; WFD, 2000 [1]).

4.3 Spatial structure (river basin districts, sub catchment area, planning units, water bodies)

In Europe, the management of waters is realized by so-called *river basin districts*. The natural river basin of the flowing waters from its source to its estuary forms a river basin district, i.e. it includes the five categories of flowing waters, lakes, transitional waters and coastal waters as well as the groundwater. Overall, Germany takes part in ten river basins districts (Eider, Schlei/Trave, Warnow/Peene, Oder, Elbe, Weser, Ems, Rhine, Meuse and Danube). Most of these river basins are located in the territories of several federal states/Länder respectively EU member states. The river basin districts NRW take part in the Rhine, Weser, Ems and Meuse catchments. None of these river basin districts can be managed by NRW alone. In order to be able to coordinate the works and synchronization for WFD's implementation in the large river basin districts, transnational coordination offices were established. These coordination offices or coordination groups are, for example, the international commission for the protection of the Rhine (IKSR) and the German commission for the protection of the Rhine (DK-Rhein), respectively, or the river basin community Weser (FGG-Weser). From the German side, these groups include the Federation as well as the federal states which are located in the river basin. The necessary coordination are carried out in various working and expert groups.

Due to the size and the complexity of these river basin districts, they are spatially divided into practicable catchment areas (working areas) and further subdivided into sub-catchment areas and planning units. This shall be done in due consideration of hydrographic and natural environment conditions. The Rhine river basin district, for example, is divided into nine practicable catchment areas: the Rhine Delta, Alpine Rhine/Lake Constance, High Rhine, Upper Rhine, Neckar, Main, Middle Rhine, Mosel/Saar and the Lower Rhine (see annex: Figure A1 on catchment areas of the river Rhine). The further division of practicable catchment areas (working areas) into sub-catchment areas serves for the integration of local knowledge into the management planning, for the verification of management questions as well as for the reporting to the EU. The people can identify with the sub-catchment areas since they connect them with their habitats. Overall, 13 sub catchments areas are delineated in NRW. The implementation process of the WFD is regionally accompanied by regular meetings of the working groups at the sub-basin level. For the purpose of investigation and processing regarding a management planning, sub-catchment areas are relatively large since an active participation of the local authorities (municipality, cities, rural districts, and district-free cities) must be achieved. Thus, a further subdivision was made in planning units (see annex: Figure A2 on sub-catchment area and planning units), according to hydrographic criteria. In fact, the planning units represent the actual planning level, since an intensive participation process with regional actors takes place on this level. Planning units are larger units consisting of water bodies and coherent regions, which are to be managed well. They are comparatively homogeneous with reference to pollutions and respective measures. Moreover, ecosystems have to be taken into consideration as well.

In NRW, there are 83 planning units. For the planning unit so-called planning unit profiles were created. They contain the most important information for one region in a compact form. Altogether, 14 of such profiles are available in NRW. The planning unit profiles contain general information about the region (size of the area, land use, main rivers), a detailed overview about the status of waters, about the management objectives until 2015 and about the planned measures for the achievement of objectives within one sub-catchment area. The profile of the planning units is part of the management plan and the measure program (Steckbriefe der Planungseinheiten in den nordrhein-westfälischen Anteilen von Rhein, Weser, Ems und Maas, Oberflächengewässer und Grundwasser, Dezember 2009 [28]).

The last subdivision is conducted with the designation of water bodies as the smallest unit. According to the WFD, a surface water body is defined as „…*a uniform and significant element of a surface water such as a lake, a reservoir, a stream, river or canal, a part of a stream, river or canal, a transitional water or a stretch of coastal water*“ (WFD Article 2, paragraph 10 [1]). A differentiation of surface water bodies is useful for the biological water monitoring (monitoring of surface waters) and necessary as well. Regarding the delimitation of water bodies, the term „uniform“ leads to the following conditions:

- *No overlap of water bodies,*
- *Delimitation in the transition from one waters category (river, lake, transitional waters, coastal waters) to the next waters category,*
- *Delimitation in the transition from one waters type to the next waters type,*
- *Delimitation in the event of significant changes of physical (geographic and hydro morphological) properties,*
- *Delimitation in turns between natural, heavily modified and artificial river section.*

A water body shall be selected in a way that its condition can be precisely described and compared with the environmental objectives of the WFD, meaning a section of a water where comparable conditions exist in order to get robust conclusions concerning the status of the waters. The water body is a coherent part of the river basin district. In NRW, for example, the surface water bodies have on average a length of 7.5 km. In NRW, there are 1897 surface water bodies (OFWK) and 22 lakes. Regarding the establishment of measure programs and the management of waters, larger units can be built, the so-called level of water body groups. Account must be taken of local coherences in order to ensure the interconnection of habitats and biospheres. The surface water body groups have on average a length of approx. 31 km or a catchment area of averagely 75 km², respectively. In NRW, there are 447 surface water body groups and the water body group canals. In a database called water body profiles („Wasserkörpersteckbriefe“) for each water body the actual state, their correlation with existent loads and the framework conditions of the waters were recorded at the level of working areas of the district governments. Based on this measure plans for the waters were prepared by using the database. For this purpose, in addition to the deemed necessary measures also the prognosticated costs, the impacts which the measure would have on the waters as well as the planning relevant data are recorded. The water body profiles serve as input for the next higher planning level (Bewirtschaftungsplan für die nordrhein-westfälischen Anteile von Rhein, Weser, Ems und Maas 2010 - 2015, September 2009 [11]).

5 Quality components

In order to assess the ecological status, aquatic communities have to be considered since an assessment based on only one component is inadequate. Therefore, the biological components and in support of them hydro-morphology as well as the chemical and physico-chemical components have to be considered regarding the ecological quality. Previous to WFD entered into force, Germany tried to achieve a good water quality and had appropriate monitoring programs. Nevertheless, WFD's requirements on the biological water quality go beyond the previous practice. The biological quality components encompass phytoplankton, other aquatic flora, the fauna of invertebrates as well as the fish fauna. In this case it is important to record the species composition and the species abundance. Regarding the fish fauna, the age structure is also of importance and concerning the phytoplankton, the biomass is relevant as well. The biological quality components are listed in table 5.

Table 5: Biological quality components (R = Rivers, S = Seas/Lakes, T = Transitional waters, C = Coastal waters). * In the case of plankton-rich waters in addition phytoplankton is to determine. ** In addition to phytoplankton the appropriate sub-component is to determine. Source: LAWA-Arbeitshilfe zur Umsetzung der WRRL, http://www.lawa.de/documents/Arbeitshilfe_30-04-2003_314.pdf.

Component group	Quality element	Parameter	R	S	T	C
Aquatic flora	Phytoplankton (free floating algae)	Species composition, Species abundance, biomass	X*	X	X	X
	Large algae or Angiosperms	Species composition, Species abundance			X**	X**
	Makrophyten, Phytobenthos (proof plants and algae)	Species composition, Species abundance	X*	X*		
Aquatic fauna	Makrozoobenthos (small invertebrates in the substrate)	Species composition, Species abundance, vulnerable Species, diversity	X	X	X	X
	Fish fauna	Species composition, Species abundance, vulnerable Species, age structure (the latter solely for R + S)	X	X	X	

A high degree of accuracy and reliability of the collected data is of particular importance since rehabilitation measures can be linked with high costs. Therefore, for biological investigations - from sampling to the final result - all work steps should be subjected to quality assurance measures (Bewirtschaftungsplan für die internationale Flussgebietseinheit Rhein, 2009 [29]; LAWA-Arbeitshilfe zur Umsetzung der WRRL, 2003 [7]).

Hydromorphological quality components for surface waters are:

- *The water balance (runoff and runoff dynamics, connection to groundwater). In Germany, hydromorphological data of waters can be obtained from hydrological yearbooks. The data are published annually.*

- *Passability of water bodies; transverse structures (e.g. sills, barriers, dams, weirs > 20 cm height) which represents a significant load for the passability of waters are recorded. The collected data are continuously recorded, e.g. positive modifications in the form of a fish passage facility for up and downstream fish migration.*
- *Morphology: Channel patterns, width and depth variations, flow velocities and substrate conditions as well as the structure and conditions of riparian zones (Leitfaden Monitoring Oberflächengewässer, 2009 [10]). The morphological components are shown in table 6.*

Table 6: Hydromorphological quality components (R = Rivers, S = Seas/Lakes, T = Transitional waters, C = Coastal waters). Source: LAWA-Arbeitshilfe zur Umsetzung der WRRL, http://www.lawa.de/documents/Arbeitshilfe_30-04-2003_314.pdf.

Quality component	Sub-component	R	S	T	C
Water balance	runoff and runoff dynamics	X			
	Connection to groundwater bodies	X	X		
	Water level dynamics		X		
	Water renewal time		X		
Passability of water bodies		X			
Morphology	Depth and width variation	X			
	Depth variation		X	X	X
	Structure and substrate of the river bed	X			X
	Quantity, structure and substrate of the river bed		X	X	
	Structure of the riparian zone	X	X		
	Structure of the intertidal zone			X	X
Tide regime	Fresh water flow			X	
	Shaft load			X	X
	Direction of predominant stream				X

The eco-chemical and chemical-physical parameters are – such as the water structure – additional quality components to biology. Furthermore, environmental quality standards for so-called specific pollutants – selected agricultural and industrial chemicals which could damage animals and plants – were stated.

The general chemical-physical components are:

- *Water temperature,*
- *Oxygen content,*
- *Salinity,*
- *pH-value,*
- *Nutrients (phosphorus, nitrogen).*

The limit values depend on the water types, e.g. rivers of the low mountain range total phosphorus 100 µg/l, ammonium nitrogen 300 µg/l, pH-value 6.5 – 8.5.

The parameters for the "eco-chemistry", specific pollutants of annex 4 of the GewBEÜ-V are:

- *Arsenic 40 mg/kg,*
- *Chrome 540 mg/kg,*
- *Copper 160 mg/kg,*
- *Zinc 800 mg/kg,*
- *PCB 20 µg/kg,*
- *Plant protection products, e.g., like metolachlor 0.2 µg/l,*
- *Some organic tin compounds in suspended matter,*
- *Organic phosphoric acid ester.*

According to the WFD, chemical quality standards are stated EU wide for currently 33 priority substances with regard to the chemical status of water bodies. For the chemical status of surface waters, the environmental quality standard directive 2008/105/EC is authoritative. The aim of the directive is to reduce the chemical load of waters in Europe. For further substances which are not regulated either nationally or all over Europe, orientation values were introduced. As new substances are constantly developed, like for example in medical science or in the industry. The list is not static, but has to be updated continuously. These substances are observed, investigated and taken into account in water management-related actions, e.g. as an indication to possible measures, even if there are no quality standards and only orientation values available. It should be noted that the compliance with orientation values is no fundamental requirement of the WFD since the extent of the orientation value has not been scientifically proven yet (Environmental quality standard directive 2008/105/EC, Dec. 2008 [30]). Depending on the significance of the substances, it is distinguished between:

- *EU wide stated substances,*
- *Nationally stated substances,*
- *New substances.*

In order to decide whether a substance is problematic for a water body or not, different criteria are considered:

- *The risk for the aquatic ecosystem,*
- *The risk for the human health,*
- *The biodegradability of the substance,*
- *The actual dissemination in the environment.*

The substances which are currently investigated are listed in the table “Environmental quality standards for priority substances and certain other pollutants” in the annex (Tab. A4).

The discharge and emissions of priority, hazardous substances, such as cadmium, mercury, pentachlorophenol and polychlorinated aromatic compounds should be completely terminated within the next 20 years. In the long term these substances should no longer occur in the surface waters and in the marine environment. Apart from this, measures have to be taken by the member states in order to ensure that the concentrations (trend) of the priority substances do not increase in the waters (Environmental quality standard directive 2008/105/EC, Dec. 2008 [30]).

In annex 5 of the WFD, the criteria for the quantitative and chemical status of the groundwater are expressed. These criteria are further concretized in the daughter directive groundwater (2006/118/EC, Dec. 2006 [5]). In terms of its quantity, the groundwater has a good status, if no over-exploitation of the groundwater and no significant impacts of groundwater-dependent terrestrial ecosystems (e.g. wetlands) exist. The quality of the quantitative status is determined by table 7.

Table 7: Quantitative status on the basis of trend analyses and water balances. Source: Leitfaden Monitoring Grundwasser, 2008 [15].

Coverage degree of the spheres of action for trend analysis	Water management significance	Result of the trend analysis	Result of the water balance	Quantitative status
< 50 %	Low (with no indication of a negative trend)	–	–	good
	medium/high		balanced/ positive	good
			negative	bad/poor
> 50%	minor/medium/high	positive	–	good
		negative	balanced/ positive	good
			negative	bad/poor

Groundwaters may be polluted by both point sources as well as by diffuse sources. Diffuse pollutants particularly include the land use in agriculture. Regarding point sources, contaminated sites, old deposits and wild landfills have to be considered. The quality standards predetermined by the GewBEÜ-V and the daughter directive groundwater are for

- *Nitrate:* *50 mg/l,*
- *Pesticides (individual substance):* *0,1 µg/l,*
- *Pesticides in total:* *0,5 µg/l.*

According to the daughter directive groundwater, threshold values have to be determined by the member states for certain parameters. They are monitored like the quality standards. For this purpose uniform nationwide "insignificance thresholds" of the LAWA are used as threshold values (see table 8). If modifications result from the future federal ordinance, they will be taken into consideration in the second management plan (Leitfaden Monitoring Grundwasser, März 2008 [15]).

Table 8: Threshold values are taken as a basis for the first management planning. Source: Leitfaden Monitoring Grundwasser, 2008 [15].

Parameter	Threshold value	Parameter	Threshold value
Arsenic	10 µg/l	Chloride	250 mg/l
Cadmium	0,5 µg/l	Sulphate	240 mg/l
Lead	7 µg/l	Sum of Trichloroethylene a. Tetrachloroethylene	10 µg/l
Mercury	0,2 µg/l	Ammonium	0,5 mg/l
Nickel	14 µg/l	Ammonium nitrogen	0,39 mg/l

6 Evaluation

According to the WFD, the evaluation of the water's ecological as well as of its chemical status is carried out related to water bodies. At first, the evaluation of the quality components is carried out in relation to the measuring point. Afterwards, the result of the evaluation is transferred to the associated water body or the water body group. In the case that there is just one measuring point in a water body for the component of interest, the result of the measuring point is transferred. If there are several measuring points in the water body for the component of interest, the measuring point which best represents the water body usually provides the basis for the evaluation. The results of the other measuring stations/points are also used to support the evaluation (Leitfaden Monitoring Oberflächengewässer, August 2009 [10]).

With reference to the biological quality components, the evaluation of the measuring point of the water body is based on the waters-specific reference condition in an initial step. The comparison with the reference condition is also realized at heavily modified and artificial water bodies, followed by an additional evaluation of the ecological potential. Currently, dams and lakes are exceptions. They were evaluated on the basis of the trophy for the first management plan. The reason is that reliable procedures for evaluation at federal level which are compliant with the WFD have not finally been developed yet. Regarding the biological components, the ecological status of the waters is valuated using a five-stage scale: very good, good, moderate, unsatisfactory and poor (see figure 5).

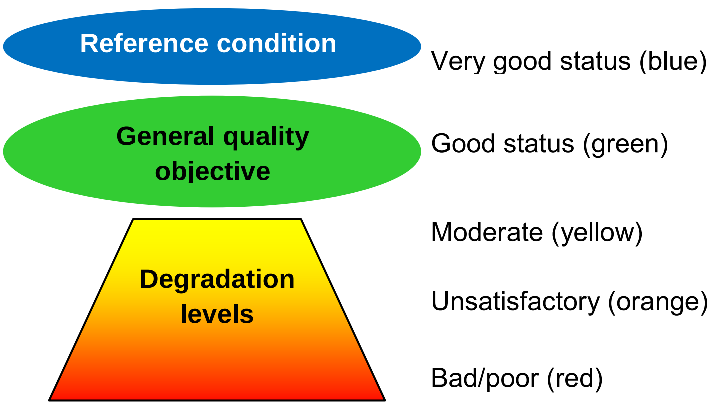

Figure 5: Five levels of degradation.

Concerning the classification of water bodies, the following components are taken into consideration:

- *Macrozoobenthos,*
- *Macrophytes,*
- *Diatoms,*
- *Phytobenthos without diatoms,*
- *Fish fauna (patomodromous and diadromous)*
- *Phytoplankton (only in certain river types).*

Relating to the fish fauna, it should be emphasized that apart from the structural morphological and physico-chemical environmental parameters, isolation by transverse structures (e.g. weirs or groundsills), fish mortality in the past as well as by a different fisheries management can have a essential effect on the fish fauna to be judged. Moreover, the data to the transverse structures are to evaluate together with the data to potamodromous and diadromous indicator species, in order to be able to make supra-regional statements regarding the consistency of waters. The evaluation of biological components is based on the „worse case“ as shown in figure 6.

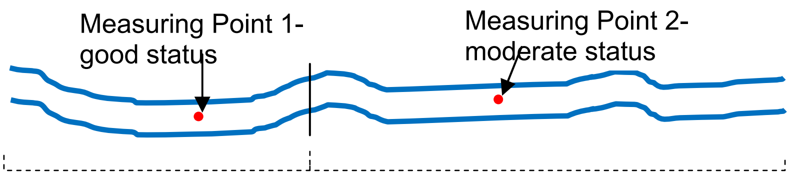

Figure 6: Worst case scenario.

The overall assessment of the water body is based on measuring point 2 since it is representative for more than half of the length of the water body. If there are several measuring points in one water body and the results of the different measuring points deviate from each other by more than one quality class, special attention has to be attached to this specific water body during the next monitoring cycle. The evaluation methods for biology partially include different modules whereas the different modules can consist of particular metrics (waters-specific indices). The assessment of the overall biological status is based on a hierarchically arranged system, aggregating the results of the various levels (Leitfaden Monitoring Oberflächengewässer, August 2009 [10]).

- *“Individual results of the metrics of the biological components,*
- *Results of the modules of the biological components,*
- *Results of the biological components (macrozoobenthos, macrophytes, phyto-benthos, fishes, phytoplankton),*
- *Overall results biology” (Bewirtschaftungsplan für die nordrhein-westfälischen Anteile von Rhein, Weser, Ems und Maas 2010 - 2015, September 2009 [11]).*

Apart from the biological status of the waters, the chemical components will also be assessed. In this context, one has to differentiate between:

- *Specific pollutants of annex 4 of the river assessment, classification and monitoring regulation (Gewässerbewertungs-, Einstufungs- und Überwachungsverordnung GewBEÜ-V [9]). These are pollutants which are not categorized as priority or priority hazardous substances. They are used for the evaluation of the ecological status – the ecological status chemistry. The environmental quality standards determined by the GewBEÜ-V provide the basis for the evaluation. In the future, the evaluation will take place on the basis of the corresponding federal regulation. If these pollutants do not comply with the determined standards, good ecological status is not reached.*
- *Supporting quality components (general chemical and physical components) – ecological status. Accompanying to and in order to validate the results of the biological investigations, the general chemical and physical components are investigated (ACP).*
- *Specific pollutants (priority substances and priority hazardous substances) of the daughter directive „environmental quality standards in the field of water policy", draft from the 20th December 2007 of the environmental council as well as of annex 5 of the GewBEÜ-V. The daughter directive – the directive on environmental quality standards 2008/105/EU – was published on the 24th December 2008 in the official journal of the European Union and came into force on the 13th January 2009. The requirements of the directive are decisive for the status chemistry.*
- *Relevant pollutants for each water body which are not covered by the indicated groups.*

As mentioned previously, the requirements concerning the chemical status are described in the environmental quality standard directive 2008/105/EU. Despite the fact that the directive could not be implemented in national law until the river basin management planning, the standards laid down in the directive were used for the evaluation in NRW. Pollutants for which legally binding norms do not exist or have not been introduced yet, are assessed on the basis of orientation values which are scientifically derived, but not yet generally confirmed (Leitfaden Monitoring Oberflächengewässer, August 2009 [10]). The evaluation based on orientation values is not used for the evaluation of the ecological status. However, it serves the purpose of identifying the need for further investigation, if the orientation value is exceeded.

The investigated components are evaluated *a priori* according to the substance and the measuring point. Principally, the evaluation which is related to the measuring points is based on a five level scale, so that the distance from the target becomes more apparent. Table 9 shows the five level scale.

Afterwards, an evaluation for all components has to be performed which is related to the water body. Here the scale of evaluation for the „eco-chemistry" is based on a three-stage system (very good, good, not more than moderate) and a two-level system for chemistry (good, not good) as shown in table 10.

Table 9: Five level scale for classification concerning the measuring. EQN = Environmental quality standard/norm (legally binding); OV = orientation values (legally not binding). Source: Landesamt für Natur, Umwelt und Verbraucherschutz, NRW.

Very good status	Value ≤ ½ EQN/OV
Good status	½ EQN/OV < Value ≤ EQN/OV
Moderate status	EQN/OV < Value ≤ 2 x EQN/OV
Unsatisfactory status	2 x EQN/OV < Value ≤ 4 x EQN/OV
Bad/Poor status	Value > 4 x EQN/OV

The compliance with environmental quality standards as well as with orientation values are checked at one measuring point usually by the annual average value from at least four measurements. The measurements should be carried out in equidistant time intervals. If there are not enough measurements in one year, the investigation period has to be extended (data from up to three years in succession). Regarding the priority substances for which a maximum allowable concentration is mentioned in the daughter directive priority substances, 2008/105/EU, the maximum measured value has to be compared with the maximum allowable concentration according to the daughter directive and that apart from the annual average value (Leitfaden Monitoring Oberflächengewässer, August 2009 [10]). Concerning the chemical status the evaluation of the substantial parameters in lakes and dams is carried out analogously to the approach in flowing waters.

Table 10: Scale for classification concerning the water body. EQN = Environmental quality standard/norm (legally binding); OV = orientation values (legally not binding). Source: Landesamt für Natur, Umwelt und Verbraucherschutz, NRW.

<table>
<tr><th>Eco - Chemistry
Annex 4.2 GewBEÜ_V</th><th>Chemistry
Annex 5 GewBEÜ_V</th></tr>
<tr><td>Very good status
Value ≤ ½ EQN/OV</td><td rowspan="2">Good status
Value ≤ EQN/OV</td></tr>
<tr><td>Good status
½ EQN/OV < Value ≤ EQN/OV</td></tr>
<tr><td>Moderate status
Value > EQN/OV</td><td>Not good/Poor status
Value > EQN/OV</td></tr>
</table>

The evaluation is based on the worse case. This means that according to the WFD, the worst evaluation of the biological quality component is relevant. The ecological status is also classified as "not more than moderate" if one or more chemical environmental quality standards (Annex 4 GewBEÜ-V) are not complied. In order to assess the ecological status, the above-mentioned levels of aggregation (biology) will be completed and can be shown as follows:

- *"Overall results biology and ACP (physical and chemical parameters),*

- *Results of the biological components (macrozoobenthos, macrophytes, phytobenthos, fishes, phytoplankton),*
- *Results of the modules of the biological components,*
- *Individual results of the metrics of the biological components ,*
- *Ecological status chemistry" (Bewirtschaftungsplan für die nordrhein-westfälischen Anteile von Rhein, Weser, Ems und Maas 2010 - 2015, September 2009 [11]).*

In order to be able to evaluate the ecological status, not only the overall result biology, but also the status eco-chemistry as well as supportive the general chemical-physical status are relevant for the evaluation (see figure 7, worst case scenario).

Concerning the chemical status, a surface water body is assessed as „good", if all relevant environmental quality standards are fulfilled. If this is not the case, i.e. if quality standards are exceeded, the water body has to be classified as „not good" or "poor status", as figure 8 shows.

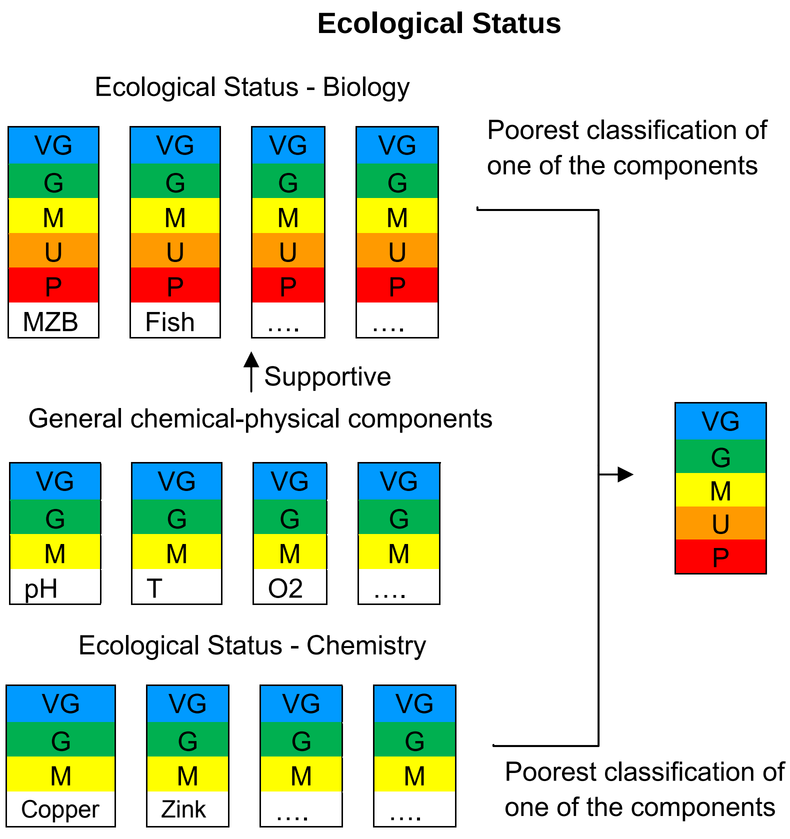

Figure 7: Evaluation of the ecological status of surface waters Source: Leitfaden Monitoring Oberflächengewässer, August 2009 [10].

The results are finally combined in an overall result is shown in figure 9. The poorest/worst evaluation is the decisive factor for the evaluation of the surface water bodies (WFD, 2000 [1]; GewBEÜ-V, Annex 7, 2006 [9]; Leitfaden Monitoring Oberflächengewässer, August 2009 [10]).

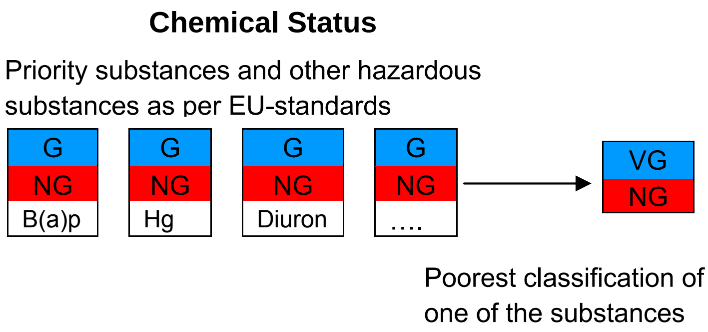

Figure 8: Evaluation of the chemical status of surface waters Source: Leitfaden Monitoring Oberflächengewässer, August 2009 [10].

Regarding the groundwater, the "good quantitative" and the "good chemical" status have to be assessed. This is made at the level of groundwater bodies. The basis of the assessment is the GewBEÜ-V and the daughter directive groundwater as well as the CIS guidelines (e.g. groundwater status, trend assessment). The results are finally combined in an overall result (figure 9).

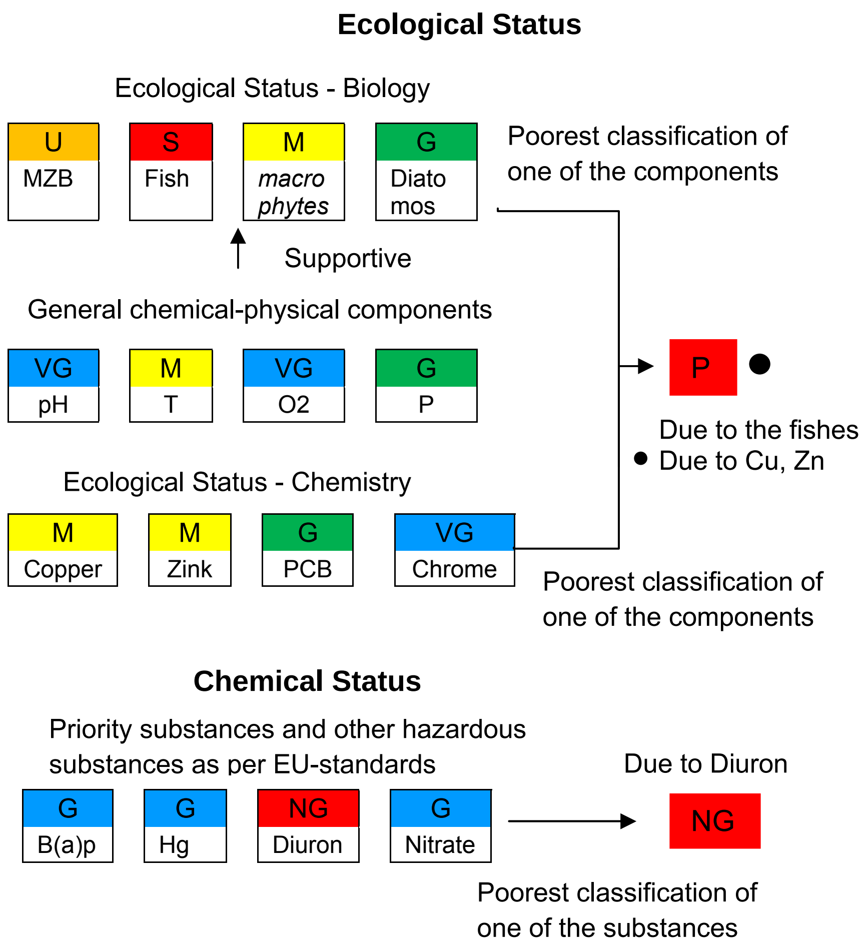

Figure 9: Overall results of the ecological status and the chemical status Source: Leitfaden Monitoring Oberflächengewässer, August 2009 [10].

In order to assess the quantitative status, the depth to water table or the groundwater table, respectively, is principally decisive. Trend analyses of groundwater table hydrograph are assessed at the measuring points which are transferred to the groundwater body as well as possibly water balances for the relevant groundwater body. In NRW, trend analyses were only carried out at measuring points with a time series from 1971 which have at least a six-monthly measurement frequency and do not have any measurement gaps of more than 400 days. For the purpose of assessment, an "effective surface" of 50 km² is defined for each measuring point. If the measuring point density or the effective surfaces of the measuring points, respectively, cover ≥ 50 % of the groundwater body's surface, this is sufficient for an assessment on the basis of a trend analysis. In case that a sufficient number of trend measuring points is not available or a negative trend of more than 1 cm/a has become apparent at one third of the surface of the groundwater body concerned, a water balance has to be additionally taken into account for the assessment of the groundwater body. A groundwater body has a good quantitative status, if no over-exploitation takes place. Moreover, no significant impacts of groundwater dependent terrestrial ecosystems or surface waters which are connected with the groundwater may be in place. This equally applies to the chemical status (Leitfaden Monitoring Grundwasser, März 2008 [15]; Bewirtschaftungsplan für die nordrhein-westfälischen Anteile von Rhein, Weser, Ems und Maas 2010 - 2015, September 2009 [11]).

In order to assess the chemical status, average values are calculated at the individual representative measuring points and this is done with regard to the 6 year period of the management plan. The assessment which is related to the measuring point is subsequently transferred to the surface in order to obtain an assessment for the whole groundwater body. The groundwater body has a good status, if the quality standards and the threshold values are not exceeded at any monitoring point. The good status is also reached in case that a quality standard or a threshold value is exceeded at one or several measuring points. However, an appropriate investigation confirms that next to other criteria which have to be complied, the pollutant concentration does not constitute a significant endangering of the environment. In NRW a characteristic land use is assigned for the significance test of each measuring point. The analysis of the significance takes place in two steps and in fact individually for each single parameter. First the representative areas of the affected measuring points are added up within a land use (effective area). If the sum of the loaded surfaces exceeds 33% of the effective area, then it is called a relevant load with regard to the land use (see figure 10). If the groundwater body shows relevant loads of different land uses, these areas are also added up. A poor chemical status can be identified, if the area added up is > 25km² or > 33% of the groundwater body surface in case of small groundwater bodies (Leitfaden Monitoring Grundwasser, März 2008 [15]). According to the requirements of the CIS-guideline No.15 (Guidance on groundwater monitoring, 2007), a poor chemical status exists, if more than 20% of the measuring points in a groundwater body exceed the limit values. The CIS-guideline was established at a later date. The monitoring and the assessment process had reached an advanced stage so that it was not anymore possible to carry out the significance test according to the CIS-guideline. Geogenic subsurface pollution was also included in the assessment process. Concerning point sources (e.g. contaminated sites) significance exists, if the area segment of the sphere of action (radius of damage 500m per point source) is > 33% of the groundwater body surface. If the spread of the contaminant plume exceeds 10% of the groundwater body surface or 25km², the groundwater body is in a bad status (Leitfaden Monitoring Grundwasser, März 2008 [15]; CIS Guidance on groundwater monitoring, 2007 [16]).

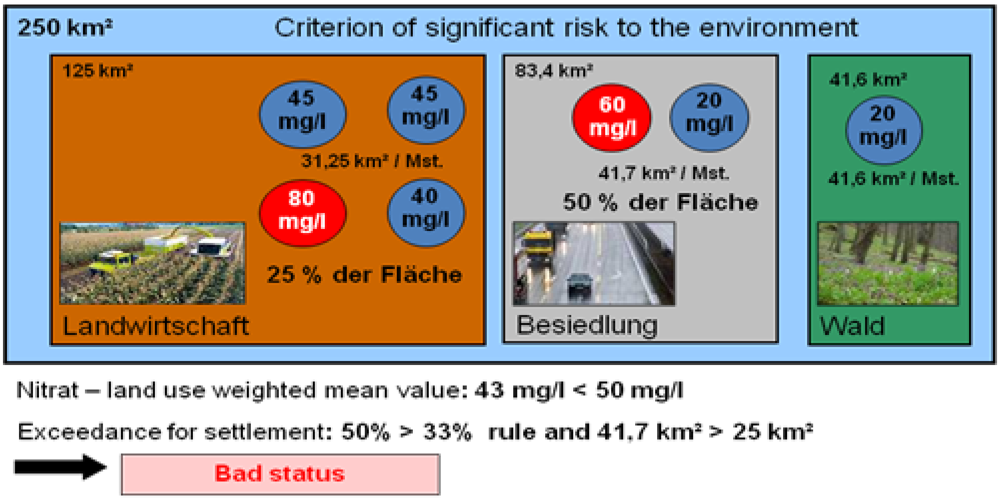

Figure 10: Criteria of significant risk to the groundwater body. Source: Bezirksregierung Arnsberg, F. Garbe.

A trend calculation has to be carried out at least in the groundwater bodies or for the parameters, respectively, that were classified as "achievement of objectives improbable". Here the prerequisite is that sufficient measuring points are available and the data are available for at least two third of the years of the monitoring period. As a starting point for a trend reversal, the WFD and the daughter directive groundwater default 75% of the quality standard as well as of the threshold value. The member states may also fix their own more stringent values. It should be noted that the trend determination and the starting point for the trend reversal are not decisive or no criterion, respectively, for the definition of the groundwater's good and bad status. The trend determination and the starting point are significant for the planning and the implementation of measures. In NRW two different trend determination are considered, i.e. the trend determination at the particular measuring point and the trend determination aggregated at the groundwater body (Leitfaden Monitoring Grundwasser, März 2008 [15]; CIS Guidance on groundwater monitoring, 2007 [16]).

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8 Annex

Table A1: Time schedule of the WFD. Source: WISE-Water Information System for Europe; http://water.europa.eu.

Year	Issue	Reference
2000	Directive entered into force	Art. 25
2003	Transposition in national legislation	Art. 23
	Identification of River Basin Districts and Authorities	Art. 3
2004	Characterisation of river basin: pressures, impacts and economic analysis	Art. 5
2006	Establishment of monitoring network	Art. 8
	Start public consultation (at the latest)	Art. 14
2008	Present draft river basin management plan	Art. 13
2009	Finalise river basin management plan including progamme of measures	Art. 13 & 11
2010	Introduce pricing policies	Art. 9
2012	Make operational programmes of measures	Art. 11
2015	Meet environmental objectives First management cycle ends Second river basin management plan & first flood risk management plan.	Art. 4
2021	Second management cycle ends	Art. 4 & 13
2027	Third management cycle ends, final deadline for meeting objectives	Art. 4 & 13
Year	Issue	Reference
2000	Directive entered into force	Art. 25
2003	Transposition in national legislation	Art. 23
	Identification of River Basin Districts and Authorities	Art. 3
2004	Characterisation of river basin: pressures, impacts and economic analysis	Art. 5

Table A2: Surveillance monitoring of surface waters. Measuring frequency and investigation periods of surveillance monitoring of flowing waters (see also guideline on monitoring of surface waters part B (2008), table B -2.1). Source: Bewirtschaftungsplan für die nordrhein-westfälischen Anteile von Rhein, Weser, Ems und Maas 2010 – 2015, Ministerium für Umwelt und Naturschutz, Landwirtschaft und Verbraucherschutz, NRW September 2009

Quality component	Measuring frequency	Monitoring period	Monitoring frequency
Phytoplankton (if relevant)	6 x / year	April to October	Every three years
Macrophytes/Phytobe nthos (diatoms)	1x / year	June to September	Every three years
Macrozoobenthos	1x / year	March to September or specific for water body types according to part A of the guideline, respectively.	Every three years
Fish fauna	1x / year	August to Mid-October	Every three years
Non priority (2) and priority substances which are relevant for the monitoring (1)	A-Measuring station Sample, 13x / year For substances, for which a calculation of loads should be made (3), two-week composite samples. If no composite sample is possible, 26 samples are taken instead/year. For the calculation of load, the corresponding run off data should be collected at the gauging stations which are registered to the monitoring stations	Continuously or equidistant, respectively	2006/2007 for the first time If relevant, annually afterwards If not relevant, a new examination every six years (at least until 2013)
	B-Measuring stations 13x / year	Equidistant (1)	2006/2007 for the first time; If relevant, annually afterwards
Other priority and non priority substances (2) whose discharge in the catchment area in quantities which are relevant for the monitoring cannot be excluded entirely	A and B measuring stations 4x / year (sample and composite sample)		On a random basis Systematic review according to the GewBEÜ-V and GewQV every six years
General chemical and physical quality components	A-Measuring station Continuously or in addition to the sampling, respectively.	Continuously or equidistant, respectively.	Annually
(ACP)	B-Measuring station 13x / year	Equidistant	Annually

[1]: All substances of the GewQV in 2007 and 2013 (at the main measuring stations), priority substances in 2007 and afterwards, if the relevance is proven, general chemical-physical quality components generally, other substances, if an exceedance of the environmental quality standard

cannot be excluded and the statements which have to be made are not received by Länder-wide operations.

[2]: Initially, i.e. until a final settlement of the evaluation matrix as part of the EU decision on chemical monitoring and/or the Daughter Directive on Priority Substances, metals are investigated on the basis of the filtered water sample as well as on the basis of the whole water sample in order to enable a comparison with standards which are determined for the matrix of suspended matter. Provided that the environmental quality standards are already met in the whole water sample, investigations on the basis of the filtered sample can be left out. Even if the dissolved phase (filtrated water sample) is defined as relevant matrix in the future, the examination of the whole water sample will be further required for the determination of loads at the surveillance measuring stations. This does not apply to A-measuring stations. Principally, the filtrated water sample has to be examined with regard to metals as well.

[3]: Heavy metals, nutritional parameters, salts, detergents, river basin specific substances if necessary, for example.

Table A3: Operational monitoring of surface waters. Measuring frequency and investigation periods of operational monitoring of flowing waters. Source: Bewirtschaftungsplan für die nordrhein-westfälischen Anteile von Rhein, Weser, Ems und Maas 2010 – 2015, Ministerium für Umwelt und Naturschutz, Landwirtschaft und Verbraucherschutz, NRW September 2009.

Quality component	Measuring frequency	Monitoring period	Monitoring frequency
Phytoplankton (if relevant)	6 x / year	Relevant vegetation period	Every three years[1]
Macrophytes/Phytobenthos (diatoms and where > 10% coverage rate PoD as well)	Phytobenthos 1x / year	Mid-June to September	Every three years[1]
	Macrophytes 1x / year	Mid-June to September	Every three years[1]
Macrozoobenthos	1x / year	Spring to summer or autumn, respectively; depends on the type of flowing water	Every three years[1]
Fish fauna	1x / year	August to Mid-October	Every three years[1]
Non priority substances which are relevant for the monitoring[2]	4x / year[3]	Equidistant[4]	At least once per three years period
Priority substances which are relevant for the monitoring[2]	4x / year[3]	Equidistant[4]	At least once per three years period
Other priority and non priority substances whose discharge at the measuring station cannot be excluded entirely (on a sample basis control)[2]	1-4x/year[3]		Examination on a sample basis
ACP = General chemical and physical quality components[5]	In addition to the sampling of the other quality components (except from fish fauna)		
	On our own account: 4x / year (recommended)	Equidistant	At least one per three years period

[1]: If the good condition is achieved for the considered component or an improvement cannot be expected due to an unchanged load situation and as long as the statement cannot be received by a "group of water bodies", the frequency of repetition can be increased to every six years.

[2]: Initially, i.e. until a final settlement of the evaluation matrix as part of the EU decision on chemical monitoring and/or the Daughter Directive on Priority Substances, metals are investigated on the basis of the filtered water sample as well as on the basis of the whole water sample in order to enable a comparison with standards which are determined for the matrix of suspended matter. Provided that the environmental quality standards are already met in the whole water sample, investigations on the basis of the filtered sample can be left out.

[3]: According to the GeWBEÜ-V, for waters, from which drinking water is extracted, the investigation should be carried out 8x/year in case of extraction quantities of 10.000-30.000 inhabitants; in case of extraction quantities of >30.0000, the investigation should be carried out 12x/year.

[4]: Substances which are registered seasonally: The periods of application should be registered.

[5]: For waters, which underlie the regulations of the "FischgewV" or the "QOTV", the measuring frequencies listed there have to be taken into account (in case that they are higher).

Table A4: Environmental quality standards for priority substances and certain other pollutants. Source: DIRECTIVE 2008/105/EC on environmental quality standards, December 2008 [30].

Substances of Annex 5 GewBEÜ-V and the guideline 2008/105/EC / Unit µg/l				
13 priority hazardous substances	AA-EQN ISW[1)]	AA-EQN OSW[2)]	MAC-EQN ISW[1)]	MAC-EQN OSW[2)]
Anthracene	0.1	0.1	0.4	0.4
Brominated diphenylether	0.0005	0.0002	-	-
Cadminum and cadminum compounds				
< 40 mg $CaCO_3$/l	≤ 0.08	0.2	≤ 0.45	≤ 0.45
40 bis < 50 mg $CaCO_3$/l	0.08		0.45	0.45
50 bis < 100 mg $CaCO_3$/l	0.09		0.6	0.6
100 bis < 200 mg $CaCO_3$/l	0.15		0.9	0.9
≥ 200 mg $CaCO_3$/l	0.25		1.5	1.5
C10-13-Choralkanes	0.4	0.4	1.4	1.4
Endosulfan	0.005	0.0005	0.01	0.004
Hexachloro-benzene	0.01	0.01	0.05	0.05
Hexachloro-butadiene	0.1	0.1	0.6	0.6
Hexachloro-cyclohexane	0.02	0.002	0.04	0.02
Mercury and mercury compounds	0.05	0.05	0.07	0.07
Nonylphenols	0.3	0.3	2.0	2.0
Pentachloro-benzene	0.007	0.0007	-	-
Polycyclic aromatic hydrocarbons (PAH)				
Benzo(a)pyrene	0.05	0.05	0.1	01
Benzo(b)fluoranthene/Benzo(k)fluoranthene	∑ = 0.03	∑ = 0.03	-	-
Benzo(g,h,i)-perylene / Indeno(1,2,3-cd)-pyrene	∑ = 0.002	∑ = 0.002	-	-
Tributyltin compounds	0.0002	0.0002	0.0015	0.0015
20 priority substances				
Alachlor	0.3	0.3	0,7	0,7
Atrazine	0.6	0.6	2,0	2,0
Benzene	10	8	50	50
Chlorfenvinphos	0.1	0.1	0,3	0,3
Chlorpyrifos	0.03	0.03	0,1	0,1
1,2-Dichloroethane	10	10	-	-
Dichloromethane	20	20	-	-
Di(2-ethylhexyl)-phthalate	1.3	1.3	-	-
Diuron	0.2	0.2	1,8	1,8
Fluoranthene	0.1	0.1	1	1
Isoproturon	0.3	0.3	1,0	1,0
Lead and lead compounds	7.2	7.2	-	-
Naphthalene	2.4	1.2	-	-
Nickel and nickel compounds	20	20	-	-
Octylphenol	0.1	0.01	-	-
Pentachloro-phenol	0.4	0.4	1	1
Simazine	1	1	4	4
Trichloro-benzenes	0.4	0.4	-	-
Trichloro-methane (chloroform)	2.5	2.5	-	-
Trifluralin	0.03	0.03	-	-

[1)] Inland surface waters; [2)] Other surface waters

AA: Annual average; MAC: Maximum allowable concentration; EQN: Environmental quality standard

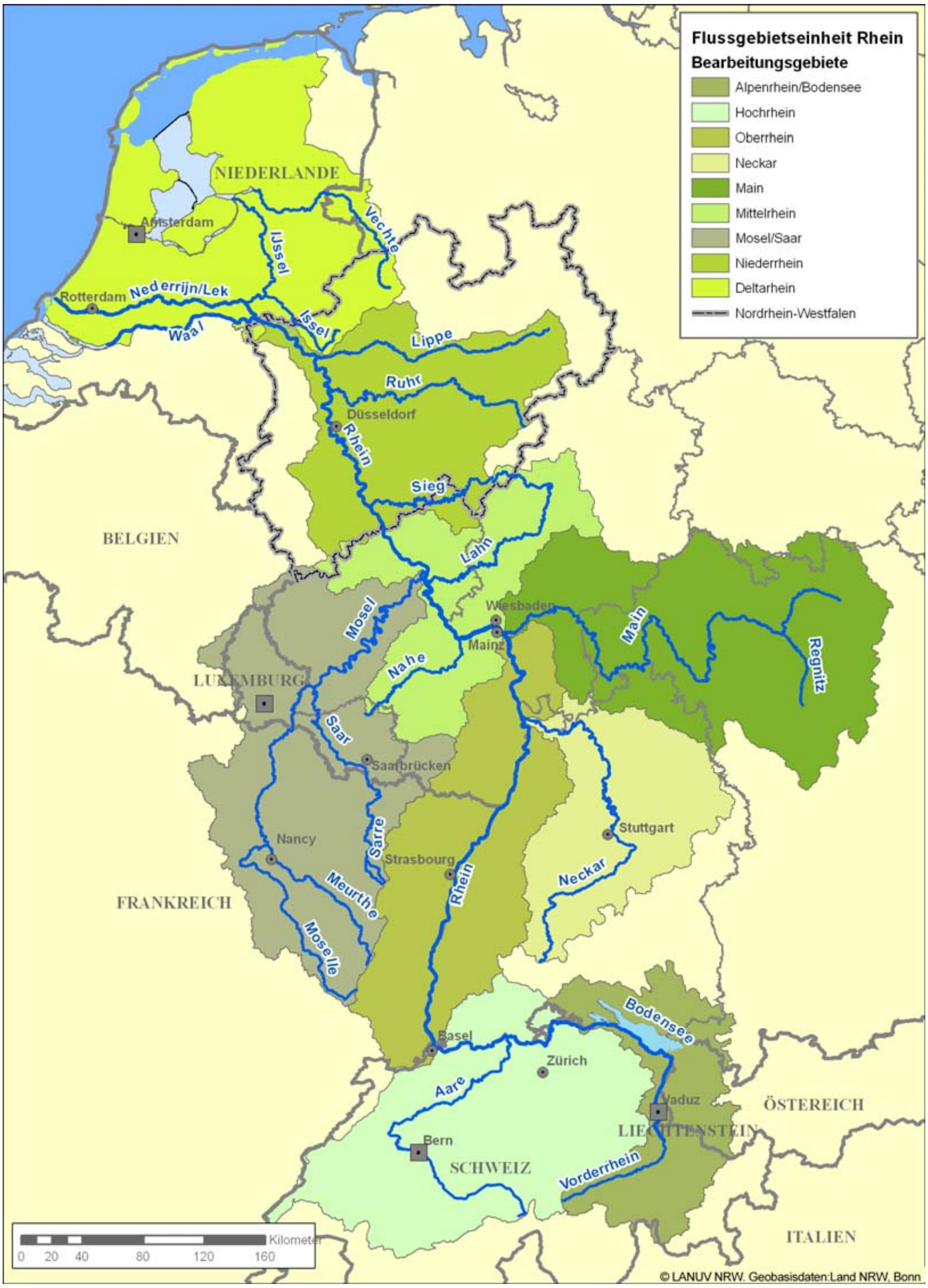

Figure A1: Catchment aeras of the Rhine River. Source: Ministerium für Umwelt und Naturschutz, Landwirtschaft und Verbraucherschutz, NRW.

Figure A2: Sub-catchment areas and planning units of the river Rhine in NRW. Source: www.flussgebiete.nrw.de/Bewirtschaftungsplanung.

Legal aspects of water management and sanitation in Brazil

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1 Introduction

The statistics on water scarcity and lack of sanitation are not new. Over 1 billion people do not have access to drinking water, and for 2.5 billion people waste water collection networks are not available. In this context, Brazil is considered to be "wealthy" in terms of its fresh water reservoirs. Some say the country owns approximately 13% of the world's fresh water, two of the biggest river basins in the world and one of the biggest aquifers. But this great richness of water resources does not mean that the Brazilians live in good and healthy conditions, that the country has a good management of its water resources nor that it is prepared to deal with the challenges imposed by the global economy. Amongst other analysis (economic, sociological, historical, political) the evaluation and critique of the legal treatment given to water resources and sanitation is necessary to understand the reality of a country so rich of natural resources and yet so underdeveloped.

This paper summarizes the results of the presentation and work developed at the "DAAD Expert Seminar on Rural Sanitation and Watershed Management in Latin America" held in 2009 in João Pessoa, Paraíba, Northeast of Brazil. It intends to highlight some of the legal aspects of water management in Brazil, like the principles of the water policy, the decision making process and its main actors. The paper also presents the state of the regulation of sanitation services, as well as the main criticism and faults that could be pointed out on these legal texts.

2 Water management in Brazil: what the Constitution and the Law say

The Brazilian Constitution from 1988 is the first text to be studied to understand water management, because it determines who in the Federation owns which water resources and also who has the power to legislate and to take measures related to water resources. It's important to say that, before 1988, it was possible to find "private water" as a legal category, as well as in reality.

According to Brazil's Constitution, the surface waters (rivers and lakes) belong to the federal government that exists in the territory of 2 or more states, that constitutes borders with other countries, that comes from or goes to other country's territory and the reservoirs of federal construction (art. 20, III), as well as all mineral resources, including those of the underground (art. 20, IX and art. 176).

On the other hand, surface water that does not belong to the federal government (according to the criteria mentioned above) is under state jurisdiction. Likewise, groundwater in general belongs to the states (art. 26, I).

The federal government also has the power to legislate on water resources, to establish a national water resources management system and to define criteria to authorize its use (art. 21, XIX). To regulate the article 21, XIX of Brazil's Constitution, in 1997 was enacted the federal Law no. 9433 that creates the National Policy of Water Resources and establishes the National Water Resources Management System.

On the Law no. 9433's first article there are the grounds of the national policy for water: water is a public good; water is a limited natural resource with economic value; in scarcity, the priority is human consumption and animal thirst-quenching; management should favor multiple uses; hydrographic basin is the territorial unit to implement the policy; water resources management should be decentralized and count on the participation of the government, users and communities.

The goals of the national policy of water resources are (according to art. 20): to guarantee to the present and future generations water resources in adequate quality for its use; to achieve sustainable development and a rational and integrated use of water resources; to prevent and react against "critical hydrological events" because of natural causes or because of inadequate use of natural resources.

The law creates instruments that are supposed to achieve these goals. The instruments are, first of all, charging a price for the use of water resources. The use of bulk water depends on an administrative act of authorization, a permit or a license to use water, called "outorga" in Portuguese. Other instruments are: the development of plans for water resources, the classification of water bodies according to its uses and the establishment of a data system (art. 5). This classification was made by the National Council of Environment (Conselho Nacional de Meio Ambiente – CONAMA) in 2005 with the Resolution n. 357.

One of the criticisms that can be made on the Brazilian law, so far, is that it is grounded on the concept of water as a public good. The Constitution mentions the environment as a good of common use of the people ("bem de uso comum do povo", in Portuguese), which is more restricted than "public good" in Brazilian legal system. The Constitution says: "article 225. Everyone has the right to an ecologically balanced environment and the common use and essential to a healthy quality of life, imposing upon the Government and the community the duty to defend it and preserve it for present and future generations". Besides, Brazil already has a law for the National Policy of Environment (Law. n. 6938/1981) that establishes that the environment is a "public property that has to be guaranteed and protected, considering the collective use" (art. 2, I) and also defines surface and groundwater as an "environmental resource" (art. 3, V). Contrarily, the Law 9433/1997 does not mention water bodies being linked to the environment or to the people.

The law is grounded on the idea of water as a limited natural resource with economic value, with no regard whatsoever to social, environmental, cultural and religious values of fresh water. The prominence of the economic approach (besides representing an enormous regression on the social apprehension of fresh water) explains that the main instrument to implement the policy is the idea of pricing water, making no exception to the small amount that every human being needs per day - even thought the priority of use is for human consumption, in situation of scarcity. It is not ignored that charging a price for the use of water is one way to incentive the rationalization its use (so is environmental education, for example, which is not even mentioned), but it should take into consideration other aspects necessary to truly make a public policy (Brzezinski, 2009; Caubet, 2004). Anyhow, after 13 years of the enactment of the law, the charging for the use of water has been imposed only in 4 river basins. Even though the pricing of water is only begging, the Federal government already gains 27 millions of Reais (approximately 14 million american dollars), pricing the use of water of only 2 river basins: Paraíba do Sul (that occurs in São Paulo, Paraná, Minas Gerais and Rio de Janeiro) and the basin of the rivers Piracicaba, Capivari and Jundiaí (that occurs in São Paulo and in Minas Gerais). Probably by the second semester of 2010, the Federal government will start charging for the use of water from São Francisco river basin (the second largest in Brazil) which represents another 20 million Reais per year. The management of the resources gathered with pricing the surface water is in charge of the National Water Agency (Coimbra, 2009). According to the website of the National Water Agency, there are so far 8 established committees in river basins that comprehend the territory of two or more States, thus, under federal jurisdiction. They are: the committee of São Francisco River (comprehends the States of Alagoas, Bahia, Distrito Federal, Goiás, Minas Gerais, Sergipe and Pernambuco); committee of Rio Doce (Minas Gerais and Espírito Santo); committee of Pomba e Muriaé rivers (Minas Gerais and Rio de Janeiro); committee of Paraíba do Sul (São Paulo, Rio de Janeiro e Minas Gerais); committee of Piracicaba, Capivari and Jundiaí rivers (São Paulo and Minas Gerais); committee of Rio Verde Grande (Bahia and Minas Gerais); committee of Paranaíba river (Distrito Federal, Minas Gerais, Goiás and Mato Grosso do Sul); and committee of Piranhas-Açu river (Paraíba and Rio Grande do Norte).

Another problem that could be pointed out is the following: the law establishes the need for an administrative act of authorization for the use of water, a water permit, and says literally that it doesn't mean the selling of water (because water cannot be sold), only the right to use (art. 18). However, the allowed water uses range from an input to the production process to waste water disposal (with the exception of insignificant uses). Considering that the permit can only be given according to the classification of water bodies and the priority of uses established by the plans of water (both instruments of the policy), according to article 13, no license could be given before there are well established river committees that have already made a plan of water resources, determining the priority of uses. But in fact entire rivers have been sold: many river basins committees yet do not exist to begin with, permits of use are given with no regard for the priority of use, since there isn't priority of use established on the plan of water resources for that basin. The reason is that there is no plan for the basin (Caubet, 2004).

Another purpose of the Law n. 9433/1997 is to create a National Water Resources Management System. According to article 32, the system has the following goals: coordinate water resources management; decide on the conflicts related to water resources; implement the National Policy of Water Resources; plan, regulate and control the uses, the conservation and the recovery of water resources.

The institutional arrangement of the management system in Brazil covers: the National Council of Water Resources (Conselho Nacional de Recursos Hídricos - CNRH); the National Water Agency (Agência Nacional de Água - ANA), the States Councils and Federal District Council of water resources; river basins committees; public institutions whose work is related to water resources management; and water agencies. Each of these institutions has a precise agenda to fulfill with regard to water resources management (art. 33).

Most of the power is concentrated on the executive institutions and on the councils. The most important institution is the National Council of Water Resources. According to article 35 of the Law 9433/1997, the Council has the power:

I – to link the planning of water resources with national, regional, state and users planning;

II – to decide (in the last administrative level), the conflicts between states councils of water resources;

III – to debate and resolve projects for the use of water with repercussions beyond State's level;

IV – to decide on issues that have been forwarded by state councils of water resources or river basin committees;

V – to examine proposals to amend the legislation relating to water resources and to the national policy of water resources;

VI – to establish supplementary guidelines for the implementation of the national policy, for the use of its instruments and for the activities of the water resources management system;

VII – to approve proposals for the creation of river basin committees and establish general criteria for the establishment of their regiments;

IX – to monitor the implementation and approve the National Plan for Water Resources and determine the steps needed to meet its goals;

X – to establish general criteria for the granting of rights of use of water resources and for charging for their use.

The river basin committees have mainly consultative purpose. They can debate and decide only on primary administrative level. The most important tasks of the river basin committees determinate by the Law 9433/1997 are: establishing the Plans of water resources and establishing the criteria for the pricing of water (art. 38; Table 1). The water agencies are secretariats of the river basin committees (art. 41 and 42).

The water management system's arrangement can be illustrated by Figure 1. The main issue in terms of the system's arrangement is the fact that it doesn't actually favor public participation on the decision making process. Taking a close look to the grounds of the policy, it can be realized that public participation was not even meant to be possible. The Law talks about the participation "of the government, users and communities" (art. 1, VI).

Table 1: The competence of the river basin committees, in their sphere of operation, is specified by art. 38 of the Law 9433/1997. Decisions of the river basin committees may be appealed to the National Council of Water Resources or to the States Councils of Water Resources, in accordance with its jurisdiction.

No.	River basin committee competence
I	To promote the discussion of issues related to water resources and defining the activities of the entities involved
II	To arbitrate in the first administrative level, disputes relating to water resources
III	To approve the water resources Plan for the basin
IV	To monitor the implementation of the water resources Plan for the basin and suggest the steps necessary to accomplish its goals
V	To propose to the National and the State Water Resources accumulations, derivations, borrowings and of low significance, for purposes of exemption from the requirement for granting rights of use of water resources, according to these areas
VI	To establish mechanisms for charging for the use of water resources and suggest the values to be charged
X	To establish criteria and promote distribution of the cost of the works of multiple use of community interest

First of all, is obvious that the policy is made with the participation of the government, because the government makes it. Second, the participation of users does not mean public participation in the sense of a formula of participative democracy, because "users" is a category that gathers industry, agriculture, dam builders, mining business, navigation business, in other words, the economic sectors interested. No human being is a user. There could be some public participation if the "participation of communities" meant something besides an isolated statement on art. 1 of the Law 9433/1997. But it does not.

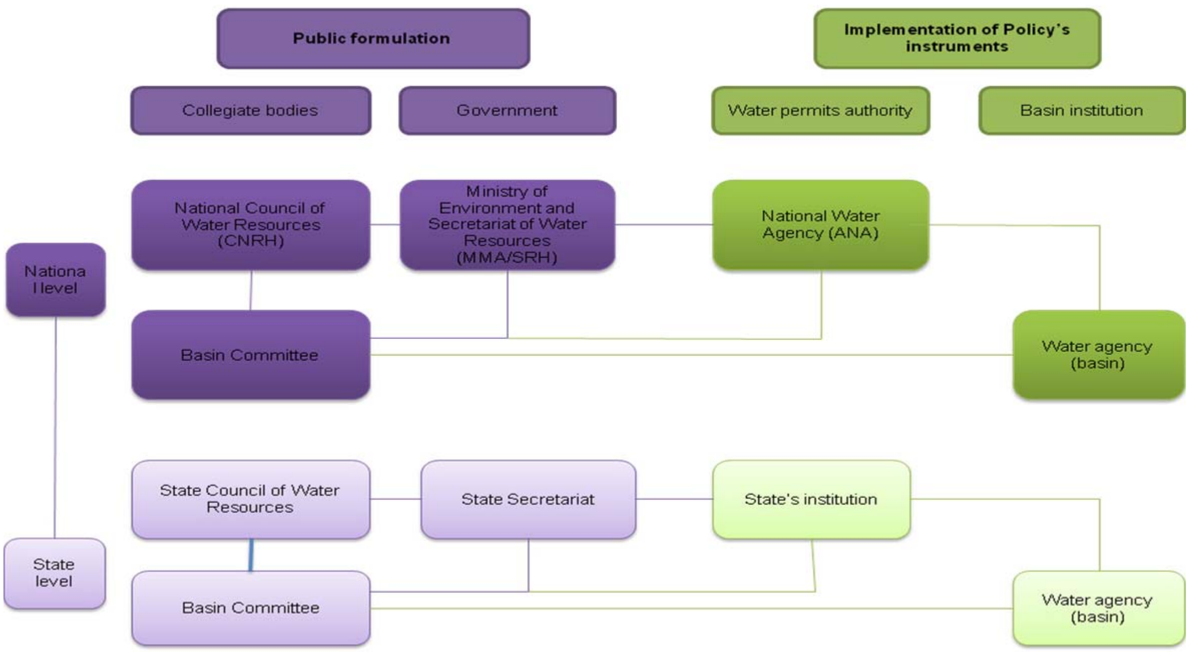

Figure 1: Translation and adaptation of the chart representing the national management system of water resources, presented by Secretariat of water resources from the Ministry of Environment of Brazil on its website. Available at: http://www.mma.gov.br.

This happens because the composition of the National Council of Water Resources (*According to art. 34 of the Law 9433/1997, the National Council is composed of: representatives of Ministries and Secretariats involved in the management or use of water resources; representatives nominated by the State's Councils of water resources; representatives of users and representatives of civil organizations. The number of representatives from the Federal government cannot exceed one-half plus one of all members of the Council*) – and therefore the State's councils and also the river basin committees (Table 2) – is based on a division of power that gives no chance for public (or community, to be precise) participation.

Table 2: The River Basin Committees are composed of representatives (Article 39). § 1 - The number of representatives from each sector mentioned in this article, as well as the criteria for appointing them, will be established within the committee, but the representatives of Federal government, States, Federal District and Municipalities are limited to half of the total membership.

No.	River basin committee representatives
I	from the Federal government
II	from the States and the Federal District whose territories are located, even partially, in their respective areas of operation
III	from the Municipalities located in whole or in part in its area of operation;
IV	from the users of water in their area of operation;
V	from the civil society groups related to water resources with proven activities in the basin.

40% of the chairs belong to the government, 40% to the users (that are the representatives from industry, dam builders, agriculture etc) and 20% of the chairs should be fulfilled with "civil society organizations" dedicated to the issue of water resources (Table 3).

Table 3: The Law stipulates what are civil organizations of water resources (art. 47).

No.	River basin committee representatives
I	intermunicipal associations and consortia of watersheds;
II	regional, local or sectoral associations of users of water resources;
III	technical and research organizations with interest in the area of water resources;
IV	non-governmental organizations with goals to defend diffuse and collective interests of society;
V	other organizations recognized by the National or State Councils of Water Resources

In the end, the "public" that is allowed to participate does not have enough power to stand up and be counted. On the contrary, it only provides coverage to the decisions that have already being made by the strongest participants (Caubet, 2004). Public participation on collegiate bodies of the water management system in Brazil can be illustrated by Figure 2.

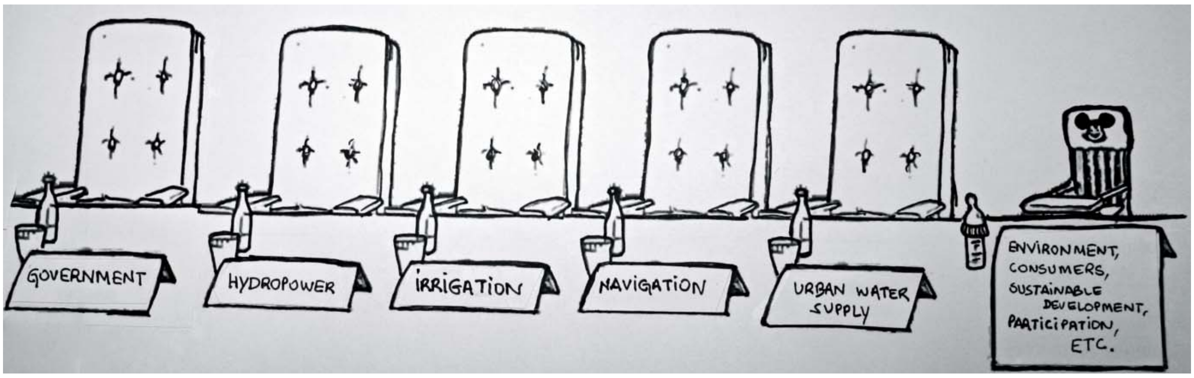

Figure 2: Public participation on collegiate bodies of the water management system in Brazil.

Integrated water management is considered to be a good practice and it is internationally recommended. About integrating the management of Brazilian water, the Law 9433 only offer general "guidelines for action" on its article 3. It says that water resources should be based on a systemic approach, integrating environmental, soil and estuarine and coastal zones management. But it is not only a problem of coordinating all public policies somehow related to water resources. There is also the issue of coordinating public institutions in the complex repartition of power of the Brazilian Federation.

For example, there are national and states policies for the environment, sanitation, hydroelectricity, and there are municipal policies of urban soil occupation, garbage disposal, etc. Many institutions in all spheres of the Federation (federal, state, municipal and the federal district) need to exchange information and make their activities coherent.

The law simply says that the federal government (art. 29, IV) and the states (art. 30, IV) have to foment the integration of water resources management with environmental management. States and Federal Governmental shall cooperate (art. 4) in case of "water resources of common interest". Besides that, "in the implementation of the National Policy of Water Resources, federal, state and municipal governments will promote integration of local policies for sanitation, for use, occupation and conservation of soil and for the environment, with the federal and state policies for water resources" (art. 31). It does not actually describe the instruments to do so.

There is another issue not addressed by the Law 9433, namely integrating the management of surface water with groundwater. In fact, the law barely mentions groundwater, except to prescribe that groundwater exploitation depends on a permit (art. 12), the same one needed for surface water. The attempt to integrate the management of surface and groundwater is being made infralegis by the National Council of Water Resources (Conselho Nacional de Recursos Hídricos – CNRH), which enacted in 2001 the Resolution n. 15, and the National Council of the Environment (Conselho Nacional de Meio Ambiente – CONAMA), that enacted in 2008 the Resolution n. 396, as a regulatory framework for groundwater (Novaes, 2008).

The issue of groundwater is delicate because, as mentioned before, the Brazilian Constitution establishes that groundwater belongs to the States, but mineral water (all mineral resources, including those on the underground) is under federal domain. So there are two different legal regimes for groundwater and mineral water, and two different administrative acts to allow the use of one or another. The groundwater considered to be mineral is subject to the Mining Code (Decreto-lei n° 227/67) and the Mineral Water Code (Decreto-lei n. 7841/45) and its exploitation depends on authorization from the National Department of Mine Production (Departamento Nacional de Produção Mineral – DNPM). Groundwater in general is subject to the permit of the State, according to its own state policy (whose guidelines are given by the National Policy) (Camargo, 2009).

It is worth to mention that the situation of transboundary groundwater is particularly more delicate. The Constitution prescribes clearly that groundwater belong to the States. But the Federal government tries to deal with it analogously to surface water. Legally, it is considered to be federal domain when groundwater crosses the territory of two or more States, when it marks the border with another country, or when it comes from or goes to the territory of another country. As one of the directors from the National Water Agency says: a "federative pact" is needed to integrate the management of groundwater resources, either that or a change on the law (ANA, 2009). This is fact is what it's happening: since 2000 there's a proposal to emend the Constitution (PEC n. 45/2000) on that matter (Coimbra, 2009).

The main concern of the federal government is to assure its control over one of the biggest reservoirs of fresh water, the Guarani Aquifer, that extends over Brazil (71%), Argentina (19%), Paraguay (6%) and Uruguay (4%). In Brazil, the Guarani extends over eight states of the Federation: Rio Grande do Sul, Santa Catarina, Paraná, São Paulo, Mato Grosso do Sul, Mato Grosso, Goiás and Minas Gerais. Covering a total area do 1,2 million square kilometers, the aquifer holds 45 thousand cubic kilometers of water (Figure 3).

Even though it was "discovered" in the 1990's and it hasn't been studied enough, the Guarani is exploited already: 500 cities in Brazil are partially or fully supplied with the groundwater from the aquifer. The most important study on the aquifer was carried out by the Organization of American States, in the context of a Project financed by the World Bank, through the Global Environmental Fund (GEF): "Environmental protection and integrated sustainable management of the Guarani Aquifer". Ribeirão Preto is a city in the State of São Paulo that is completely dependent on the water from the aquifer, and its inhabitants consume 400 liters per day, on average (Coimbra, 2009). There is no legal framework to regulate the exploitation of the aquifer and the relations between the four countries where it occurs. Inside Mercosul (the international organization of economic integration that gathers Brazil, Argentina, Paraguay and Uruguay), an attempt to develop an agreement failed.

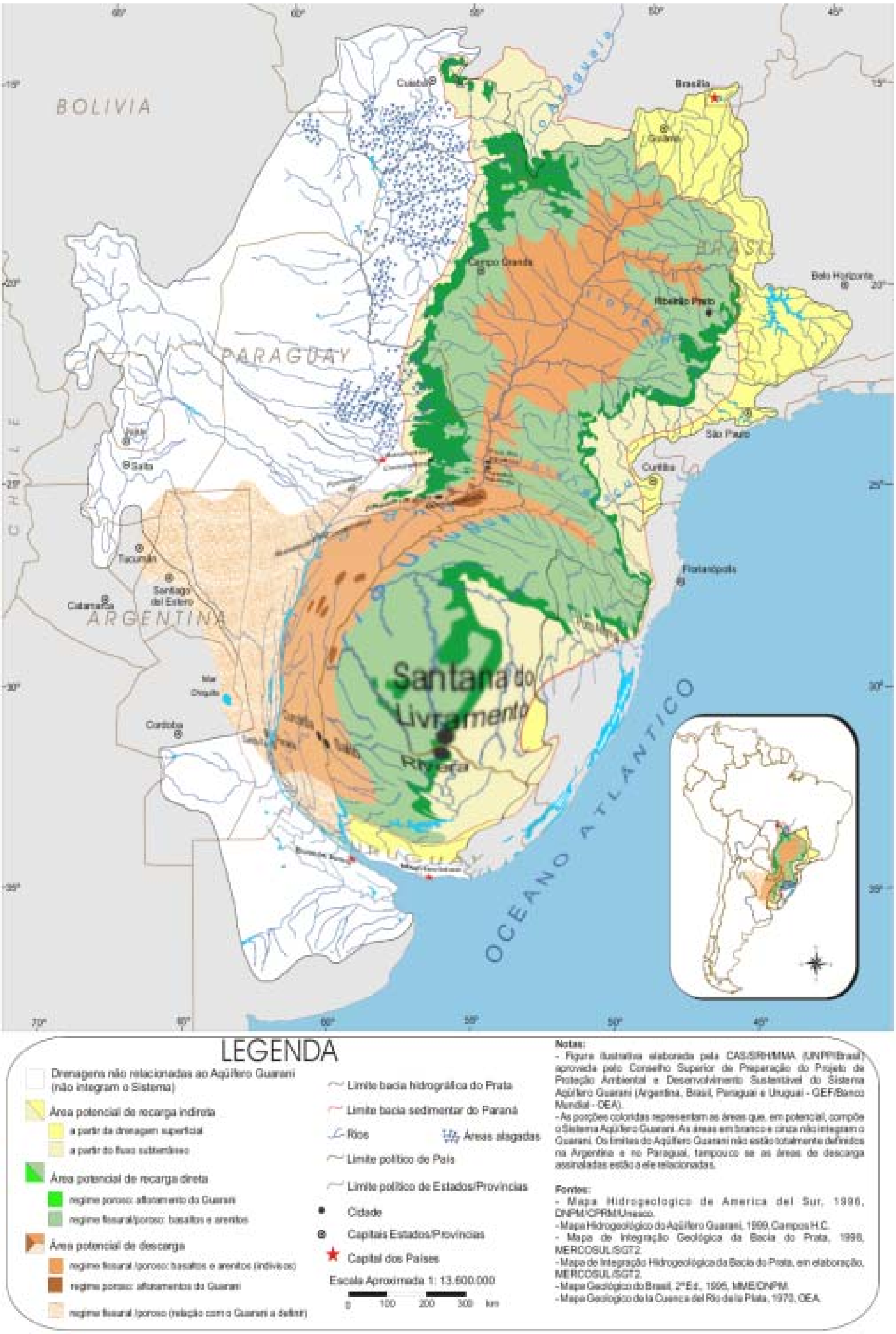

Figure 3: The Guarani Aquifer.

3 Regulation of sanitation: no man’s land?

While Brazilians national water policy Law is already 13 years old and is not fully implemented yet (not to mention monitored and enforced), the situation in the sanitation sector is even worse. For a long time, there was no regulation whatsoever to sanitation services. First, it is necessary to mention that sanitation in Brazil is considered to be a group of actions with the intention of promoting public health and the population’s well being and it comprehends: water supply, sewage, urban drainage and garbage management – according to the Brazilian institute for geography and statistics (Instituto Brasileiro de Geografia e Estatística – IBGE). Second, it is necessary to explain the context of the current legal framework of sanitation. In the 1960’s, the military government dealt with the issue of sanitation, establishing the National Plan for Basic Sanitation (Plano Nacional de Saneamento Básico – PLANASA) through the Law n. 5318/1967 and “Decreto” n. 82.587/1978.

PLANASA had amongst other goals: to eliminate the deficit and maintain the balance between demand and supply of public water and sewage, to establish a financially self-sustained sector, to adequate tariffs to the possibilities of the users and to develop state sanitation companies. These states companies were supposed to use “crossed subsidies” (the tariffs paid in places where the service was profitable should subsidize the places with deficits) in order to provide access to sanitation services to all levels of society. The users of the service would only pay for the sanitation service costs and return on capital invested (a maximum of 12% per year), but not by the volume of water supplied. The system was also financed by the National Bank of Habitation (Banco Nacional de Habitação - BNH).

At least in terms of water supply, the program can be called successful, because between 1970 and 1971, the percentage of urban households served by public network increased from 60% to 86%. With the closing of the bank that helped financing the system and its expansion, the PLANASA was officially extinct in 1992. Between 1992 and 2007 there was no legal framework to regulate sanitation. State’s companies had no investment and the municipalities tried to recover the network, in order to privatize or delegate the service. There was (and there is until today) a competition between states and municipalities for the exercise of jurisdiction over the sanitation sector (Brzezinski, 2009).

The Brazilian Constitution of 1988 didn’t bring any definition of public service, nonetheless sanitation service, except for the attribution of competences. Art. 22, XX of the Constitution says that it is federal government’s responsibility to establish general rules on urban development, including habitation, sanitation and urban public transport. But it’s a duty of all Federation spheres (Municipal, State and Federal) to protect the environment (according to art. 23, VI of the Constitution).

Because there is a rule (art. 30, V of the Constitution) predicting that municipalities are responsible for the public services of “local interest”, the majority of the jurists agree that sanitation services are within the jurisdiction of municipalities – although the environmental issue if a responsibility of the 3 levels of government and despite the fact that water resources belong to the states or, eventually, to the federal government.

Finally, on January 5th of 2007, the Law No 11.445, which "establishes national guidelines for sanitation and for the federal policy of sanitation", also called the new regulatory framework for the sanitation service, was enacted.

The new regulatory framework for sanitation establishes: principles (chapter I); rules for who “owns” the service (chapter II); rules on regional supply (chapter III); rules on planning (chapter IV); regulation (chapter V); rules on social and economical aspects of the service (chapter VI); rules technical aspects (chapter VII); and rules on social control (chapter VIII). In addition to the national guidelines, the Law 11445/2007 creates a "Federal Policy of Sanitation”, which handles the allocation of federal resources (art. 50), the development of a National Plan of Sanitation (art. 52) and establishment of a National Information System on Sanitation (art. 53).

The fundamental principles of basic sanitation, according to article 2 of the Law 11445/2007, are:

I – universal access;

II – sanitation as a whole, a set of all activities and components of each of several basic sanitation services, providing access to the population in accordance to their needs and maximizing the effectiveness of actions and results;

III - water supply, sanitation, urban sanitation and waste management performed in a manner appropriate with public health and environmental protection;

IV – urban drainage and rain water management according to public health and safety of life and public property and private sectors;

V – the adoption of methods, techniques and processes that take into consideration local and regional peculiarities;

VI – integration with policies of urban and rural development, habitation, strike to hunger and poverty, environmental protection, health promotion and other policies socially relevant to improve the quality of life for which sanitation is a determining factor;

VII – efficiency and economic sustainability;

VIII – use of appropriate technologies, considering the payment capacity of users and the adoption of progressive solutions;

IX – transparency of actions;

X – social control;

XI – safety, quality and regularity;

XII – integration of infrastructure and services with the efficient management of water resources.

The Law recognizes that sanitation is a complex setting of measures, infrastructure and operating facilities for water supply, sewage (collection, transport, treatment and final placing), urban cleaning and solid (domestic) waste management, drainage and management of rainwater in urban areas (art. 3).

Although the Law doesn't face the issue of the ownership of the service of sanitation, it establishes what the owner can and cannot do. First, according to art. 8 of Law 11445/2007, the entity can delegate almost everything: the organization, regulation, the monitoring and the provision of the service. The only thing that it cannot do is to delegate the power of making a public policy for sanitation. And the formulation of a public policy for sanitation means:

I – to prepare plans for sanitation;

II – to directly provide or authorize the delegation of services and define the entity responsible for regulation and monitoring, as well as the procedures for these actions;

III – to adopt standards to assure public health, including regarding the minimum amount of water per capita by public supply, in compliance with national standards on drinking water;

IV – to set the rights and duties of users;

V – to establish mechanisms of social control;

VI – to establish an information system, in conjunction with the national sanitation information system;

VII – to intervene and take over delegated services, by appointment of the regulator, under the conditions prescribed by the law and contracts (art. 9, Law 11445/2007).

The obligation of the federal government or the states or the municipalities to elaborate public policies under its respective jurisdiction is something obvious. Instead of reaffirming the obvious, why did the Law not establish standards for sanitation to assure public health? Why did it not lay down the rights and duties of the users? Why did it not settle the minimum amount of water each and every human being has a right to?

The Law says that the delegation of the provision of sanitation services has to happen through a contract, which must obey certain requirements of validity. They are: the existence of a plan of sanitation, the existence of a study demonstrating the technical feasibility, economic and financial benefit of universal and comprehensive services, the existence of regulatory standards that provide the means to respect the guidelines of the law, including the nomination of the entity that will regulate and monitor, a hearing and public consultation on the bidding procedure and on the contract (art. 11 of Law 11445/2007).

Even though the Law mentions the principles of regulation (transparency, celerity, objectivity, technicality – art. 21) and its objectives (establish standards, guarantee the fulfilling of goals, prevent and oppose the abuse of economic power, as well as define tariffs that guarantee the financial and economical balance of contracts), there is no prediction on how the goals will be achieved. The regulation, as it was mentioned by the Law, is only a matter of "juridical security".

But the main criticism that must be made is the fact that the Law allows the interruption of the services in case of lack of payment by the users. Instead of establishing conditions to maintain minimum standards of public health and respect for human rights, the Law simply leaves the conditions for future regulation in which exceptions will be accepted. The art. 40

sets the possibilities of interruption of the providing the services: emergency situations (I); need to make repairs, modifications or improvements in the system (II); user's refusal to allow the installation of a metering device for water consumed after having been notified about it (III); improper handling of pipes, meters or other facility (IV); and the lack of payment by the user, after having being formally notified (V).

There is an exception, on paragraph 3: the interruption or restriction of the water supply due to non-payment, in case of health facilities, educational institutions, hospitals and individual user of low-income shall observe criteria that preserve minimum health conditions of the people affected. Depending on how the regulation is developed, this could be interpreted as the guarantee of a human right to water. But, considering the general context of these legal provisions, it is most likely that this exception to the interruption of services will not mean anything.

Finally, it has to be mentioned that the Law places social control as one of the principles of sanitation (art. 2, X), but the only prediction about it on art. 47 do not allow much social control. The article stipulates that "the social control of the public services of sanitation may include the participation in collegiate consultative bodies, assured the representation of: the 'owner' of the service; governmental bodies related to sanitation; providers of the services; the users; technical institutions; NGOs related to sanitation". It is obvious that public participation, as one way to make democracy concrete, is not something wished by the legislator, when dealing with water management and sanitation.

4 Some conclusions

It is possible to draw some conclusions about water management and sanitation in Brazil out of these notes above. They are not definite, as they only comprehend some aspects of the legal texts.

The Law 9433/1997 has interesting provisions on water management, and at the same time provisions that aren't really progressive. The river basin committees and its duties of setting the priority of water uses, solving conflicts (even in first administrative level) and elaborating a plan for the basin are very important. Notwithstanding, many committees even do not exist, and the permits for water uses are given with no concern about priorities or planning. In some of the existing committees, the public participation is only wishful thinking. Projects like the construction of big dams or channels for irrigation are approved without the consent of those who will be more affected. Examples are the transposition of São Francisco river and the dams on rivers of the Amazon, projects from the military government that were stalled for years, to be approved and executed under this pseudo-democratic system.

The Law 11445/2007 is a technicality to refill a vacuum of legislation on the issue of sanitation. It was enacted with the single purpose of providing "juridical security" to private investors, as if the legal texts of bidding procedure and contracts were not sufficiently assuring. Since the Law determines that those, who "own" the sanitation services, may delegate the organization, regulation, monitoring and the provision of the services, the sole obligation it imposes is to elaborate a "public policy for sanitation". This was already obvious before the Law was approved. It is not even possible to say that the Law regulates the sector. It leaves the regulation to be done case-by-case, by the “owners” of the service, the federal entity, whoever it may be.

The population is not profiting at all of Brazil’s water richness. According to the Brazilian Institute for applied economic research (Instituto de Pesquisa Econômica Aplicada – IPEA), 28.6% of the urban population do not have sewage collection by network (only 20% of the sewage collected receive any treatment), and 10% are not even connected to the water supply network. Universal access to sanitation (the first principle of the Brazilian law) is not going to happen before 20 years (Novaes, 2009).

The situation in rural areas is even more dramatic. According to the United Nations Development Program, Brazil is the 40 worst in Latin America and Caribbean with respect to rural sanitation, behind Haiti, Bolivia and Peru. Two thirds of the Brazilians in rural areas do not have access to sanitation. It will be very unlikely to achieve the Millennium Development Goals. The country is not only not achieving the MDG’s in terms of rural sanitation, it is even regressing: in 1990, 37% of the rural population had proper access to sanitation, in 2002, the percentage was 35% (Infante, 2005).

Most of the statistics of people with or without access to sanitation or about the MDG’s do not even consider very important facts of our times like population growth and global warming. It does not seem like the huge challenges imposed by the international economic relations are being considered either. Challenges such as the infinite need of energy and the international trade patterns - that requires the exportation of goods that need lots of water to be produced – are still to be faced.

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The role of modeling for integrated water resource management

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Abstract

Integrated water resource management requires a thorough understanding of the relevant processes, fluxes and pools. Quantification of fluxes is based on environmental modeling at different spatial and temporal scales. If used for decision making, modeling should answer the question "what happens if" in an adequate way. This requires adapted modeling systems acting on the information scale which is used for balancing options for action. In this study, the model system SWAT (Soil Water Assessment Tool) was used to simulate water and sediment yields in the sub-humid Upper Ouémé catchment (about 15,000 km2) in Benin, West Africa. The simulations show a good agreement between observed and simulated discharge and suspended load for the period 1998 to 2005. The calibrated and validated model was used to evaluate the effect of Global Change on water and sediment yields. In a first step, climate as well as land use change scenarios were simulated separately. In a second step they were combined. The simulation results show a decrease in discharge and suspended load due to reduction in rainfall for the period up to 2050. Land use change due to an increase in the demand of agricultural products causes a significant increase in soil erosion and sediment yield. The combined scenarios show an ambiguous signal for the future, as climate and land use change effects are partly balancing out. Nevertheless, hotspots of soil erosion will aggravate and new hotspots will appear near settlements which show a high population growth.

Keywords: *SWAT, soil erosion, IWRM, environmental modeling, scale aspects.*

1 Introduction

1.1 Integrated water resource management

Integrated water resource management (IWRM) is based on the Dublin principles (Solanes & Gonzalez-Villarreal, 1999) and on the Millennium Development Goals (Rees, 2006). It is a process which requires a sound scientific basis, participation of stakeholders, and the consideration of ecological, economic, and social aspects. By IWRM, water demand and water availability should be balanced such that water resources are used in a sustainable way considering the needs of the downstream riparian communities and ecosystems.

The scale of IWRM is the basin scale. Although administrative boundaries complicate management at this scale, only the natural boundaries guarantee to be able to quantify water balance and solute as well as sediment transport. Nowadays, this is widely accepted as the Water Framework Directive of the European Union requires that for the integrated river basin management for Europe.

1.2 Integrated modeling for water resource management

Resource management requires a thorough understanding of structures, pools, and fluxes. While some pools like surface water reservoirs and groundwater may be quantified by measurements, the description of their dynamic requires appropriate simulations models. Model development and model application is usually done in five steps (Beven 2001):

1. *perceptual model development: deciding on the processes,*
2. *conceptual model development: deciding on the equations,*
3. *procedural model development: getting the code to run on a computer,*
4. *model calibration, and*
5. *model validation.*

After successful model calibration and validation (Anderson & Bates, 2001) environmental models can be applied for

- *analyzing the status: to assess current environmental conditions,*
- *determining trends: to evaluate historical change,*
- *predictions: to evaluate future impact as a result of change, and*
- *decision making: to evaluate alternative management plans.*

Integrated water resource management is concerned with all of these topics. The assessment of the current condition is a prerequisite for balancing options for action. To be able to differentiate between short term and long term effects, trends have to be identified. Because management means intervention, it is important to quantify the effects of those interventions on water related issues. Robust decisions can only be taken if alternative solutions are balanced. Because this can usually not be done by experiments, evidence-based decision making requires adapted modeling systems. Currently, watershed management policies are often based on myths or for political reasons, rather than scientific evidence. According to Loucks et al. (2005) models can be in the range between fully data driven (often called *Black Box Models*) and fully process oriented (*White Box Models*) approaches. Models applied in IWRM are often in-between these limits and called *Grey Box Models*. Depending on the degree of process representation, the grey color may vary between light grey and dark grey. Usually it is assumed that with increasing process knowledge it is feasible to apply those models for predictions. That this may not be true will be discussed below. When an approach has to be chosen, the area of conflict between scientific uncertainty and applicability to IWRM has to be considered. Before selecting a specific model approach a number of questions have to be answered (Westervelt, 2001):

- *What is the aim of the model; is it intended to support decisions?*
- *Is the model appropriate for the region?*
- *What information is required as inputs, and what outputs are available?*
- *What are the user, hard- and software, and time requirements?*
- *Is the system designed to be predictive?*

Furthermore, the scale aspect has to be considered. Concerning the data, the scale triplet extent (length of measurement period, spatial extent of measured space), spacing (spatio-temporal distance between measurements), and support (volume or time span of the measurements is important as it provides the basis for model development and validation (Western & Blöschl, 1999). According to Loucks et al. (2005), the sampling scale is often not identical with the process scale and both may differ from the information scale. The information scale is the scale on which decision makers require the model results. Renschler (2000) further sub-divided these categories into the scale of the model and the scale for model comparison. As an example, if one is interested in water fluxes within a catchment, sampling can be performed at the laboratory scale (taken soil samples of a few hundred cm^3). The processes may take place on a much finer (pore scale, mm) or larger (m^2) scale. A model may be applied at the field scale (ha) or the sub-catchment scale (a few km^2). Model evaluation is often performed using discharge measurements which only provide integral information concerning the investigated catchment. Data required for model application (e.g. soil map, climate data, geological information) may lie in-between these scales. One of the key-questions is therefore related to these scale issues like upscaling and downscaling for which numerous methods are available in hydrology (Blöschl & Sivapalan, 1995).

For the applicability of a certain model for decision making, the spatial extent is most important. How representative is a local scale model for a regional analysis? Do dominant pro-cesses vary with spatial extent, and if so, how? The temporal extent is important if one would like to apply a model for predictions or scenario analysis. What can be learned from a short run time (e.g. some months) concerning the water balance of larger catchments? It is very important that the model has been validated on the scale of interest (the information scale) as extrapolation often fails.

1.3 Modeling soil erosion for watershed management

Although scale and modeling issues are already complex when water fluxes are analyzed, this is even more the case if solute and suspended transport are involved. As an example, soil erosion will be analyzed in this study. Simulating soil erosion by water requires a good simu-lation of surface runoff and infiltration which depends non-linearly on soil properties and pre-cipitation. Erosion itself is a non-linear process which includes thresholds. Transport and sedimentation are also non-linearly dependent on surface water fluxes and soil properties. Furthermore, feedback mechanisms (Fig. 1) are to be considered which may be of minor importance at small temporal scales but can not be neglected if long-term effects are to be studied.

Concerning the temporal scale, erosion models are differentiated in single event and continuous simulation models. While single event models like LISEM (de Roo et al., 1996) only simulate the processes important during an event, continuous models also consider processes which take place between events. As an example of this type of models, SWAT (Soil Water Assessment Tool, Arnold et al., 1993, Version AVSWAT 2005) is applied in this study. Continuous modeling is much more challenging as it includes more processes but reduces the problems of finding appropriate initial conditions for the single events.

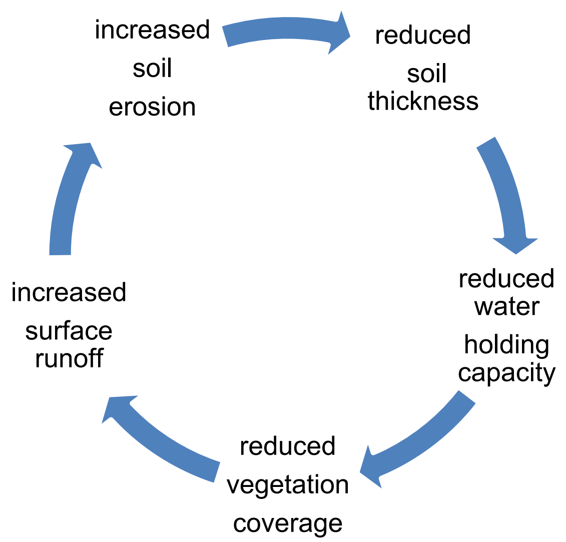

Figure 1: Feedback between soil erosion, soil physical properties, and plant growth.

Considering the scale discussion given above, the spatial scale is of utmost importance. With increasing basin size the net export of sediments called sediment yield reduces. This is due to the fact that deposition along the flow path gains increasing importance. SWAT is a basin scale model which is applied in this study to an area of about 15,000 km^2. Although this is the scale on which decision are to be made, field scale protection measures could not be simulated. The expressiveness of the results is therefore limited to the basin scale.

This study is part of the IMPETUS research project (Christoph et al., 2008) which mainly investigates the effect of Global Change on water related topics in West Africa (Benin) and Northwest Africa (Morocco). In this study the focus is set on the current situation concerning soil erosion in the Upper Ouémé catchment in Central Benin and its future development under Global Change.

2 Study area

The study area is situated in Central Benin, West Africa (cf. Fig. 2). The Upper Ouémé catchment has a size of about 15,000 km^2 and is situated in the sub-humid Sudan-Guinea-Zone which is a transition zone between the dry northern part of Benin and the wetter South. It has one rainy and one dry season with annual rainfalls between 1100 and 1400 mm (mean annual rainfall at the Parakou station is 1196 ± 212 mm/a, Hiepe 2008) and a mean temperature of 26.4°C. Annual discharge occurs periodically from June to December and varies between 100 and 300 mm. The vegetation is dominated by wet savannah types, which are severely degraded in the north-western part of the catchment. Farmers depend mostly on subsistence farming based on crops like yam, cassava and maize, besides cotton and cashew as cash crops. The catchment can be characterized as an undulating pediplain relief overlying a precambrian crystalline basement. Fersialitic and ferralitic soils are dominant and have often gravelly or plinthic horizons. The agricultural area is rapidly expanding due to population growth, migration and an improved accessibility (Hiepe, 2008).

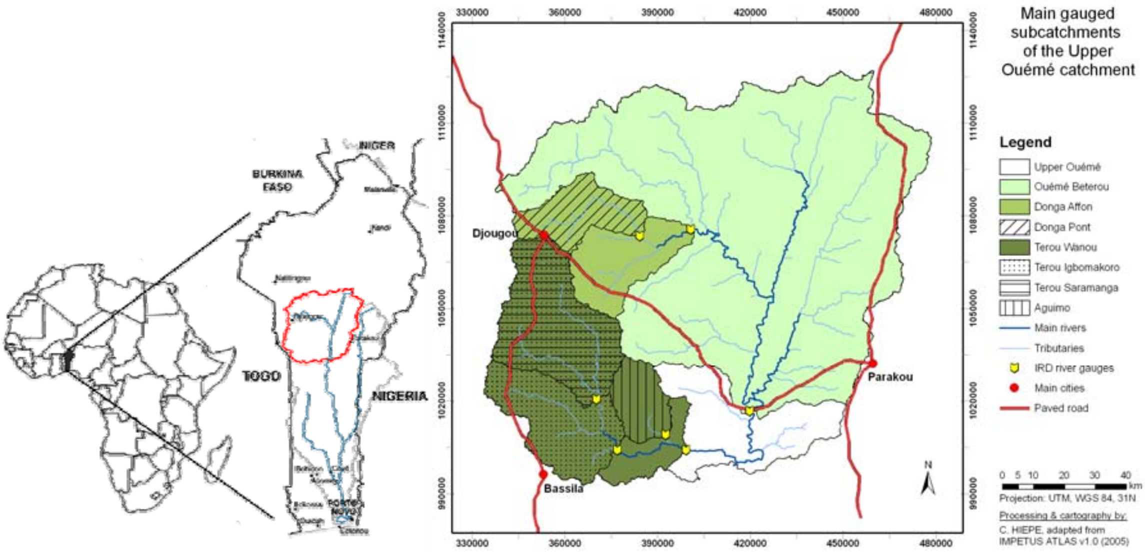

Figure 2: Study area Upper Ouémé catchment (West of Parakou, about 15,000 km^2) in Benin, West Africa, and gauging stations as used in this study.

3 Simulation model SWAT and data availability

SWAT (Soil Water Assessment Tool, Arnold et al., 1993) is a freely available, full-coupled eco-hydrological model for simulating water fluxes, soil erosion and sedimentation, nutrient transformation and transport, plant growth as well as river processes (http://swatmodel.tamu.edu/). It has been developed for studying long-term impacts of climate, land use and management on water quantity and quality. It follows a semi-distributed discretization in which the catchment is sub-divided into a number of sub-catchments by analyzing the digital elevation model (DEM). A further sub-division into hydrological response units (HRUs) is done by the intersection of land use and soil properties. By definition, HRUs are homogenous units concerning soil and land use. While the sub-catchments are connected via the river, the HRUs are not geo-referenced and therefore not interconnected. SWAT is a continuous model system which describes all relevant processes and has proven to be appli-cable for the situation in West Africa (Hiepe, 2008; Oboubie 2008).

SWAT has been applied to the Upper Ouémé catchment in a daily resolution. The delineation of sub-catchments led to 121 sub-catchments and 926 HRUs. Delineation of sub-catchments is always a compromise concerning accuracy and computational effort. Considering the data base (90 m DEM, soil map 1:200,000, and LANDSAT satellite land use classification cf. Tab. 1) this spatial resolution uses the data available without over-interpreting them. Nevertheless, it has to be kept in mind that interpretation of the results is only possible at this spatial resolution. Hiepe (2008) showed in her study, that the spatial discretization may influence the model results significantly. This is not only due to an increase in the number of HRUs and therefore a better representation of reality concerning soil and vegetation but mainly due to the fact that the attribution to the climate stations may also vary. According to the concept of SWAT one climate station is representative for each sub-catchment. Reducing the number of sub-catchments results in a worse pattern of driving forces.

Model calibration and validation are performed using data from different gauging stations. While discharge has been measured in daily resolution at eight stations, suspended load was estimated using turbidity measurement at three stations. More details concerning the data is given by Hiepe (2008).

Table 1: Model input data and data sources

	Variable	Resolution	Source
Climate	temperature, solar radiation, relative humidity, wind velocity	2 stations, daily	meteorological service Benin, IMPETUS project
	precipitation	13 stations, daily	
Soil	soil map	1:200,000	Faure & Volkoff, 1998
Discharge	total discharge	8 gauging stations, daily	hydrological service Benin, IMPETUS project
Suspended sediment load	turbidity	3 gauging stations, 30 min	Hiepe 2008
Land use	land use given in 12 classes	30*30 m^2 from LANDSAT satellite	IMPETUS project
DEM	elevation	90*90 m^2	NASA-SRTM

4 Scenario development

Nowadays, scenario development is a common tool for studying the effect of Global Change on environmental processes. Scenarios are not predictions as no one can forecast what may happen in future. Therefore, scenarios cannot be qualified by probability. Nevertheless, scenarios should be consistent and plausible images of alternative futures that are detailed enough to support the decision making process (Reichert & Jaeger, 2010). Therefore, it is required that the most important driving forces are considered. In the case of soil erosion, the main driving forces are climate and land use change.

Climate Change is often simulated following the scenarios of the IPCC. In this study three ensemble runs with the regional climate model REMO for the period 1960-2000 and for the IPCC SRES scenarios A1B and B1 for the period 2001-2050 were used (Paeth et al., 2009). While scenario A1B describes a more globalized world with high economic growth, scenario B1 is characterized by a more sustainable economic growth (Christoph et al., 2008)

Land use is driven by a number of external forces. The most important driver in Benin is the population growth which demands an increase in agricultural production. This is mainly achieved by a shift in land cover from forests or savannah to agricultural land given limited progress in enhancing productivity per hectare. For this study, the land use change scenarios developed within the IMPETUS project by Judex (2008) were available. Judex computed the demand for cropland in an annual time step until the year 2025 considering population growth and technological development. In a second step, this demand is spatially distributed over the catchment considering distance to settlements, roads, and markets, protected areas etc. as limiting factors using logistic regressions. The resulting annual maps show possible distributions of cropland, forest, savannah, and settlements in a spatial resolution of 250 m. These scenario maps could be used for analyzing future soil erosion after the adjustment of the land use classes (Hiepe, 2008). According to the IMPETUS approach, Judex (2008) considered three different socio-economic scenarios:

- *L1 "economic growth" with a reduced population growth, an increased agricultural productivity and an adherence of the protected areas,*
- *L2 "economic stagnation" with a high population growth, no technological advancement and the neglect of protected areas, and*
- *L3 "business as usual" with a population growth as in the past (about 3.2% per year), decreasing cropland demand per capita and a partial consideration of protected areas.*

Climate and socio-economic scenarios can be analyzed separately or simultaneously allowing the differentiation of the effects of climate change and land use change. For more details concerning the scenarios cf. Hiepe (2008) and Judex (2008) and concerning the methodology used in IMPETUS cf. Reichert & Jaeger (2010).

5 Results and Discussion

5.1 Calibration and validation

The SWAT model was applied to simulate water transport and soil erosion for the period 1998-2005 in which 1998-2001 was used for model calibration and 2002-2005 for model validation. Model calibration was performed for two gauging stations simultaneously. The Donga-Pont (586 km^2) catchment is characterized by a high fraction of cropland area (39%) while the Terou-Igbomaroko catchment (2324 km^2) has a large fraction of savannah and forests (together 89%). Six gauging stations with catchment sizes between 586 and 10,085 km^2 were used for model validation.

As an example, the comparison between simulated and measured discharge is given in Fig. 3 for the validation period for both catchments. The quality measures (for a discussion of quality measures cf. Janssen & Heuberger, 1995) show a good agreement between simulation and measurements on a weekly basis. Although the model runs in a daily time step and daily measurements were available, a high agreement is not expected on a daily basis due to limited quality of the data.

Compared to the calibration period, water yield is overestimated by the model by 28% at the Donga-Pont outlet and slightly underestimated by 5% for the Terou-Igbomaroko catchment. The reason for the overestimation was the occurrence of extreme events with weekly rainfalls of about 150 to 200 mm. A poor agreement for such events may have a number of reasons. On one hand, it is difficult to measure severe rainfalls correctly and a local scale measurement may not be representative for the whole sub-catchment. On the other hand, extreme discharge is also difficult to measure, as the extrapolation of the rating curve may cause a high uncertainty. Another reason may be the approach implemented in SWAT. Due to available data, only the empirical SCS-Curve Number method (NRCS, 1999) could be chosen for calculating surface runoff whose applicability is limited due to missing physical meaning.

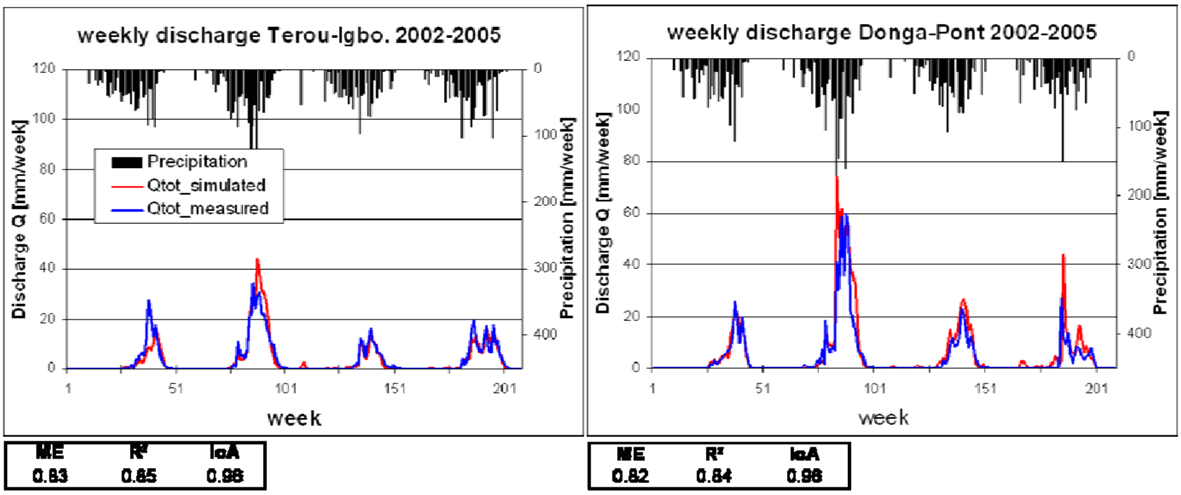

Figure 3: Comparison of measured and simulated weekly discharge (Qtot) for the validation period: Terou-Igbomakoro (2324 km^2) and Donga-Pont (586 km^2) outlets. ME Model Efficiency, IoA Index of agreement, R^2 coefficient of correlation. Source Hiepe, 2008.

A comparison between simulated and measured daily sediment yield is given in Fig. 4. Com-pared to the Terou-Igbomaroko catchment, sediment yield of the Donga-Pont catchment is up to 10 times higher which is caused by the high fraction of cropland and the smaller catchment size. Although the temporal patterns of sediment and water yield are well reproduced, large differences are observed for the total amounts which may be due errors in the measurements.

Although differences between simulations and measurements can be noticed, the water and sediment budgets could be successfully computed by SWAT. A better agreement would be possible if each sub-catchment is calibrated separately, but this would limit the transferability of the results in space and time.

A sensitivity analysis (Hiepe, 2008) revealed that the parameters of the SCS-Curve Number method are most sensitive concerning discharge and sediment yield. A parameter controlling base flow recession is also very sensitive together with a parameter describing channel sediment routing. Although sophisticated parameter estimation tools are available for SWAT, the uncertainty in model prediction remains high. Concerning parameter estimation, the problem of equifinality (Beven, 2001) is crucial which describes the fact that numerous parameter sets may result in acceptable model quality. Considering the uncertainties in model parameters, one is able to calculate confidence intervals for the model output reflecting the fact that model results should not be represented by single value but by a probability density function. Besides parameter uncertainty, the quality of the measured data used for comparison is important. Although the rating curve is based on numerous water level–discharge measurements, the scatter is large as erosion and sedimentation processes change the river bed. The quality of the sediment curves strongly depends on the relationship between the turbidity records and sediment concentration obtained in the laboratory. As the composition of the sediments changes over time, this relationship includes high uncertainty which makes calibration difficult.

In addition to these aspects, uncertainties in model concepts and model equations, driving forces (e.g. precipitation), and model discretization have to be considered. More details are given by Hiepe (2008). Nevertheless, in the face of these limitations, the model validation using independent data is promising. Although there is no reason to be enthusiastic, it seems that the model system describes reality in a satisfying way. This leads to the appraisal that SWAT can be used for scenario quantification.

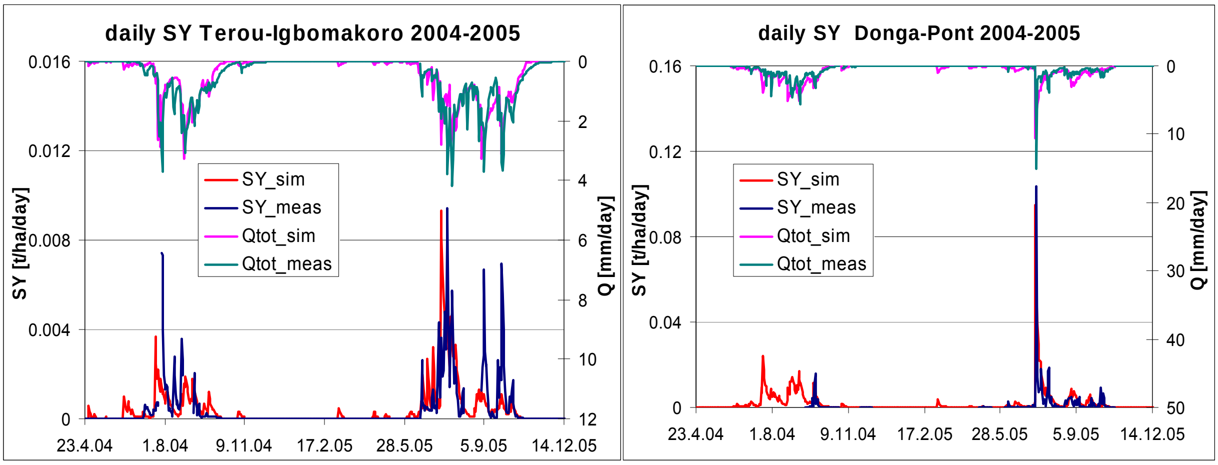

Figure 4: Measured and simulated daily sediment yield (SY) and total discharge (Qtot) at the Terou-Igbomakoro and the Donga-Pont outlets in the sediment calibration period 2004/2005. Source Hiepe, 2008.

5.2 Scenario analysis

As described before, climate as well as land use change scenarios were calculated. For land use change, the simulation results reveal a linear relationship between fraction of cropland and sediment yield for the Upper Ouémé basin (cf. Fig. 5). Differences in this relationship between the three scenarios are small. Nevertheless, the three scenarios differ significantly concerning the spatial extent and spatial pattern of land use change. While in 2000, 12.2% of the area was cropland, this increases for the scenarios up to 18.4 % (L1), 25.4% (L2) and 21.4% (L3). This means that cropland increases by 50 to 100% depending on the scenario. As an example the differences for the most important model results of the three scenarios for the year 2025 compared to the current situation is given in Fig. 6. While surface runoff is only slightly increased at this scale (up to 23%), sediment yield increases up to 95 %. All other results are only slightly influenced by the land use changes. At the sub-catchment scale a large variability is found. This is due to the fact that some sub-catchments have already nowadays a high fraction of cropland and therefore a low potential of land use change. As an example, the sediment yield at the Donga-Pont catchment will increase up to 50% whereas the sediment yield of the Terou-Igbomaroko catchment will increase by more than 100%.

As mentioned before, climate scenarios were calculated by Paeth et al. (2009) using the REMO model. A post-processing of the model output was required to guarantee that the probability density function of simulated daily rainfall amounts fits the observed (M. Christoph et al., 2010).

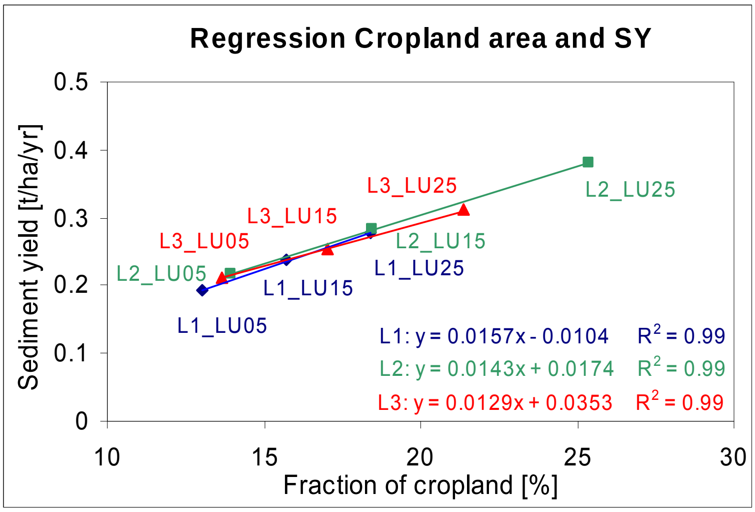

Figure 5: Regression between the fraction of cropland and the sediment yield (SY) for the land use scenarios L1 to L3. LUxx land use in year 20xx. Source Hiepe, 2008.

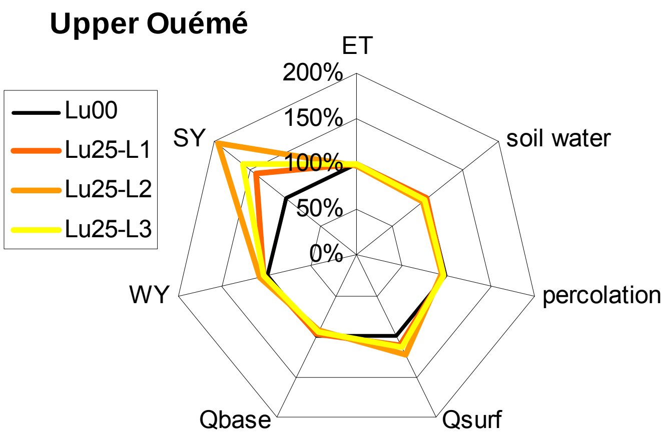

Figure 6: Relative comparison of the components of the water balance in the Upper Ouémé catchment: land use scenarios Lu00 (current situation, black, 100%), Lu25-L1 (orange), Lu25-L2 (ochre), Lu25-L3 (yellow). Source Hiepe, 2008.

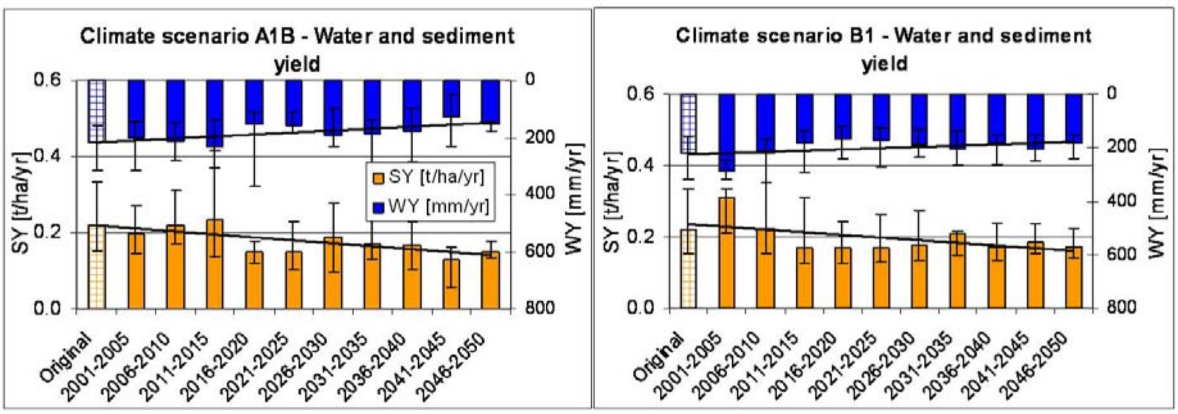

Figure 7: Mean simulated annual values of sediment yield (SY) and water yield (WY) of the three ensemble runs for the climate scenarios A1B and B1 for the period 2001-2050 for the Upper Ouémé catchment. The error bars denote the range of the results for the ensemble runs. Source Hiepe, 2008.

Although this may also influence the water yield by changing infiltration and evapotranspiration behavior, the largest impact is on surface runoff and soil erosion. In this study, the adapted climate scenario output was used. According to the simulations, mean annual water yield as well as mean annual sediment yield will decrease in future as it is illustrated in Fig. 7 for climate scenarios A1B and B1 due to a decrease in mean annual rainfall. The water balance the two catchments and the Upper Ouémé catchment is given in Tab. 2.

The differences between the sub-catchments are not as pronounced as for the land use change scenarios although a higher decrease in sediment yield is computed for Donga-Pont. A decrease in precipitation and an increase in evapotranspiration (not shown) will result in a decrease in water yield and surface runoff. As shown in Fig. 7, the sediment yield decreases due to the changes in hydrology. Nevertheless, the scenarios show a large interannual variability as it has also been observed for the past.

Table 2: Mean simulated annual values of rainfall (PCP), sediment yield (SY), and water yield (WY) of the three ensemble runs for the climate scenarios A1B and B1, change in [%] from the original model (1998-2005).

	1998-2005 Original			2001-2015 A1B			2026-2050 A1B		
	PCP [mm/a]	WY [mm/a]	SY [t/ha/a]	PCP [Δ%]	WY [Δ%]	SY [Δ%]	PCP [Δ%]	WY [Δ%]	SY [Δ%]
Upper Ouémé	1184	219	0.22	-4	-12	-14	-8	-23	-27
Donga Pont	1294	297	0.85	-10	-23	-27	-14	-33	-35
Térou-Igbo.	1157	213	0.14	2	1	-5	-2	-11	-21
				2001-2015 B1			2026-2050 B1		
				PCP [Δ%]	WY [Δ%]	SY [Δ%]	PCP [Δ%]	WY [Δ%]	SY [Δ%]
Upper Ouémé				-3	-6	-5	-5	-12	-17
Donga Pont				-9	-18	-19	-12	-25	-28
Térou-Igbo.				4	10	7	1	3	-7

Combining land use and climate change scenarios results in a complex response. For the Upper Ouémé catchment (Fig. 8), sediment yield increases strongly for all scenarios, while percolation and base flow are reduced. While total water flow decreases for all scenarios, surface runoff increases slightly for most scenarios. Actual evapotranspiration remains nearly constant although potential evapotranspiration increases. Climate change reduces the risk for erosion while land use change increases it. In the already nowadays intensively used Donga-Pont catchment, water and sediment yield will reduce strongly while they will increase in the Terou-Igbomaroko catchment. Thus, in the Donga-Pont catchment the effect of climate change is stronger than that of land use change; this is contrary in the Terou-Igbomakoro catchment. The behavior of all other sub-catchments is in-between these two.

An example for the spatial distribution of the change in sediment yield under Global Change is given in Fig. 9. There, the combination of climate scenario B1 and land use scenario L2 led to the highest increase in sediment yield while for the combination of climate scenario A1B and land use scenario L1 the strongest decrease is simulated.

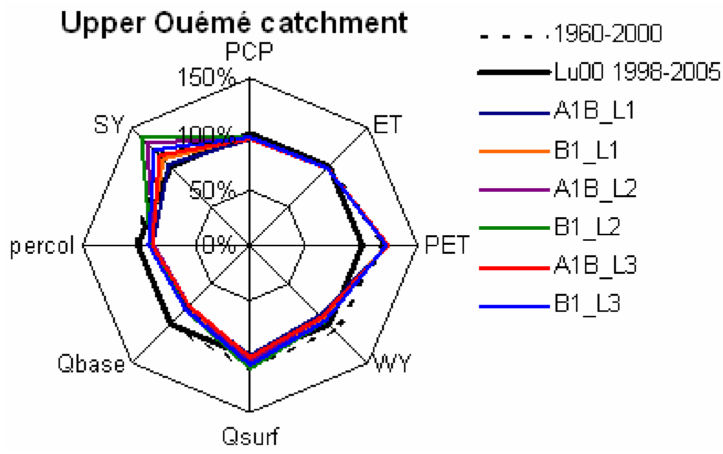

Figure 8: Components of the water balance in the Upper Ouémé catchment for the period 2001 to 2025 relative to the current situation model (1998-2005). Source Hiepe, 2008.

This shows the spectrum of possible developments in the future. Nevertheless, despite the differences in absolute values, the spatial pattern is similar showing the highest increase in soil erosion near the settlements Parakou, Djougou, and Bassila. While the first two regions are already current hot spots of soil erosion, the strong increase of sediment yield around Bassila indicates a new future hot spot.

According to the simulation results, the land use change effects are expected to dominate in the next years. However, this may change until 2050 when the signal from climate change may become clearer.

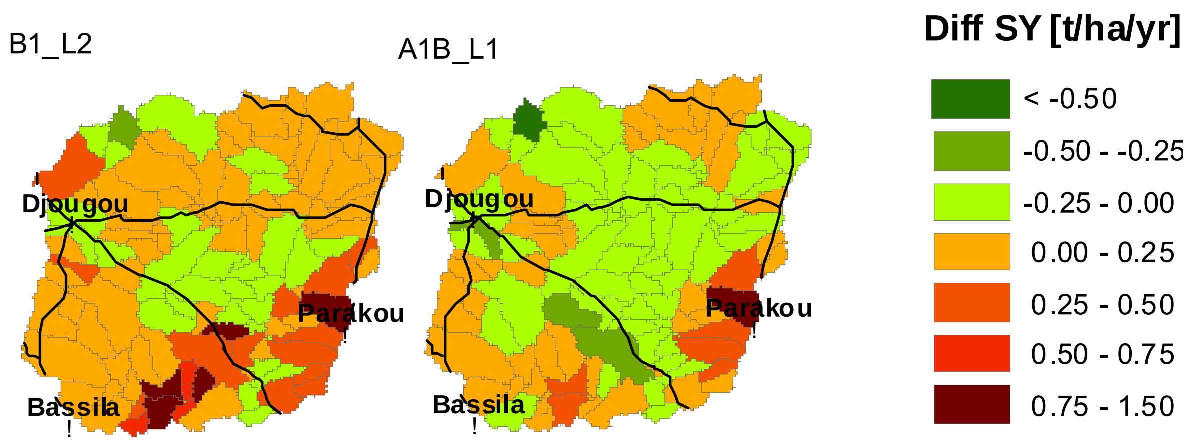

Figure 9: Spatial distribution of mean annual sediment yield for the combined land use and climate change scenarios for 2001-2030 compared to current situation.

6 Conclusions

The model system SWAT chosen in this study has a number of advantages and disadvantages. It is a fully-coupled model which computes water, solute, and sediment balances in a comprehensive way. It requires physically-based inputs which makes parameterization of ungauged catchments possible. As plant growth is interacting with hydrology and nutrients, scenarios calculations are not limited to single aspects. The configuration of the catchments is rather flexible due to an available GIS interface. It runs in a daily (or hourly) time step and offers numerous tools for sensitivity analysis and uncertainty analysis. It was designed for predicting the effect of management decisions on environmental fluxes and is therefore a valuable tool for the catchment scale. The disadvantages are that some approaches are rather rough (e.g. soil erosion) and not all feedbacks are considered. As an example, the feed-back loop described in Fig. 1 cannot be modeled with SWAT as the change in soil thickness due to soil erosion is not considered. The discretization concept may cause problems because sub-catchments are only linked via the river, and within the sub-catchment the single HRUs are completely independent of each other. Due to the coarse discretization, local scale best management practices cannot be simulated. In the case of soil erosion, one would identify hot spots using the SWAT model followed by a local scale analysis with other simulation models like EPIC (Environmental Policy Integrated Climate; Williams, 1995).

Environmental modeling is subject to a number of uncertainties. These can be related to model structure, numerical approximation, boundary and initial condition, model parameters and measurements for model calibration and validation (Brown & Heuvelink, 2005). A common approach is to calibrate environmental models to minimize the deviation of simulation results from observations. Numerous advanced methods are available for that purpose. This approach includes the risk that one reduces differences due to the wrong reason. Keeping all uncertainties in mind, it is difficult to clearly identify that part of the model which should be calibrated to improve predictions.

If models are applied for scenario analysis, one of the most challenging aspects is the unknown future. Beven (2009) discusses knowledge, modeling and decision making and one aspect is the unknown unknowns. This is the component where one does not know what one does not know. For decision making this is the most difficult aspect because one is not able to critically evaluate model results or scenario calculations.

While interpreting the results one has to keep in mind the limitations due to the underlying assumptions of the scenarios. No one is able to look into the future and therefore, scenarios are just one image of what may happen but are never the truth. This is true for climate as well as for socio-economic scenarios. As an example, the IPCC (2007) stated that global circulation models show quite different rainfall trends for West Africa. Using other scenarios and other models like MM5 led to significantly different results regarding rainfall amount and distribution in West Africa (Kunstmann & Jung, 2005).

It has to be kept in mind, that the probability of occurrence of each scenario is undefined. However, the analysis of scenarios can show the spectrum of possible futures. Of course, IWRM is more than applying simulation models. But environmental modeling is an indispensable part of the Integrated Water Resource Management as it offers the possibility answering the question “what happens if”. Furthermore, scenario development and the communication of the modeling results can be very powerful tools to engage various stakeholders in IWRM.

Numerous studies have shown that appropriate tools are available for simulating hydrology as well as substance transport. Scale aspects are to be kept in mind as data availability, regionalization, and scaling are the key issues in the successful application of models.

Nowadays, uncertainty analysis is a must in environmental modeling exercises. Uncertainty analysis is not an end in itself. It has to be communicated and to be considered in the decision making process. Therefore, a real challenge is to communicate uncertainties to decision makers and to consider how uncertainties are framed in the water management practice (Isendahl et al., 2009). With regard to soil erosion a big challenge is to communicate why decision makers should care about soil erosion and invest in IWRM. On one hand, economic losses through decreased yields may be a significant threat for the people. On the other hand, reducing the siltation of dams is crucial for sustainable water supply. Ecosystem services and ecosystem functioning (ESS/ESF, MEA, 2005) are keys in sustainable land management which is a prerequisite for IWRM. There exists a strong need for integrated studies including environmental economic assessment as it is demanded by the ESS/ESF concept. Nowadays, policymakers are much more aware of selected water issues than of integrated concepts including soil degradation.

7 Acknowledgement

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Water contamination by agrichemicals in a small subtropical watershed with steep slopes and shallow soils under tobacco cultivation

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1 Agriculture and agrichemicals

Tobacco cultivation is an activity with a high potential for contamination of water resources in watersheds and it leads to a rapid decline in the productive capacity of the soil and water quality in these locations. This is largely due to the improper agricultural practices of these lands and the utilization of high doses of fertilizers and pesticides.

Diffuse contamination and leaching of agrichemicals through the soil profile is one of the main problems impacting water quality in agricultural areas. Movement of nitrate, for instance, is favored by its high solubility and the low adsorption energy of the anion with the soil particles, especially in soils with the predominance of negative charges.

A chemical applied to the environment is subjected to several processes (Figure 1). Runoff and leaching are the two main ways pesticides may reach surface and ground water. Runoff is the physical transport of pollutants over the soil surface by overland flow, whereas by leaching pollutants are transported through the soil with infiltrating, ascending or laterally draining water (Rao & Hornsby, 1993).

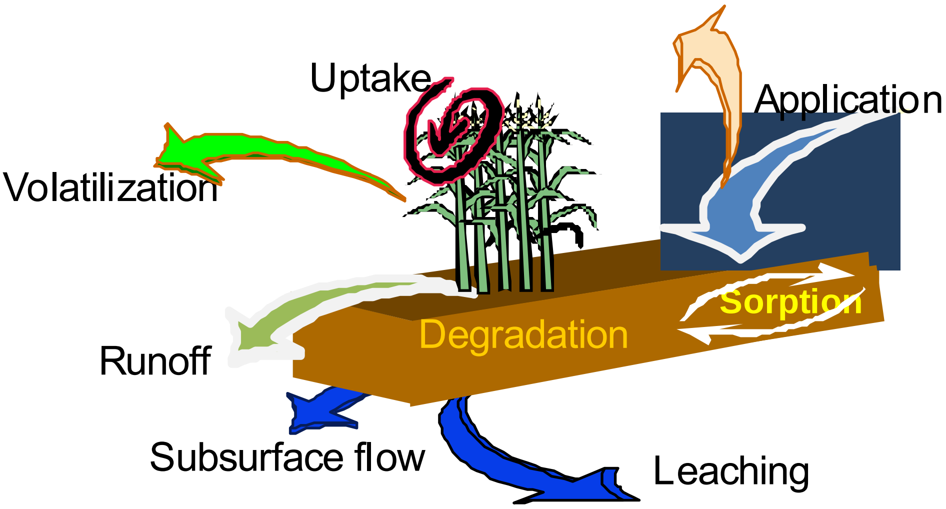

Figure 1: Environmental fate of agricultural pesticides.

The amount of pesticide runoff depends on slope, soil texture, moisture content, rainfall characteristics, and pesticide characteristics. In watershed scale, the cropped areas distribution in the landscape affects sediment and pesticides concentration. The natural buffer zones (such as riparian zones) may act as pesticide trap along agricultural fields. Leaching is increased for water-soluble pesticide, sandy texture, rainfall right after pesticide application, and low-adsorbing pesticide (Kerle et al., 1996), and existence of preferential flow through macropores and other large voids.

Adsorption, water solubility, and persistence cannot separately predict pesticide behavior. Pesticide behavior depends on the interaction of these factors and on their interaction with the particular soil type and environmental conditions (Figure 2).

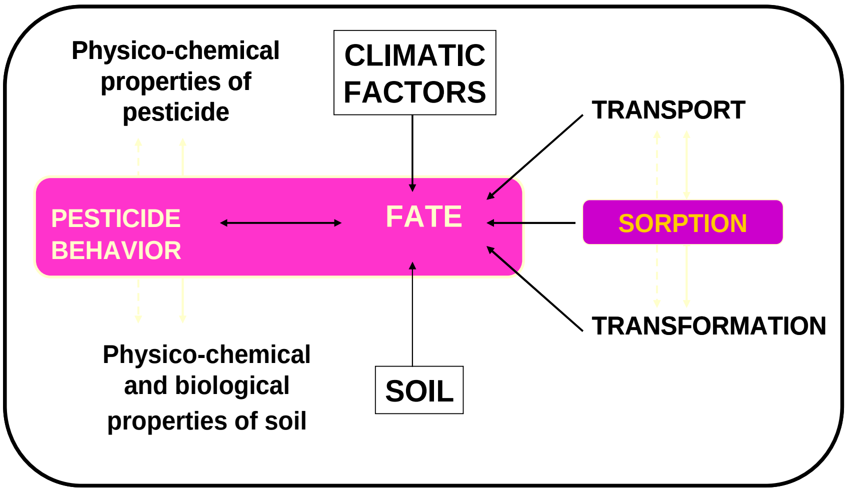

Figure 2: Properties and processes of pesticides in the environment.

In general, however, solubility and sorption, which are inversely related, are important in explaining movement with water, volatilization and bounding to soil (Figure 3).

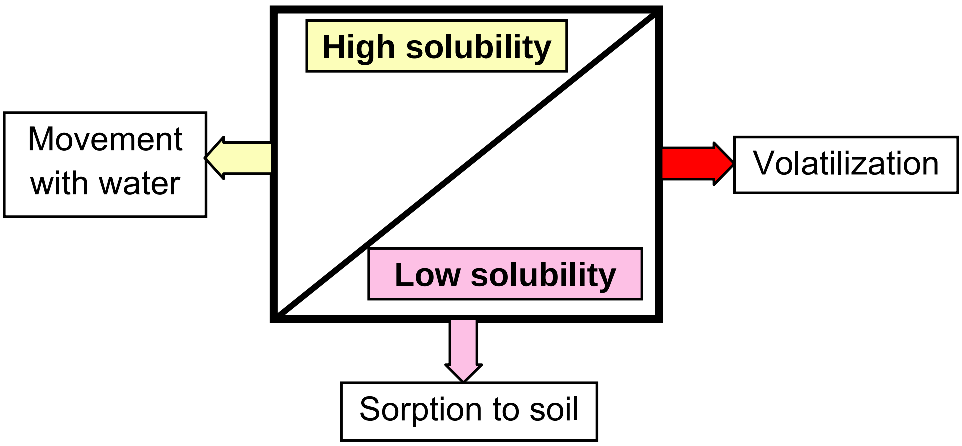

Figure 3: Pesticide solubility and processes.

Runoff transport to water bodies is increased for strongly-sorbed and persistent pesticides (large partition coefficient K_{oc} and large half-life $t_{1/2}$), since they are likely to remain near the ground surface (Rao & Hornsby, 1993). Half-life is the time required for a concentration of a pesticide to be reduced via degradation, metabolization or dissipation to one-half. Adsorption of a chemical to soil is expressed as adsorption coefficients (K_d and K_{oc}). K_d is the distribution or partition coefficient which describes the equilibrium distribution of a chemical between solids and groundwater, whereas K_{oc} is the distribution coefficient divided by the amount of organic carbon in the soil.

Groundwater contamination is favored by weakly-sorbed but persistent pesticides (small K_{oc} and large $t_{1/2}$), since they are readily leached through the soil. The possibility of surface water or groundwater contamination by nonpersistent pesticides with small $t_{1/2}$ is increased when heavy rains occur soon after pesticide application. Low risk of contamination is expected for pesticides with intermediate K_{oc} values and short $t_{1/2}$ values because of reduced leachability and faster degradation (Rao & Hornsby, 1993). The following generalizations can be made:

1. *The higher the K_{oc} value, the more strongly the pesticide is sorbed, and therefore, the less mobile it is in soluble form. However, in the highland watershed and conventional tillage these pesticides are transferred also in particulate forms.*
2. *Highly soluble pesticides are more likely to be moved – within the site or off site – by runoff or leaching.*
3. *Pesticides that are highly water soluble, relatively persistent, and not readily sorbed to soil particles (low K_{oc} or low distribution coefficient) have the greatest potential for movement* (Kerle et al., 1996).

A more extensive discussion on processes, impacts and modeling pesticides in the soil environment is presented in several books, such as Sawhney and Brown (1989) and Cheng (1990).

Pesticides and other agrichemicals are applied at field scale and react in the soil at molecular scale, but the impact might be at the watershed (sum of soil-water interactions). The hydrologic cycle of water influences the complex partitioning of molecules and ions within and between the environmental components soil, water and air. Watershed is the unit where conservation strategies should be planned to favor soil and water conservation and amelioration. Thus, watershed scale studies and planning are of uppermost importance to elucidate agrichemicals behavior in the environment.

2 Cases studies of agrichemicals in tobacco production

Although tobacco might be seen as a "dirty crop" due its risk to human health, both for producers and for smokers, the crop has an important social and economical impact in many countries. Brazil is the second largest producer of tobacco, where thousand families make their living. About 50% of those families live in the state of Rio Grande do Sul (RS), located in southern Brazil, where the three studies presented herein were done.

A small watershed in Agudo-RS, southern Brazil, with an area of 480ha was studied. Lino Creek and its tributaries constitute the drainage system of the watershed located in a basaltic mountain side, between the Central Depression and Mid Plateau. The region is characterized by the presence of native forest and also of tobacco crop, which uses pesticides without proper control. The watershed is characterized by (i) a low anthropic activity site with steep slopes and stream borders protected with permanent vegetation (riparian zone) and few agricultural fields and (ii) a high anthropic activity site also with steep slopes, but there are agricultural fields close to the stream and less riparian vegetation.

Figure 4: Lino Creek watershed, Agudo-RS, Brazil.

Surveys demonstrated that sediment discharge in the watershed is high and that phosphate ions are released to solution, on average, twice as rapidly as sediments collected from sub-watersheds with low anthropic activity than those from sub-watersheds with high anthropic activity.

Several pesticides commonly used in tobacco crops, such as chlorpyriphos, imidacloprid, flumetralin, and clomazone, are applied in southern Brazil, as well as non-recommended pesticides for tobacco crops as iprodione, atrazine and simazine.

These data show that anthropic activities in the watershed cause soil and water degradation. Three studies are presented below, on nitrate and pesticides, showing the need for conservation practices, in the short term, and change of cash crop, in the long term.

2.1 Pesticides in wells and in surface waters

Intensive farming significantly changes the natural ecosystem and the impacts may be assessed by analysis of surface water. The sediment and runoff leaving crop fields may transport several environmental pollutants used for crop protection against pests and diseases. Thus, water becomes unfit for human consumption bringing negative impact of major significance to rural communities, with repercussions also in urban communities.

In the tobacco production system in southern Brazil many types of pesticides are used. Some properties of these pesticides are indicated (Becker et al., 2009). Imidacloprid is a systemic insecticide that presents a high residual effect and mobility in the soil and has a half-life in soil from 48 to 190 days. Atrazine is a highly persistent herbicide in the soil, has a high potential for groundwater contamination despite its moderate solubility in water and has a half-life from 60 to more than 100 days. Clomazone is a highly effective herbicide but causes groundwater contamination due to its water solubility (1100 mg l^{-1}) and long half-life that averages from 28 to 84 days. Chlorpyrifos is an organophosphate insecticide that is classified as moderately hazardous. In soil, chlorpyrifos is degraded at a moderate rate; due to the the low solubility (1.4 mg l^{-1}) and hydrophobic nature (log K_{ow} 3.31–5.27), chlorpyrifos rapidly partitions from the water and adsorbs to sediment particles. Simazine is a persistent herbicide and does not adsorb strongly to soil particles. As it has a high half-life (36–234 days) in soil and low solubility (6.2 mg ml^{-1}) in water, it is likely to contaminate groundwater.

Water samples were collected in five water sources used for human consumption and in the Lino Creek. Besides tobacco grown as main cash crop, other crops are cultivated after tobacco harvesting, while cultivated forest is used for wood production for tobacco drying after harvest. The water samples were taken at three times during and after the cultivation of tobacco, namely: after the transplantation of the seedlings, during trimming, and after harvesting the tobacco.

The quantification of the active ingredients chlorpyrifos, iprodione and flumetralin was made by gas chromatography with electron-capture detection, whereas imidalcloprid, atrazine, simazine and clomazone were quantified by high performance liquid chromatography with ultraviolet detection.

Results have been published (Bortoluzzi et al., 2006 and 2007) or are under further analysis. Of the seven active ingredients tested, six of them (imidacloprid, atrazine, clomazone, iprodione, and chlorpyrifos) were found both in the water from the creek and from wells used for human consumption. Only flumetralin was not detected in any of the water samples. In samples taken after the transplantation of tobacco, chlorpyrifos was detected in water in all nine collecting points in the watershed and showed to be persistent over time. The water could be consumed if the Brazilian standards would be considered, but could not when considering the European standards of water quality, since the standards are higher and thus more restrictive to human consumption. This poses both a scientific and a political issue.

The indiscriminate use of prophylactic treatments for the cultivation of tobacco along with the lack of landscape planning and environmental protection explain the widespread occurrence of pesticides in water from the creek and from wells for human consumption. This result called for immediate and intensive effort to reduce pesticide use in crop production, protection of wells for human consumption, and integrated watershed planning.

2.2 Nitrate contamination

High levels of fertilizers are used by tobacco farmers, without considering the soil properties and environment conditions, posing risk to water resources degradation. The objective was to evaluate the nitrate concentration in soil solution in tobacco crop fields, native forest, grasslands and in water from two wells used for domestic supply, and to monitor the concentrations of nitrate and ammonium in the soil solution in the region of the root system and below it in an shallow soil planted to tobacco under conventional tillage (CT), minimum tillage (MT) and no-till planting (NT), in a small, hilly watershed in southern Brazil.

Monitoring of nitrate concentration in soil solution was performed in and below the root zone, using tension lysimeters with porous ceramic cup for soil solution extraction, and distillation and titration for nitrate quantification.

Results are being published (Kaiser et al., 2010) or under further analysis. Preliminary results showed that the soil in field had, on average, low bulk density (1.18 Mg m^{-3}), high porosity (0.56 m^3 m^{-3}), and high saturated hydraulic conductivity (298 mm h^{-1}). Nitrate reached depths below the tobacco root zone and represents a potential source of water contamination. The levels of nitrate were higher in crop fields compared to the grassland and native forest, reaching 80 mg l^{-1} in areas with tobacco. The well located below the tobacco crops had higher concentrations of nitrate, surpassing the critical limit of 10 mg l^{-1} in some periods.

The nitrate content, which ranged from 8 to 226 mg l^{-1}, was greater after initial fertilization and decreased throughout the cycle. The average nitrate content in the rooting zone was 75 mg l^{-1} in the NT, 95 mg l^{-1} in the MT and 49 mg l^{-1} in the CT. Below the rooting zone, the average nitrate content was 58 mg l^{-1} in the NT, 108 mg l^{-1} in the MT and 36 mg l^{-1} in the CT. Minimum tillage presented the greatest nitrate concentration in the soil solution during the tobacco cycle, but was not statistically significant in relation to conventional tillage and no-till planting. The reduction in nitrate concentration in the soil solution over time may be attributed to uptake of nitrogen from the soil solution by the growing crop, microbial immobilization and also by the losses through runoff, denitrification and leaching.

The nitrate content found represents a potential risk for contamination of groundwater sources of the watershed. In spite of the great variation in the nitrate concentration observed both among treatments through time and in space, the concentrations of nitrate found below the tobacco rooting zone were high when compared with other results in the literature.

2.3 Catfish as bioindicator of water contamination

The aquatic environment is continuously being contaminated with toxic chemicals from industrial, agricultural and domestic activity. In southern Brazil, many watersheds are used for agricultural production, including tobacco crop, in which pesticides are in common use.

How pesticide contamination of water affects the metabolism of silver catfish, *Rhamdia quelen*, was investigated by Becker et al. (2009). Fish maintained at two sites with low and high anthropic activity were studied. Several pesticides were found at both stream sites, as described below. After 30 days of fish exposure in cage nets to running water in the Creek, plasma glucose levels were higher in fish exposed to water in the low anthropic activity site than those exposed to water in the high anthropic activity site. Moreover, values of hepatic glycogen, muscle lactate and protein were higher, but glycogen and protein of the kidney were lower in fish exposed to water at the high anthropic activity site. Silver catfish is a native species to southern Brazil and was chosen as indicator since previous studies indicated that it shows stress symptoms when in the presence of contaminants such as herbicides. The stress level is measurable by biochemical changes such as glycogen, lactate and glicose in fish tissue and also changes in acetil colinesterase.

The pesticide content was measured at several sites in the Creek, including the sites where the cage nets with fish were placed. Imidacloprid and clomazone were found in significantly higher levels in the high anthropic activity site, whereas simazine was significantly higher in the low anthropic activity site. The levels of chlorpyriphos and atrazine were not significantly different in the two sites, and flumetralin and iprodione levels were below detection limits. Dissolved oxygen was higher than 6 mg l^{-1} in all sites; temperature was in the 21–28 ^{o}C range, and pH was around 7.0. Total suspended solids and electrical conductivity were higher at the high anthropic activity site, whereas total and dissolved phosphorous were significantly lower than at the low anthropic activity site.

Our results show that silver catfish can be used as pesticide toxicity indicators in streams near agricultural fields, and that anthropic acitivity poses stress to aquatic wildlife, particularly fish.

3 Conclusions

High potential for water resources contamination in watersheds cropped to tobacco and rapid decline in soil productive capacity and in water quality were observed in the watershed with shallow soil and steep slopes. Improper agricultural practices, utilization of high doses of fertilizers and pesticides, absence of riparian forest, and intense soil use are elements leading to soil and water degradation.

A shift in agricultural practices is needed in the short term, by including soil, water and wildlife conservation strategies, whereas a change in cash crop, in the long term, is necessary to move away from cultivating tobacco.

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Irrigation water quality and development of halophyte species upstream and downstream of the underground dam in Ibicuitinga, – Ceará, Brazil

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Summary

Water sources for irrigation in the Northeastern region of Brazil are predominantly superficial reservoirs, where water is stored during the rainy seasons, thus being in a general manner of good quality, of a low to medium salinity, and of a low to medium sodium content. The use of these waters under adequate management conditions should not offer great problems for irrigation. Nevertheless, this region presents an elevated predisposition towards degradation, arising from the incorrect use of farming practices adopted, which, allied with incomplete seepage and the intense evaporation, results in an accumulation of salt in the superficial soil strata and, in consequence, the increase in water salinity. The underground dam constructed in alluvia is an alternative technology for capturing rainwater. It is simple to construct, and of low cost, permitting the cultivation of traditional cultures, production of fructiferous plants, and ensuring the provision of water for animals, and, in certain circumstances, for human consumption. The study was developed in the underground dam of the Palhano River, in the municipality of Ibicuitinga, Ceará state, in the Northeastern region of Brazil. This work shows the analysis of irrigation water quality and the comparison of the vegetative growth of the gramineous plants: Vetiver grass (Vetiveria zizanioides); Evergreen (Panicum maximum); Sugarcane (Saccharum officinarum L.); Elephant grass cv. Napier (Pennisetum purpureum Schum) and Elephant grass cv. Mercker (Pennisetum purpureum Schum) and of the cultivation of Wild Piñon (Jatropha molissima) upstream and downstream of the underground dam. The assessment and analysis of the underground waters upstream and downstream of the dam shows that both have elevated salinity for the purposes of irrigation, the use of halophyte cultures being recommended. The Tukey test verifies for the variable vegetative growth of the gramineous plants Sugarcane, Vetiver grass, Elephant grass cv. Napier, Evergreen grass, and Wild Piñon, that they did not differ statistically among themselves, the only difference being in relation to the gramineous plant Elephant grass cv. Mercker.

Keywords: *Underground Dam, Underground Waters, Salinization, Halophytic Gramineous Plants*

1 Introduction

The semi-arid Northeast of Brazil has a high number of superficial dams. They range from great volume such as the Orós and Castanhão in Ceará and the Armando Ribeiro Gonçalves in Rio Grande do Norte, with an accumulation in the order of billions of cubic meters of water, to the so-called “little dams” or muddy lands, which accumulate some thousands of cubic meters. In general, the little dams do not endure without drying up in the annual dry season, thanks to the elevated evaporation (nominal), the median being 2,500 mm/year or around 7 mm/day (Costa, 2000).

The climatic instability in this region is more affected by its irregularity than by the shortage, constituting a great obstacle to the permanence of the people in the rural areas, due to the lack of water even for the furnishing of their basic needs. As in other semi-arid regions of the world, the Brazilian semi-arid tropic also presents shallow and rocky soils, with a low water-retention capacity, low organic material content, and a high potential for erosion (Cirilo, 2006).

According to Anjos et al. (2007), the problem of the Northeastern region is that of heterogeneity in the distribution of aquifers. Only two of the nine states make use of underground water in order to supply their needs. These are the states of Piauí and Maranhão. “In the rest, the water is concentrated in determined zones, and, above all, in the interior, in the crystalline semi-arid land, which makes up 55% of the region’s area. The water is in small quantity and of a very low rate of flow, in general, of high salinity, by virtue of the evaporation being very high in relation to the precipitation”.

There are different alternatives for the creation and exploitation of water reserves in this region. Superficial reservoirs are most used, due to the geological conditions which favor a high superficial drainage. The creation of artificial aquifers, by means of underground dams, makes possible the storing of water with quality and quantity, to meet the needs of a family or community, of the animals, and even for small irrigation purposes (Reboucas, 1999).

This work demonstrates that the underground dam is an alternative technology for the capturing of rainwater, of easy construction and low cost. It permits the cultivation of gramineous plants in the area, assuring the supply of water for animals and, in certain circumstances, for human consumption through the excavation of shallow or tubular wells, and producing biodiesel from the Wild Piñon (*Jatropha molissima*) on the banks, thus contributing to an improvement in the problems of shortage of water and energy.

2 Materials and methods

The study was developed around the underground dam of the Palhano River, in the municipality of Ibicuitinga, Ceará state, in the Northeastern region of Brazil. This region belongs to the semi-arid area, possessing preponderant characteristics such as the caatinga (*thorny, stunted*) vegetation and the shortage of water resources, due to the irregularity of measurable precipitation and little water shortage. The map in Figure 1 shows the locale of the experimental area.

According to Gomes (1990), the dam on the Palhano River, a tributary on the left bank of the Jaguaribe River, is limited to the upstream of the Chile dam which guarantees a periodic refilling, providing a renewal of the quantity and quality of the volume stored. The hydrographic basin is localized between the coordinates 4° 50’ – 4° 58’ south of latitude and 38° 26’ – 38° 39’ east of longitude and covers an area of 175 km²:

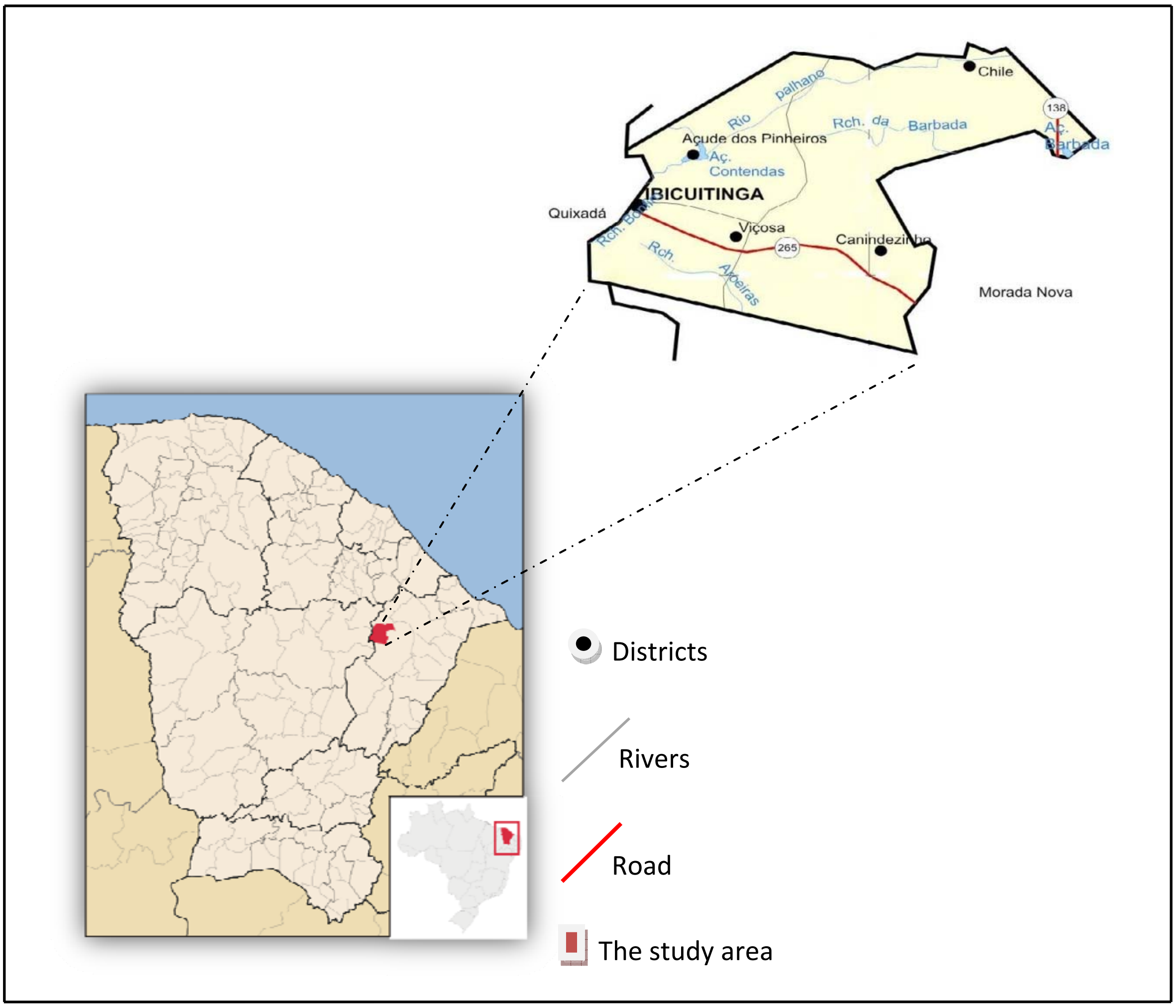

Figure 1: Map showing the localization of the study area in the Municipality of Ibicuitinga, Ceará state.

According to Monteiro (1988), the underground dam of the Palhano River constitutes an impermeable diaphragm of compacted soil transverse to the river. It lies on a rocky layer and is elevated until the groundwater of the dam reaches the riverbed, with the purpose of intercepting the flow of subterranean water, raising the water table, and, consequently, the storage of water capacity in the empty ground spaces, without interrupting the surface river drainage. It is thus attending to the basic needs of the water storage of water for human and animal consumption. Figure 2 illustrates the transverse cut and the layout of the experimental area of the underground dam.

The research project around the underground dam began with a cleaning of the area, its surroundings, and the manual digging of 2 artesian wells. Soil samples were collected, followed by the collection of water samples and the laboratory analysis of the soil and water taking the standards of EMBRAPA (1997) and APHA (1992) into account. The artesian wells were constructed using concrete rings with a diameter of 1.20 meters and a depth varying from 2.00 to 2.50 meters. They were localized one upstream and the other downstream of the underground dam. The purpose of the well construction was to provide sites for taking irrigation water upstream and downstream.

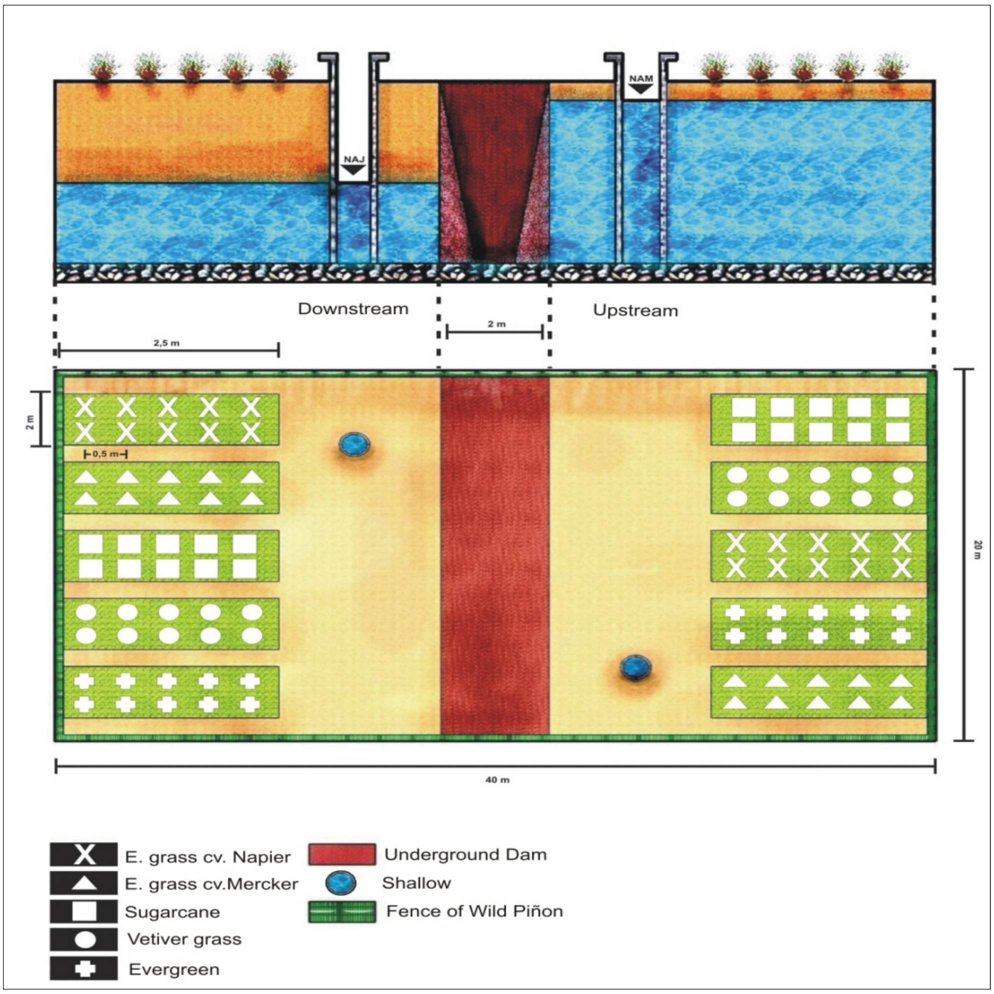

Figure 2: Layout of the experimental area of the transverse cut of the underground dam in Ibicuitinga – Ceará.

The choice of species of the majority of the gramineous plants was made principally due to the fact of the same having sprouted and grown spontaneously in salty areas near the underground dam in Ibicuitinga. The species have following characteristics: being plants belonging to the photosynthetic way C4 of gramineous plants and possessing foliage appreciated by domestic animals and fauna. The Vetiver grass was introduced by the fact having been cited in a lot in the literature as being a plant of halophytic character, that is, being resistant to extreme saline conditions.

Soon after, the planting of the following plants began: Vetiver grass (*Vetiveria zizanioides*); Evergreen (*Panicum maximum*); Sugarcane (*Saccharum officinarum L.*); Elephant grass cv. Napier (*Pennisetum purpureum Schum*) and Elephant grass cv. Mercker (*Pennisetum purpureum Schum*). Each species was planted in fifteen units, spaced 50 cm (fifty centimeters) apart, the same upstream as downstream of the underground dam, to guarantee that at least ten would survive for the weekly attendance to the growth of the same.

After the planting of the gramineous plants, the utilization of the adjacent areas was enlarged by planting a living fence of wild Piñon (*Jatropha molissima*). Wild Piñon is an abundant native plant of the caatinga (dry region), rural, perennial, adaptable to a vast range of environments and edaphoclimatic conditions, tolerant to drought, little attacked by plagues and diseases, which has the potential for the production of biodiesel. The living fence has the functions of isolating the area of the underground dam, protecting it from invasion by animals, improving the quality of the water which arrives in the dam, whether by the containment of sediments or by the filtering of water through the roots and the containment of erosion.

The production of the seedlings was made by stakes extracted from woody branches, from plants with good adaptation, good productivity, a perfect sanitary state, and free of noxious weeds or sickness (Almeida, 2009). Their length was 1 meter, with an average diameter of 5 cm, following the suggestion of Saturino et al. (2007). They were buried in the ground by the base at a depth of 20 cm, spaced 1 meter apart, as a living fence on the banks of the dam. The characteristics which accompanied the vegetative development of the Wild Piñon (*Jatropha molissima*), namely the growth in height, as well as the visual observation of symptoms of leaf burn and the percentage of mortality of the stakes, were followed weekly (Silveira Neto, 2003).

During the experiment, the levels of salt present in the waters upstream and downstream of the underground dam were measured by means of physicochemical analyses. These analyses permitted the calculation of the median content of salinity in the waters, with their basis in the parameters of Electrical Conductivity (CE) and the Ratio of Absorption of Sodium (RAS), suggested by the salinity laboratory of the United States (Bernardo, 2006).The statistical analysis of the data permitted the presentation of the results in terms of plant growth and the physicochemical classification of the waters upstream and downstream in the form of tables and graphs. From the Coefficient of Variation (CV) in the variable growth in height, the homogeneity of data collection may be evaluated. It can be tested whether the average is a good measure by which to present these data. It is also used to compare sets with units of distinct measurements.

According to Barbetta (2004), a coefficient of variation above 50% suggests a high dispersion, which indicates heterogeneity of the data. The higher this value, the less representative will be the average. In this case, the median or the mode is opted for; a practical rule does not exist for the choice of one of these characteristic values. Neither the average nor the standard deviation can be adequate measures to represent a collection of values if they are once affected in an exaggerated manner by extreme values. Further than this, only with these two measures is there no idea of asymmetry in the distribution of values. To solve these problems, the Boxplot graphic is used, which is a graphic analysis which uses five statistical measurements: minimum value, maximum value, median, first and third quartile of the quantitative variable. This group of measurements offers the idea of position, dispersion, asymmetry, extremities, and discrepant data.

Three plants of each species were randomly chosen for the measurement of their height during the time of the survey and at the end. The average of each species was calculated. This procedure was repeated seventeen times throughout the time of data collection. Bas on these data the analysis of the variance of each variable studied was carried out.

Previously, when significant by the Test F at the level of 5% probability, the Tukey test was applied at the level of 5% probability. The software “SAEG 9.0-UFV” was used for these analyses.

3 Results and discussion

For the analysis of the water quality upstream and downstream of the underground dam, the monitoring was necessary throughout the study period. Table 1 shows the result of the physicochemical analysis of the water on both sides of the dam on the Palhano River and the classification of the same according to the salinity parameters.

Table 1: Physicochemical classification of the waters upstream and downstream for the purposes of irrigation, collected through the research in Ibicuitinga, Ceará. U = Upstream; D = Downstream.

	SAMPLES							
PARAMETERS	20/09/2007		23/01/2008		28/02/2008		25/04/2008	
Cations ($mmol_c l^{-1}$)	U	D	U	D	U	D	U	D
Ca^{++}	5.0	6.0	3.1	3.9	2.2	3.8	1.3	2.6
Mg^{++}	4.5	5.0	2.9	3.1	2.5	3.3	0.6	1.9
Na^{+}	14.3	38.0	13.6	34.8	14.6	32.1	2.3	8.3
K^{+}	0.3	0.3	0.4	0.2	0.3	0.1	0.2	0.2
∑	24.1	49.3	20.0	42.0	19.6	39.3	4.4	13.0
Anions ($mmol_c l^{-1}$)								
Cl^{-}	20.4	44.0	16.0	36.0	16.4	32.0	3.4	11.0
HCO_3^{-}	4.0	4.8	3.8	5.6	3.2	7.6	1.0	2.0
∑	24.4	48.8	19.8	41.6	19.6	39.6	4.4	13.0
EC (dSm^{-1})	2.43	4.86	1.98	4.17	1.98	3.97	0.4	1.30
RAS	6.58	16.2	7.83	18.59	9.38	17.15	2.44	5.61
pH	6.7	7.4	6.8	7.2	6.7	7.1	7.3	7.4
Dissolved Solids (mgl^{-1})	2430	4860	1980	4170	1980	3970	440	1300
Classification	C4S2	C4S4	C3S2	C4S4	C3S2	C4S4	C2S1	C3S1

These parameters were chosen for the analysis of the quality of the waters in the underground dam in the study: Electrical Conductivity (EC), Ratio of Sodium Absorption (RAS) and Hydrogen Ion Potential (pH).

3.1 Analysis of Electrical Conductivity (EC)

Electrical Conductivity (EC) is a good indicator of the total quantity of salts in the water. The higher its value, the greater the quantity of salts, which, when they accumulate in the soil, reduces the yield of the cultures (Ayers & Westcott, 1991). Based on Table 1, the average of the electrical conductivity was 1.70 dSm^{-1} and 3.58 dSm^{-1}, respectively, upstream and downstream of the dam.

According to Reichart (1978), in relation to EC, the waters ranging between 0.75 and 2.25 dSm^{-1} present a high risk of salinity. They thus should receive special treatment previous to further use. Waters which present a conductivity between 2.25 and 5.0 dSm^{-1} have a very high risk of salinity.

This being the case, these waters are not appropriate for common irrigation. The soils need to be more permeable, well-drained, so that there would be an excess of seepage and they may be used with halophytic cultures. Figure 3 shows the analysis of EC throughout the experiment in the underground dam at Ibicuitinga – Ceará.

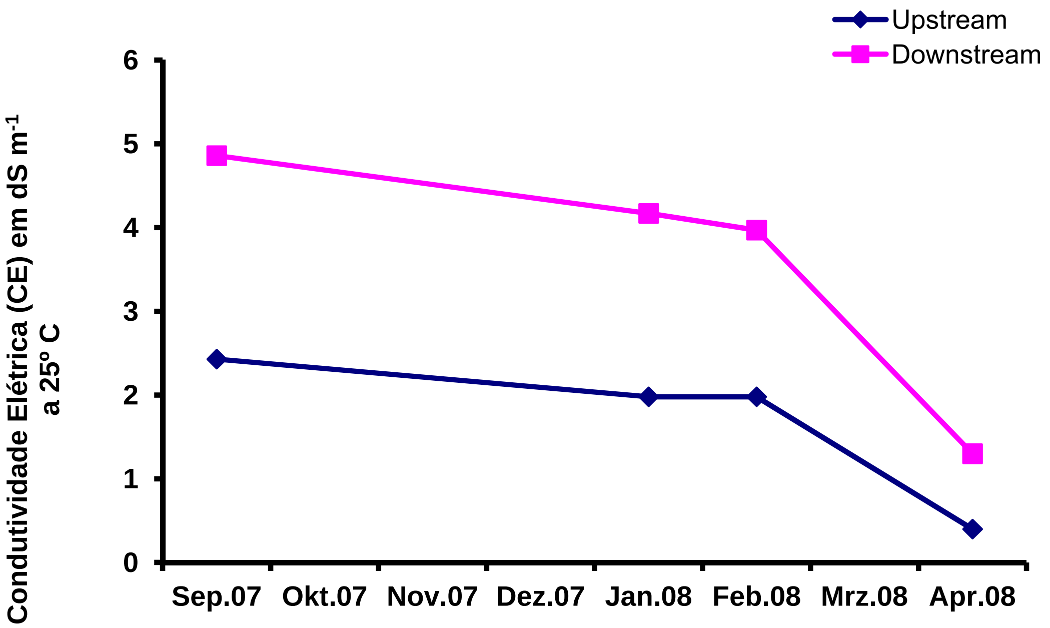

Figure 3: Analysis of Electrical Conductivity (EC) throughout the research at the underground dam in Ibicuitinga – Ceará.

According to Figure 3, the diminution of salinity of the water in the underground dam is noted from January, 2008, on. This is due to the beginning of the rainy season. With increasing precipitation, there is a greater dilution of these salts in the soil and the water.

3.2 Analysis of the effect of the Ratio of Absorption of Sodium

The parameters Na+, Ca++ and Mg++ were used for the calculation of the Ratio of Absorption of Sodium (RAS). Dispersion of the soil may occur when the calcium content is insufficient to counterbalance the dispersing effect of high levels of sodium which tend to remain accumulated in the superficial layers. Furthermore, an excess of exchangeable magnesium in the soil may induce the deficiency of calcium in the plants (Bastos, 1999; Bouwer and Idelovitch, 1988; Metcalf and Eddy, 1991). Figure 4 presents the variation of the RAS in the period of the study.

The diminution of RAS in the underground dam in the rainy season is noted, probably due to the increase in measurable precipitation and, consequently, the dilution of Na+, Ca++and Mg++ present in the soil and the water.

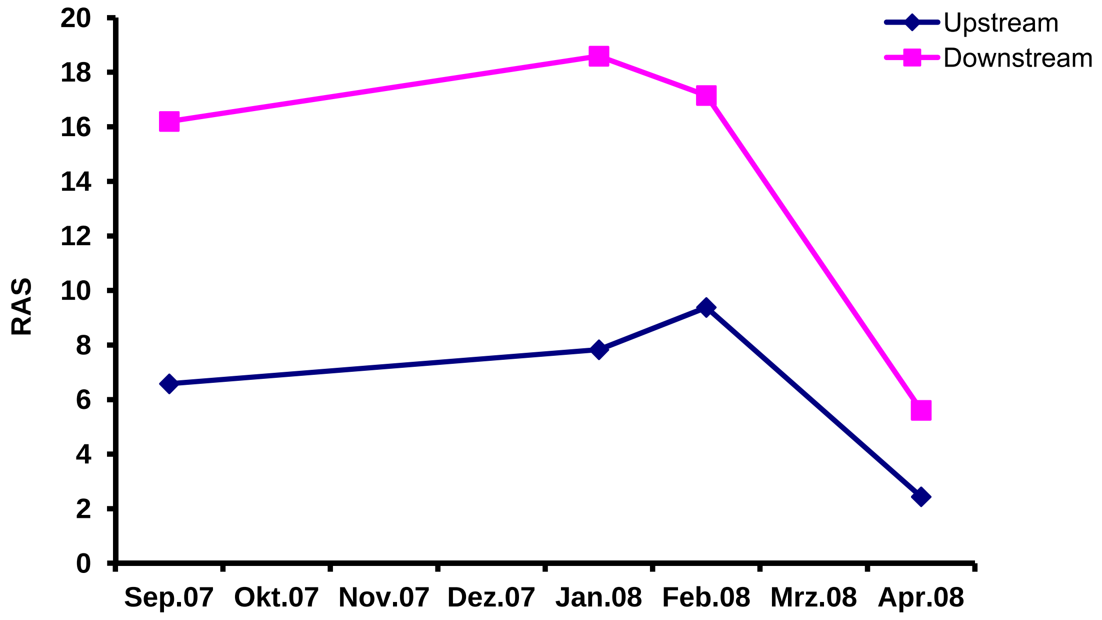

Figure 4: Analysis of the Ratio of the Absorption of Sodium (RAS) throughout the research at the underground dam in Ibicuitinga – Ceará.

In case of high sodium content, a sodic soil situation develops, which diminishes the permeability of the soil. The water quality with respect to the sodium is evaluated by the RAS, which takes into consideration the excess of sodium in relation to the calcium and magnesium.

The RAS presented average values of 6.56 and 14.39, upstream and downstream of the dam. According to Reichart (1978), in relation to the RAS, water with RAS values between 5.0 and 8.0 present a high risk of diminution of permeability. For RAS values larger than 8.0, a very high risk of diminution of permeability is given. Water use should be avoided.

3.3 Analysis of the effect of the hydrogen ion potential (pH)

The pH outside of the established patterns for irrigation water can cause serious problems for the cultures, such as excessive growth, retarded maturation, falling vegetables, reduced production, bad quality, and even nutritional imbalance. Apart from these problems, there are those related to diseases transmitted by the irrigation water (Bernardo, 2006).

When the pH values surpass the normal range of 6.5 to 8.4, the increased availability of toxic ions, such as sodium chloride, sodium, and boron, may affect the plants, whereby damage to the cultures and the soil may be provoked individually or in the combination of these ions (Ayers & Westcott, 1991).

The average pH of the water found in the underground dam was 6.9 and 7.3 upstream and downstream respectively, thus being within the recommended range and having its use indicated for irrigation according to the pH parameter.

3.4 Development of the gramineous plants

Figure 5 shows the comparative study of the growth of the planted species. The standard deviation characterizes the dispersion of the individual values around the average. Thus, considering the mean of the data and the deviation pattern, a space may be found where the majority of the data are found, that is, in a normal distribution, around 75% of the population values are within the interval (X □ – S; X □ + S), where X □ is the average and S is the deviation pattern.

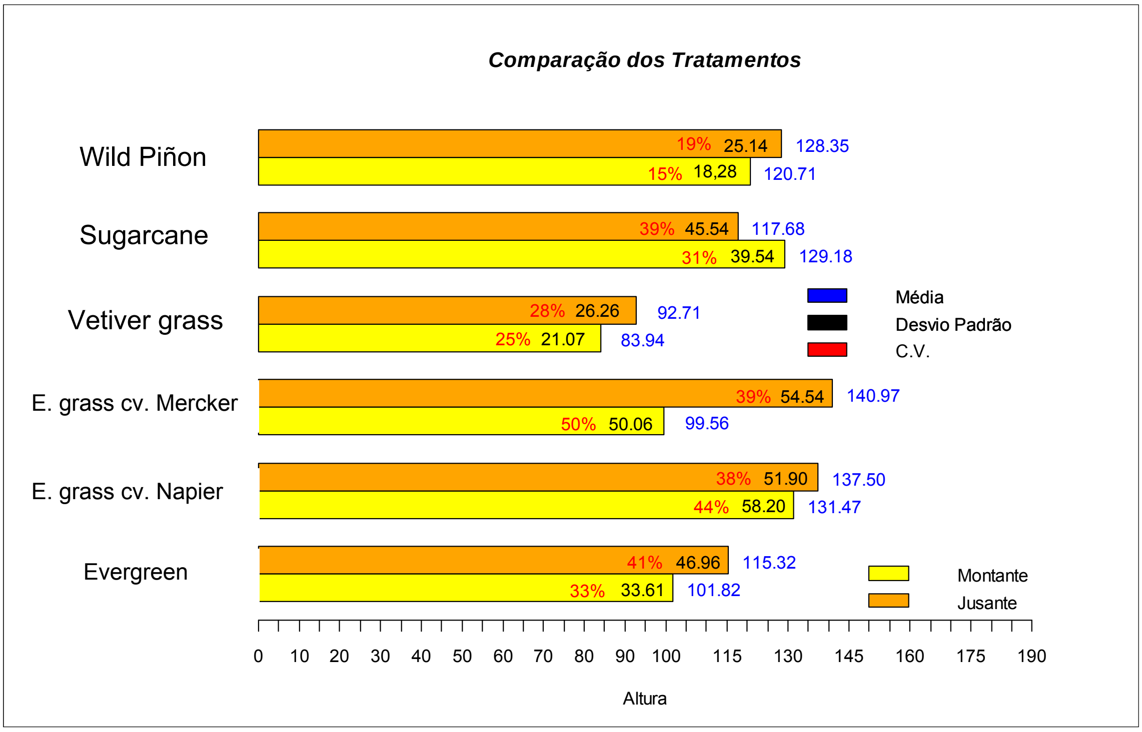

Figure 5: Comparison of the growth of the Wild Piñon and the gramineous plants upstream and downstream of the underground dam throughout the research in Ibicuitinga – Ceará.

From the Coefficient of Variation (CV), the homogeneity of the collection of data was evaluated. The greater the CV, the less representative the average is. In this case, we opted for the median, according the Boxplot in Figure 5, in order to get a better idea of the distribution of the values.

Figure 6 shows that there is an interaction effect between the variables 'kind of gramineous plant' and 'side of the dam' (upstream or downstream). It is also noted that there is some heterogeneity in the data. Adjusting the transformed data, Table 2 is obtained, with the summary of the analysis of variance in the experiment.

According to Table 2 there is a significant interaction, at the level of significance of 5%, between the side of the dam and the type of gramineous plant. Thus, the Tukey test was used for multiple comparisons of the averages.

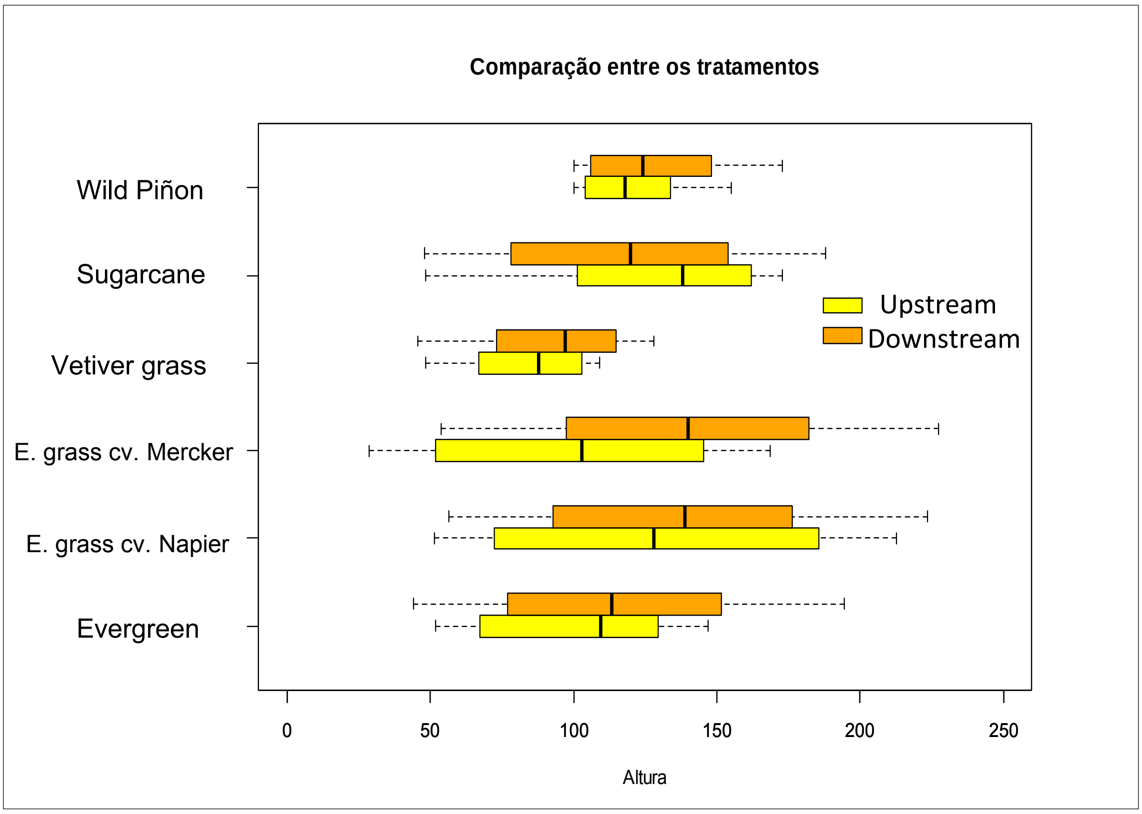

Figure 6: Boxplot Graphic between the treatment of the species upstream and downstream of the underground dam in Ibicuitinga – Ceará.

This test verifies the equality of the principal treatment when the secondary treatment is fixed, and vice versa. It is observed that there is an effect of the type of gramineous plant, but by the fact of the existence of the interaction effect, the analysis should be done on top of the interaction itself. Therefore, the isolated effect of the type of gramineous plant cannot be analyzed.

Table 2: Summary of the analysis of variance for the variables: Gramineous plant and type of soil (upstream and downstream of the dam); *** Significant to the level of 5%. Obs.: The cells left blank do not need statistical tests, since they are used for the application of the F Test.

Variation Factor	Degree of Freedom	Sum of Squares	Average Square	Value-F	Value-P
Side of Dam	1	37.651	37.651	0. 613	0.439
Error 1	32	1964.942	61.404		
Gramineous	4	232.765	58.191	64.006	< 0.0001 ***
Side of the Dam*Gramineous	4	85.228	21.307	23.436	< 0.0001 ***
Error 2	128	116.372	0.909		

Table 3 reveals that the majority of plant species does not show different responses depending on the location (= side of the dam). The gramineous plants do not differ statistically amongst location (upstream vs. downstream). Only the gramineous plant Elephant grass cv. Mercker showed a statistically significant effect.

Table 3: Average values, by treatment, obtained for the variable types of gramineous plants in function of side of the dam (upstream and downstream).

Side of Dam	Types of Gramineous					
	Evergreen	Napier Grass	Mercker Grass	Vetiver Grass	Sugarcane	Wild Piñon
Upstream	101.8235 **a**	131.4706 **a**	99.5588 **a**	83.94118 **a**	129.1765 **a**	120.7145 **a**
Downstream	115.3235 **a**	137.5000 **a**	140.9705 **b**	92.70588 **a**	117.6765 **a**	128.3567 **a**

Figure 7 illustrates this comparison between upstream and downstream height of the species used around the underground dam. Although the differences were not statistically significant, Figure 7 shows that the majority of the species grew better downstream of the dam, the area which presented greater salinity. This factor reinforces the halophytic character of the tested species. Exceptionally, the sugarcane behaved differently to the others, developing better upstream, a region which possesses lesser salinity.

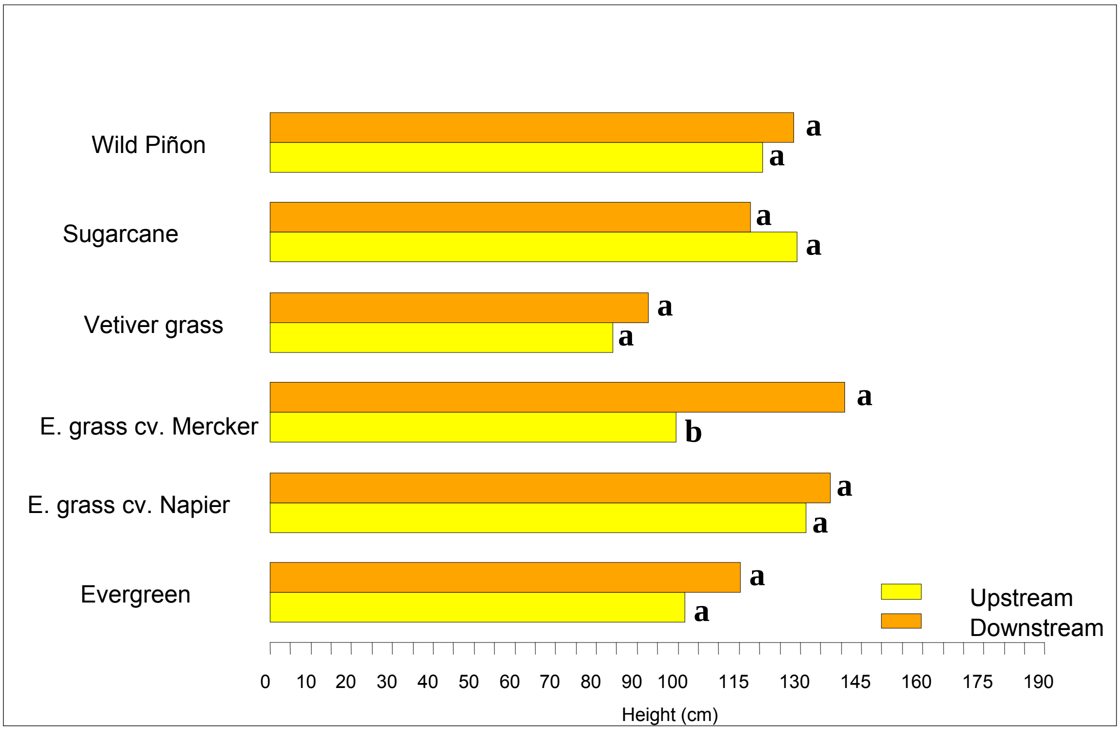

Figure 7: Representation of the test of averages for the variable growth in height when the species of gramineous plant is fixed upstream and downstream of the underground dam in Ibicuitinga – Ceará.

4 Conclusions

The collection and analysis of ground waters upstream and downstream of the underground dam showed that both water show increased salinity for the purposes of irrigation. The data analysis showed that the irrigation water upstream of the dam presents a high risk of salinity and a medium sodium content, being classified as C3S2. Obviously, downstream of the dam, the averages of the water analysis showed that the irrigation water presents a very high risk of salinity and a very high sodium content, being classified as C4S4.

As it was to be expected, there was a diminution of salinity in the water of the underground dam during the rainy season due to the increase in precipitation and, consequently, the dilution of salts present in the soil and the water.

In field observations, it was not possible to perceive symptoms of intolerance to sodium in the tested gramineous plants in the area of the underground dam on the Palhano River. These symptoms are, for example, leaf burn, atrophy in the growth of the leaves and the culms, as well as other factors which would indicate the intolerance of these plants to sodium. This fact indicates the confirmation of the halophytic character of the plants tested.

The research suggests the possibility of living with the saline conditions of the water and the soil caused by the implanting of underground dams. Utilization of halophytic gramineous plants is recommended which demonstrated their good adaptation to the imposed conditions, being suitable for the purpose of animal feeding (Elephant grass of the Mercker and Napier varieties, Evergreen grass, and Sugarcane). In addition, Vetiver grass can serve for the fabrication of perfumes, craftwork, and domestic utensils such as brushes, carpets, and mats.

Apart from this, the gramineous plants used in the research improve the soil conditions by removing salts and incorporating organic material, thus contributing to the improvement of the soil structure.

There was no indication of affecting the mortality of the wild piñon stakes. Even upstream of the underground storage dam, 100% of them developed roots. The wild piñon plants grew in a robust manner, as much upstream as downstream, without any symptoms of intoxication or weakening due to sodium or other salts. It may be concluded that the wild piñon, with regard to the variable growth in height, presented a better development upstream of the dam.

From the very beginning, this work is related to a sustainable development of the region focusing on economical ecological aspects, as well as their possible realization under given social circumstances.

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Water quality reclamation of Pinheiros River and posterior pumping to Billings Reservoir: an integrated concept of water resources management in Latin America (São Paulo, Brazil)

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Abstract

This paper analyzes an integrated concept of water resources management in São Paulo Metropolitan Area, Brazil. Urban rivers in developing countries are usually rectified channels with significant degree of degradation as a result of high concentrations of contaminants and pathogens, aerobic life absence, unpleasant odor and aspect. The Pinheiros River (São Paulo state, Brazil) is not an exception for this rule. The aim of this research was to assess the efficiency of a pilot-scale in situ flotation system for recovering the water quality of this river. The idea was to treat the water and pump about 10 $m^3 s^{-1}$ to Billings Reservoir, a multiple use aquatic system. This additional flow could enhance energy generation and favor other multiple uses in the reservoir. Besides, the environmental gain by cleaning up the river is expected to be relevant. The removal efficiency for some water quality variables (phosphorus, biochemical oxygen demand, chemical oxygen demand, nitrogen-ammonia, total suspended solids, turbidity and iron) was investigated from August 2007 to December 2008 through a monitoring program in four sampling stations located in the river axle. Results showed that the system presented high efficiency on removing phosphorus (mean removal: 90%), biochemical oxygen demand (62%) and chemical oxygen demand (53%). Poor efficiency removal was observed for some variables, especially for nitrogen-ammonia (2%), what may represent a risk for Billings Reservoir eutrophication. Nevertheless, the importance of this study referred to calling attention for the possibility of in situ technology solutions, which may be convenient in urbanized areas and also for the need of integrated water resources management in big cities of developing countries.

Keywords: *Brazil; In Situ Flotation; Latin America; Urban Rivers; Water Resources Management*

1 Introduction

Water scarcity and pollution constitute two of the biggest challenges for a sustainable development in Latin America, not only because the water demand is continuously increasing (for multiple purposes like supplying, agricultural and industrial activities), but also because the sanitation structures for great part of its citizens are either inexistent or, if available, unsatisfactory. Accordingly, water quality recovering of polluted rivers must be recognized as a pivotal tool towards natural resources sustainability.

Compared to non-urban aquatic systems, urban rivers tend to be more influenced by surface runoff and therefore by diffuse pollution (increasing concentrations of total suspended solids, cadmium, copper, lead and zinc and decreasing dissolved oxygen in the water of such rivers). According to Tucci (2004), one of the greatest environmental challenges in developed countries is to attenuate the diffuse pollution originated from urban and rural runoff. Nevertheless, the relative importance of diffuse pollution is sometimes smaller than the importance of point source pollution in these countries. Brazilian urban rivers are subordinated not only to runoff from stormflows, but also to domestic and industrial discharges, which contribute to the water quality degradation. Thus, wastewater and stormwater management is progressively becoming a complex task for the megacities around the world (Varis et al. 2006).

Pinheiros River is located in the São Paulo Metropolitan Region (SPMR), São Paulo State, Brazil (Figure 1). SPMR is a large urban area (about 8,000 km²) with about 19.6 million inhabitants. Pinheiros River is severely affected by domestic and industrial effluents and by diffuse pollution from urban runoff. Pinheiros River flow direction was reversed into Billings Reservoir until 1992 to boost electricity generation. Nonetheless, as a result of the accentuation of the pollution process after 1992, this procedure was prohibited, except in cases of flood control in São Paulo (Braga, 2000; Silva et al. 2002). In this last case, Pedreira Dam and Pumping Station convey the water from Pinheiros River to the reservoir in order to prevent flooding in its highly urbanized floodplain.

One of the most important anthropogenic negative interference on Billings Reservoir refers to the irregular occupation of its perimeter (it is estimated that more than 1 million people are living in its catchment area). Domestic wastewater is continuously being released to this aquatic system causing significant decrease in the water quality and affecting all the surrounding area. Recently, the "Billings Reservoir Law" (São Paulo state Law Number 13,579 – July 13th, 2009) came into effect as an attempt to slow down the accelerated degradation rhythm of this environmental strategic patrimony.

Figure 1: São Paulo state map, Brazil, stressing Metropolitan Region of São Paulo, where Pinheiros River is located.

To summarize, Figure 2 shows the operational routine developed for the study area, which constitutes an attempt of conciliating both qualitative and quantitative aspects of water resources in an integrated management concept. There are two situations: either the flotation system works, or flood control does. In the first case, Pinheiros River water is treated (about 10 m3.s-1) and pumped to Billings Reservoir, as a mechanism to both recover Pinheiros River water quality and increasing Billings Reservoir water level, favoring energy generation, besides others multiple uses. In the second case, Pinheiros River water is directly pumped to Billings Reservoir (flows usually bigger than 100 m3.s-1) without any previous treatment. This mechanism is used to prevent flooding in part of the São Paulo City urban area.

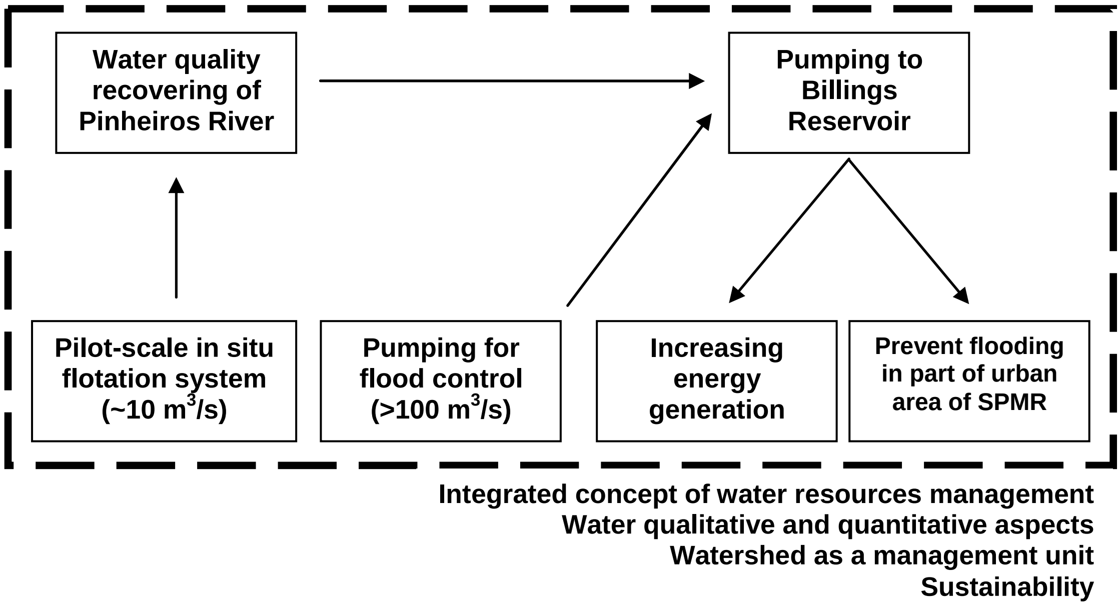

Figure 2: The integrated concept of water resources management assessed by the present research.

Therefore, both pilot-scale flotation system and flood control operation depend on weather conditions. When pilot-scale flotation system works, the pumped flow is near 10 $m^3\ s^{-1}$, significantly higher than other similar in situ treatment stations in Brazil (0.05 $m^3\ s^{-1}$ reported by Lopes and Oliveira, 1999; 0.15 $m^3\ s^{-1}$ by Oliveira et al., 2000; 0.75 $m^3\ s^{-1}$ by Coutinho and von Sperling, 2007), characterizing this prototype as a challenging pioneer structure.

The aim of this study was to assess the efficiency of the in situ flotation system for the removal of some undesirable variables (total phosphorus, biochemical oxygen demand, chemical oxygen demand, nitrogen-ammonia, total suspended solids, turbidity and iron) in Pinheiros River water among more than a hundred variables that were monitored. This investigation is quite important to verify whether this treatment technology is suitable to recover the water quality of the river, thus mitigating the negative effect of its water pumping to Billings Reservoir.

2 Methods

Sampling campaigns were performed from August 2007 to December 2008, through the quantification of some key water variables: total phosphorus, biochemical oxygen demand, chemical oxygen demand, nitrogen-ammonia, total suspended solids, turbidity and iron. All analyses were performed following APHA (2005) methods. The laboratories in response of all the analyses were Laboratório Ambiental and Ecolabor (both certified by ABNT – the Brazilian Authority on Technical Norms). It is convenient to point out that the frequency of analysis varied from substance to substance (eg. daily, weekly or biweekly). All this data is freely available at the website of the Brazilian State Attorney (http://www.mp.sp.gov.br/portal/page/portal/Billings/Monitoramento).

The water variables were quantified in samples of four stations located in the longitudinal axle of Pinheiros River (Figure 3): S1 and S2 (upstream and downstream of the Zavuvuz Flotation Station, respectively) and S3 and S4 (upstream and downstream of the Pedreira Flotation Station, respectively).

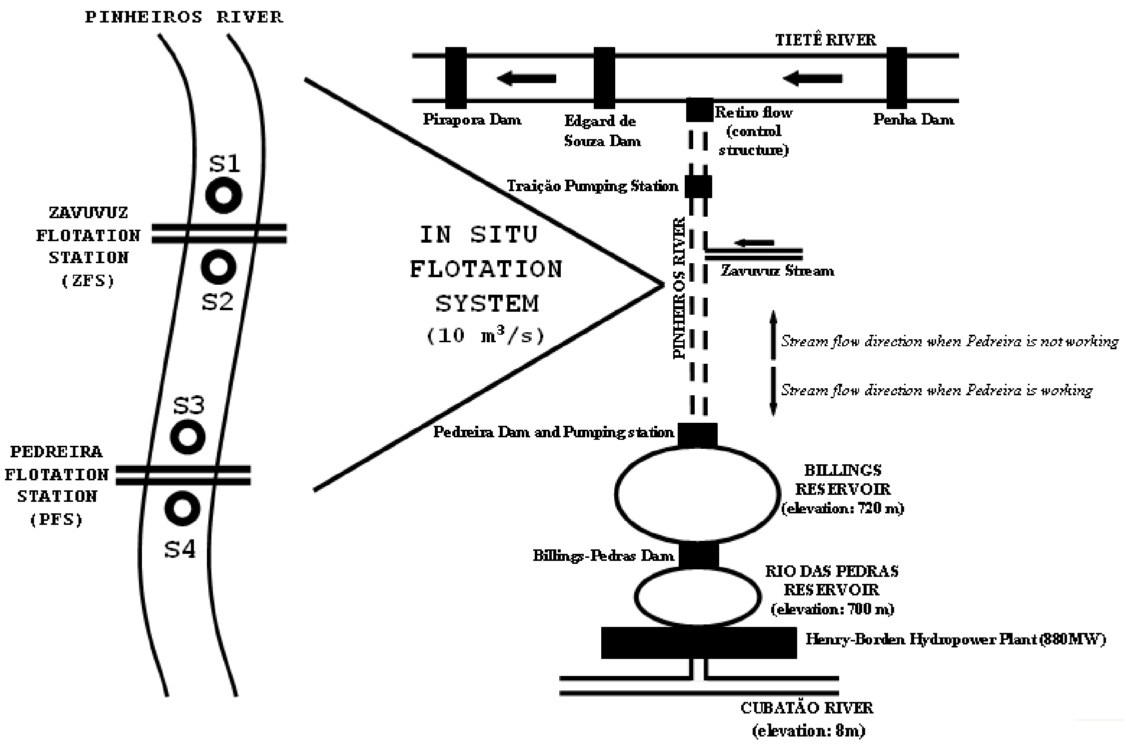

Figure 3: Scheme of the study area showing Tietê and Pinheiros River and also the sampling stations S1 (23º 40' 43.09'' S; 46º 42' 02.15'' W), S2 (23º 40' 47.74'' S; 46º 42' 03.72'' W), S3 (23º 42' 04.09'' S; 46º 40' 59.61'' W) and S4 (23º 42' 11.73'' S; 46º 40' 32.18'' W).

This monitoring structure allowed the assessment of the removal percentages of each flotation station and a combined effect derived from both for all studied variables. It is important to mention the criterion for selecting data to calculate the removal efficiency of the flotation stations. We filtered all data considering a minimum of 12h of flotation working per day as a cutoff criterion. Only data available for these days were considered in the analyses. Days with flood control working and with stops for flotation system maintenance were disregarded.

3 Results and discussion

Table 1 shows the removal efficiency of all studied variables by Zavuvuz FS (S1 vs. S2), Pedreira FS (S3 vs. S4) and the overall effect of both FS's (S1 vs. S4). As positive effects promoted by the in situ flotation system, high efficiency of phosphorus removal was observed (about 90%) as well as reasonable reduction percentages for biochemical (62%) and chemical (53%) oxygen demands and turbidity (48%). On the other hand, iron removal capacity was small (31%) and nitrogen-ammonia removal was negligible, since the associated effect did not promote percentage reduction higher than 2%. In this context, antrophic eutrophication of Billings Reservoir might bring negative effects to the aquatic systems ecological balance and also to the society and the economy of the surrounding area. Moreover, total suspended solids concentrations were not as mitigated as expected. Zavuvuz FS presented efficiency of 30% for this variable and Pedreira FS, only 10% of reduction. The overall effect in turn did not exceed 40%.

Table 1: Removal efficiency by Zavuvuz FS, Pedreira FS and the associated effect derived from both for total phosphorus, biochemical oxygen demand, chemical oxygen demand, nitrogen-ammonia, total suspended solids and turbidity; *no removal.

Variable	Zavuvuz FS S1 → S2	Pedreira FS S3 → S4	Associated effect S1 → S4
Phosphorus	48%	84%	90%
Biochemical Oxygen Demand	38%	24%	62%
Chemical Oxygen Demand	41%	18%	53%
Nitrogen-ammonia	1%	1%	2%
Total Suspended Solids	30%	10%	40%
Turbidity	37%	35%	48%
Iron	19%	*	31%

Table 2 shows a comparison between maximum, minimum and mean values and concentrations found upstream the pilot-scale flotation system (S1, "raw water") and downstream it (S4, "treated water").

The removal percentages of phosphorus were significant, as already described (mean of 90%). However, the remaining concentrations were still higher than the limit established for lentic environments, like Billings Reservoir, according to CONAMA, the Brazilian Council for the Environment (0.03 mg l^{-1}; 2005). Nitrogen-ammonia concentrations after flotation treatment were extremely high (mean of 25.8 mg l^{-1} and maximum of 70.0 mg l^{-1}), showing the system inefficiency for removing this nutrients from water. The tolerated limit for this variable is 3.7 mg l^{-1}, evidencing the unconformity of this water variable with Brazilian standards, since the mean concentration in the treated water was almost seven times above. There was also a conflict with the superior limit value established by CONAMA in respect to biochemical oxygen demand, which is equal to 5 mg l^{-1}. The mean value for this variable in treated water was 19 mg l^{-1}.

Table 2: Maximum, minimum and mean values and concentrations for phosphorus, biochemical oxygen demand, chemical oxygen demand, nitrogen-ammonia, total suspended solids and turbidity in “raw water” (upstream the flotation system, S1) and in “treated water” (downstream the flotation system, S4)

Variable	Value	Upstream (S1)	Downstream (S4)
Phosphorus ($mg\ l^{-1}$)	Maximum	3.10	1.00
	Minimum	0.001	0.001
	Mean	0.52	0.05
Biochemical Oxygen Demand ($mg\ l^{-1}$)	Maximum	110	65
	Minimum	2	2
	Mean	50	19
Chemical Oxygen Demand ($mg\ l^{-1}$)	Maximum	375	222
	Minimum	20	3
	Mean	128	60
Nitrogen-ammonia ($mg\ l^{-1}$)	Maximum	81.0	70.0
	Minimum	0.7	8.0
	Mean	26.2	25.8
Total Suspended Solids ($mg\ l^{-1}$)	Maximum	152	115
	Minimum	5	5
	Mean	30	18
Turbidity (NTU)	Maximum	217	149
	Minimum	5	1
	Mean	54	28
Iron ($mg\ l^{-1}$)	Maximum	14.3	12.3
	Minimum	0.03	0.03
	Mean	1.6	1.1

4 Conclusion

Considering the water quality variables that were studied, in situ flotation technology alone is not sufficient for recovering the water quality of Pinheiros River (Brazil) in a way that the pumping of its water into Billings Reservoir would be harmless and would not potentially contribute for the eutrophication of the reservoir. In other words, the pilot scale flotation system presented is insufficient removal for some key variables. The water monitoring program performed during the years 2007 and 2008 in this river enabled the authors to stress some conclusions:

i. The pilot scale prototype showed high efficiency for some variables like phosphorus, biochemical oxygen demand and turbidity. Poor removal was found for nitrogen-ammonia which is problematic considering the risk of eutrophication of Billings Reservoir.

ii. In situ alternatives for integrated water resources management may be an insightful solution for big cities from developing countries. The pilot-scale flotation system studied by this research showed that these alternatives are feasible in terms of installation, operation and maintenance aspects. Thus, future research on water quality recovering must consider this branch of technologies in the range of possibilities, with special attention to performance improvement, cost reduction and commitment with environmental standards and laws.

iii. The monitoring program continued during the year 2009, including other water quality variables and introducing some improvements in the pilot-system. It is advisable that future investigations about flotation treatment in the Pinheiros River focus on the following topics: the optimization of coagulation and flocculation processes (e.g. coagulants dosage, velocity gradients control) in order to increase the efficiency of pollutants removal; the establishment of clear operational rules for pumping of Pinheiros River waters depending on weather conditions and considering the possibility of flotation or flood control; finally, sludge treatment and destination.

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Water quality in a rural watershed resulting from gemstones mining operations

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Abstract

The economic development and the productive activities have accelerated the degradation of water resources. It is important that these resources are assessed and protected in order to reconcile them with water demands for human activities. Among the potentially polluting activities are those related to mining. Regarding gemstones extraction, the nature of the mining sites implies alterations of the environment that can reflect in water quality decrease of the springs. This study aimed to assess the water quality in the Lageado Grande watershed, located in Southern Brazil. The land use within the watershed is mainly characterized by agricultural activities and by gemstones extraction. Water quality was analyzed in three sampling sites: upstream and downstream of the main mine discharge, and at the watershed outlet. The water quality characteristics were assessed through the following parameters: temperature, pH, electric conductivity, turbidity, DO, BOD, COD, total solids, suspended solids, dissolved solids, fixed solids, volatile solids, total and fecal coliforms, alkalinity, Aluminum, Calcium, Copper, Chromium, Iron, Phosphate, Magnesium, Manganese, Nitrate, Sodium and Zinc. The results showed that the mining operations resulted in increased conductivity, turbidity and solids content. Although mining operations in São Martinho da Serra are recent, results indicate they are having a detrimental effect on the water quality in this watershed. Consequently, pollution control measures in the Lageado Grande Watershed are needed. A containment basin is proposed to reduce sediments from mine drainage.

Keywords: *water quality, diffuse pollution; sediments; gemstones mining*

1 Introduction

In case of gemstones extraction, the waste removed compared to very small quantities of extracted gemstones is very high when compared other bulk or massive mineral such ore, copper, industrial or building materials (Kambani, 2003).

Previous research has studied the diffuse pollution of urban surface runoff (de Luca et al., 1991; Gupta and Saul, 1996; Deletic, 1998; Bertrand-Krajewski et al., 1998; Lee and Bang, 2000; Kim et al., 2006). The pollution from gemstone mining has not yet been explored.

The state of Rio Grande do Sul, located in Southern Brazil, is known as one of the main suppliers of gems in the world, especially agate and amethyst. This kind of activity has great relevance for the socio-economic development of the regions close to localities of extraction and processing. However, it is also responsible for major modifications in the landscape and environment, being able to cause a high degree of environmental deterioration in water resources, even after the end of the extraction activities.

One example is the Lageado Grande watershed, located in the city of São Martinho da Serra, in the Brazilian State of Rio Grande do Sul. The land use in the watershed is mainly characterized by agricultural activities and by gemstones extraction. This study aimed to assess the water quality and diffuse pollution with regard to gemstones extraction, as well to propose a structure to reduce sediments from mine drainage.

2 Materials and methods

2.1 Study area

The study area was the Lageado Grande watershed, a sub-basin of Ibicuí-Mirim river. The watershed is located in the city of São Martinho da Serra, in central part of the Brazilian State of Rio Grande do Sul, between 53°52’46” and 53°57’14” in the west longitude and 29°30’16” through 29°35’04” in the south latitude (Figure 1).

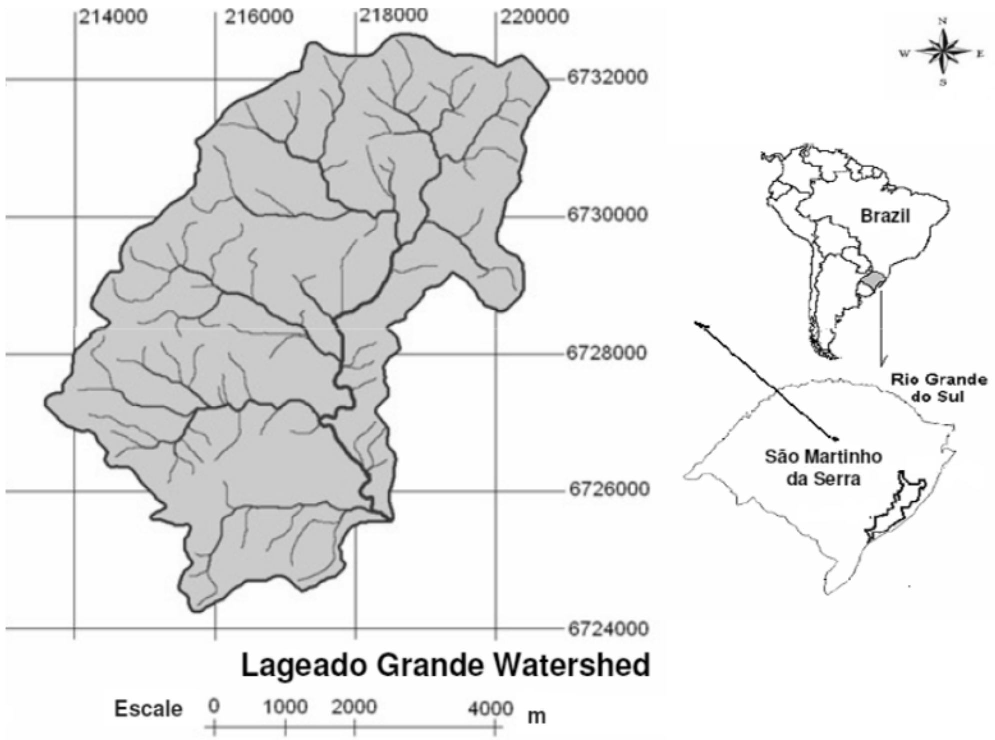


Figure 1: Location of Lageado Grande Watershed within Brazil.

The watershed area spreads over 33.19 km², and the land use is mainly characterized by agricultural activities and gemstones extraction, especially amethyst and agates.

The amethyst and agates mines are conducted entirely by open pit mining methods. The gemstones process is semi-mechanized conducted on a rudimentary level, using basic tools such as picks and shovels, and occasionally, mechanized equipments as show by Figure 2.

a. Amethyst gem.

b. Amethyst geode.

c. Gemstone extraction process.

d. Gemstone extraction process.

Figure 2: Features of the gemstones mines in São Martinho da Serra.

2.2 Data collection and analysis

From December 2004 to January 2006, the water samples were collected in dry weather and during rainfall events to establish runoff pollutant loads. Dry weather samples were taken manually. During rainfall events water samples were taken by automatic samplers. Water quality was analyzed for three sampling sites: upstream and downstream of the main mine discharge, and at the watershed outlet (Figures 3 and 4).

The use of automatic water samplers allowed to obtain samples, mainly, in nocturnal rain, which is difficult to monitor manually. This enabled the evaluation of the pollutant loads during the passage of floods. The automatic water samplers consisted of simple samplers that do not need a power supply. Thus, water was collected during the rising and the falling limbs of flood waves in pre-determined positions.

The quality of runoff water was analyzed using the following parameters: pH, conductivity (EC), turbidity (NTU), total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), fixed suspended solids (FSS), volatile suspended solids (VSS), concentration of aluminium (Al), calcium (Ca), copper (Cu), chromium (Cr), iron (Fe), magnesium (Mg), manganese (Mn), sodium (Na) and zinc (Zn) ions. The analysis followed the methodology described in APHA, AWWA, WEF (1998).

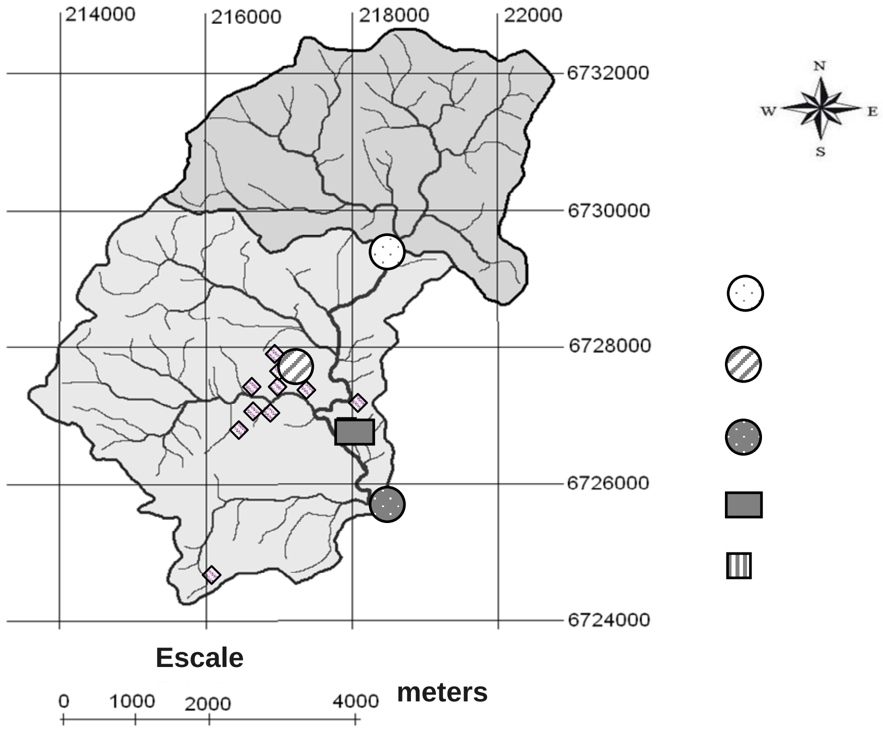


Figure 3: Monitoring and sampling sites location.

3 Results and discussion

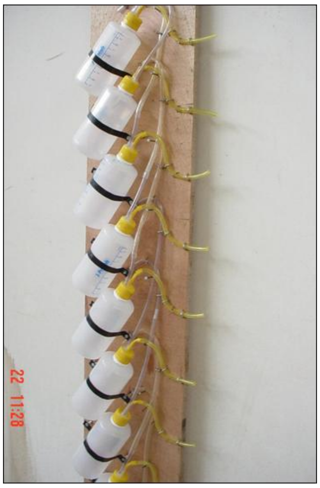
Based on the water quality characteristics, the results showed that the mining operations resulted in increased conductivity, turbidity and solids content.

The values of turbidity for the three sampling points are show in the Figure 5. At the sampling site downstream the main mine discharge the average value was 91 UNT, with values ranging from 56 to 111 UNT. The values of the other sampling sites (upstream and at the watershed outlet) remained well below the values found downstream of the mining area.

Figure 6 shows the box plot of total solids. The values downstream of the mining area are well above the values found at upstream and in the watershed outlet. About 25% of the values downstream of the main mine discharge are above 2000 mg l^{-1}.

a) Upstream sampling site

b) Outlet sampling site



c) Ascending water sampler

d) Descending water sampler

Figure 4: Monitoring and sampling details.

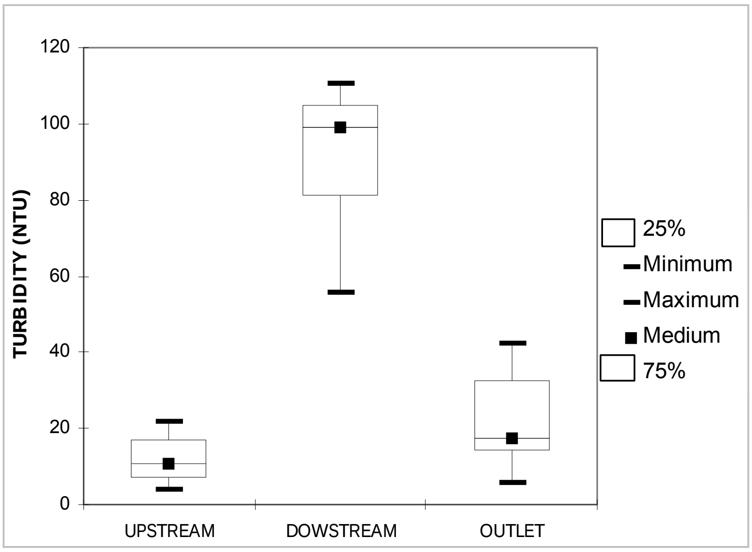


Figure 5: Box plot of turbidity.

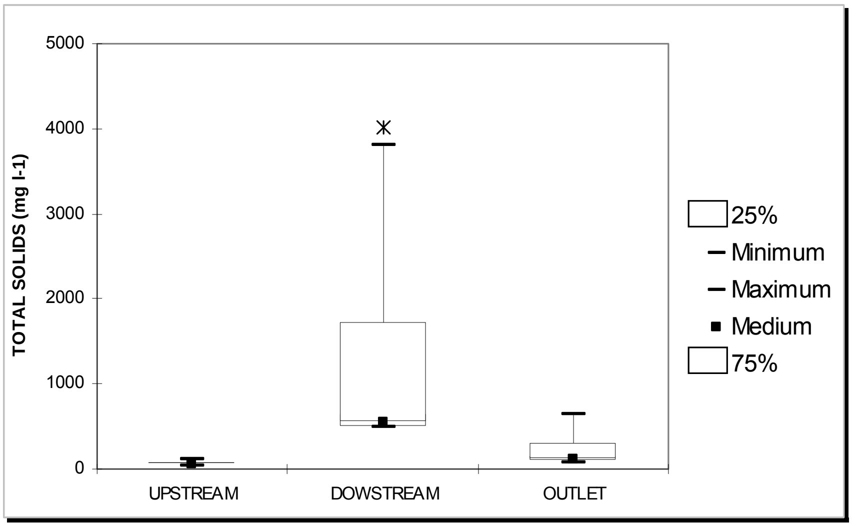


Figure 6: Box plot of total solids.

The quality of runoff water was analyzed. Table 1 gives the event mean concentrations (EMCs) of parameters analyzed. The results showed that the mining operations resulted in increased conductivity, turbidity and solids content. Wet weather EMCs showed higher values compared to dry weather, indicating that the amount of runoff affects the quality of the water in the receiving body. Higher surface runoff and rainfall values resulted in increases in the concentration of these parameters.

The relationships between the flow rate and water quality concentrations were analyzed by employing correlation analysis, in which the relationships between parameters were represented by their corresponding Pearson correlation coefficients (Table 2). Higher runoff and rainfall values resulted in increases in the concentration of these parameters. In addition, a significant correlation was observed between solids content and turbidity values. Table 3 shows the pollutant load discharged during rainfall events for the mainly parameters.

This study also investigated the first flush load. Gupta and Saul (1996) define first flush as that part of the storm up to the maximum divergence between the dimensionless cumulative percentage of pollutants and the cumulative percentage of flows plotted vs. the cumulative percentage of time. This relation allows the estimation of the detention storage necessary to capture a given percent of suspended solids.

Previous studies have proposed equations to calculate the volume necessary to control diffuse pollutions of urban surface runoff (Tomaz 2006; Tucci, 2000; Kim et al., 2006). This research suggests equation (1) to calculate the volume necessary to containment basin to reduce sediments from mine drainage:

$$Vd = (P/1000) \cdot R \cdot A \qquad (1)$$

where Vd is a detention basin volume (m^3), P is precipitation (mm), R = coefficient that depends on the area of soil displayed (mines), A = watershed area (m^2).

Table 1: Event mean concentrations of monitored stormwater runoff. SD: Standard Deviation.

Parameters	EMC				Dry Weather			
	Mean	SD	Min	Max	Mean	SD	Min	Max
EC (μS cm^{-1})								
pH	7.0	0.18	6.59	7.3	7.3	0.12	7.3	7.49
TS (mg l^{-1})	479.4	256.1	211.8	1124.9	236.2	193.5	236.2	651.5
TSS (mg l^{-1})	320.6	181.9	123.0	784.3	144.0	162.6	144.0	464.2
TSD(mg l^{-1})	160.5	76.8	88.8	340.5	92.1	44.4	92.1	187.3
VSS (mg l^{-1})	112.6	59.96	50.8	275.5	50.4	61.9	50.4	183.4
FSS (mg l^{-1})	209.1	127.4	72.3	522.7	93.6	101.6	93.6	280.8
Turbidity (NTU)	64.7	38.86	26.9	180.0	22.4	11.8	22.4	42.4
Al (mg l^{-1})	0.47	0.13	0.34	0.6	0.98	0.53	0.98	1.8
Ca (mg l^{-1})	5.88	1.17	4.70	7.01	6.48	1.27	6.48	8.0
Cu (mg l^{-1})	0.02	0.01	0.004	0.03	0.013	0.01	0.013	0.02
Cr (mg l^{-1})	0.006	0.01	0.00	0.02	0.003	0.004	0.003	0.01
Fe (mg l^{-1})	0.34	0.11	0.24	0.48	0.66	0.33	0.66	1.0
Mg (mg l^{-1})	1.48	0.10	1.34	1.55	1.64	0.31	1.64	2.1
Mn (mg l^{-1})	0.01	0.01	0.004	0.02	0.006	0.002	0.006	0.01
Na (mg l^{-1})	2.61	0.16	2.45	2.82	2.68	0.19	2.68	3.0
Zn (mg l^{-1})	0.02	0.01	0.01	0.03	1.31	2.58	1.31	5.9

Table 2: Pearson coefficients from the analysis between water quality constituents. Rain = Total rainfall, Vol = Discharged volume.

	Vol	Rain	TS	TSS	TSD	VSS	FSS	Turbidity
Vol	1.000	0.884	0.762	0.782	0.685	0.855	0.742	0.888
Rain	0.884	1.000	0.597	0.616	0.515	0.714	0.569	0.805
TS	0.762	0.597	1.000	0.997	0.973	0.954	0.997	0.844
TSS	0.782	0.616	0.997	1.000	0.952	0.970	0.994	0.851
TSD	0.685	0.515	0.973	0.952	1.000	0.881	0.966	0.781
VSS	0.855	0.714	0.954	0.970	0.881	1.000	0.939	0.898
FSS	0.742	0.569	0.997	0.994	0.966	0.939	1.000	0.820
Turbidity	0.888	0.805	0.844	0.851	0.781	0.898	0.820	1.000

Assuming the first flush as runoff equivalent to the first 25 mm of precipitation depth (Tomaz 2006), the containment basin volume was calculated. Figure 7 shows the cumulative mass of TSS vs. cumulative volume of the most important rainfall event. Figure 8 shows cumulative discharge volume vs. the cumulative discharge mass, where runoff of 25 mm precipitation is equivalent to about 60% of the TSS loads. Therefore, installing a containment basin near would help reduce sediments from mine drainage entering into the receiving body.

Table 3: Total discharged loads of monitored stormwater runoff; ADWP=antecedent dry weather period, I=rainfaill intensity.

Event	TS	TSS	TSD (ton d^{-1})	VSS	FSS	ADWP (days)	I (mm h^{-1})	Rain (mm)	Vol (m^3)
7/16/05	6.63	6.64	0.95	2.62	2.98	1	1.78	20.3	1297
8/21/05	23.22	14.48	8.74	3.52	10.96	1	4.27	19.06	3249
8/23/05	33.77	21.51	15.35	7.36	14.15	1	2.36	21.23	85002
9/10/05	212.05	140.87	71.07	49.04	91.94	6	4.69	33.64	77496
9/24/05	252.07	182.67	69.39	69.71	112.97	9	5.63	54.91	294179
10/4/05	1375	957.2	417.71	333.23	642.11	1	5	102.53	1051780
10/13/05	31.93	20.95	10.98	9.51	11.45	5	3.83	19.15	8300
10/14/05	133.33	88.5	44.83	33.5	54.99	1	3.98	38.24	242456
10/21/05	5.8	3.77	2.03	1.8	1.97	4	2.68	16.51	61809
11/6/05	9.4	6.65	2.75	2.13	4.53	15	2.14	24.21	33083
11/24/05	8.64	5.09	3.56	2.05	3.04	19	8.33	30.56	9953
1/8/06	6.24	3.92	2.32	1.72	2.2	7	23.38	52.6	5270
1/12/06	25.36	15.77	9.59	5.35	10.42	2	33.06	41.32	19824
Mean	163.34	112.92	50.71	40.12	74.13	-	-	-	-

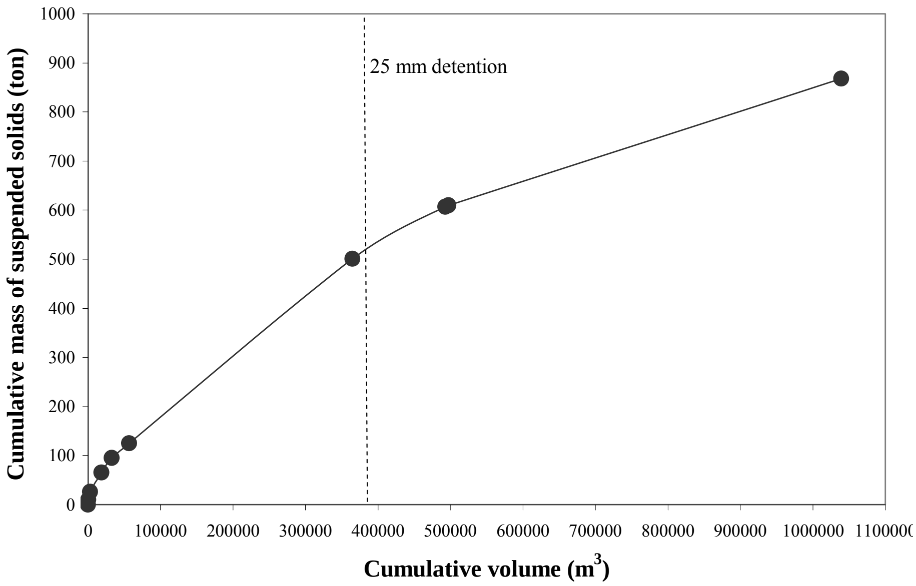


Figure 7: Cumulative mass of TSS vs. cumulative volume of 10/04/05 event.

4 Conclusions

This study aimed to assess the water quality and diffuse pollution in the Lageado Grande watershed which is mainly characterized by agricultural activities and the extraction of gemstones. The quality of runoff water was analyzed, and results showed that the mining operations resulted in increased conductivity, turbidity and solids content. Statistical analyses were used to determine the relationships between flow rate and water quality parameters. Higher surface runoff and rainfall values result in an increase in the concentrations of these parameters. The study also investigated the existence of first flush produced by surface runoff in the quality of water of this watershed. First flush volume was estimated using total suspended solid loads. Although mining operations are recent, results indicate they are having a detrimental effect on the quality of water in this watershed. Control measures of the diffuse pollution in the Lageado Grande Watershed are needed. A containment basin volume was calculated based on suspended solids first flush load. It was estimated that the detention of the first flush could reduce diffuse pollution loading to a receiving water body by up to 60% of the total suspended solid loading.

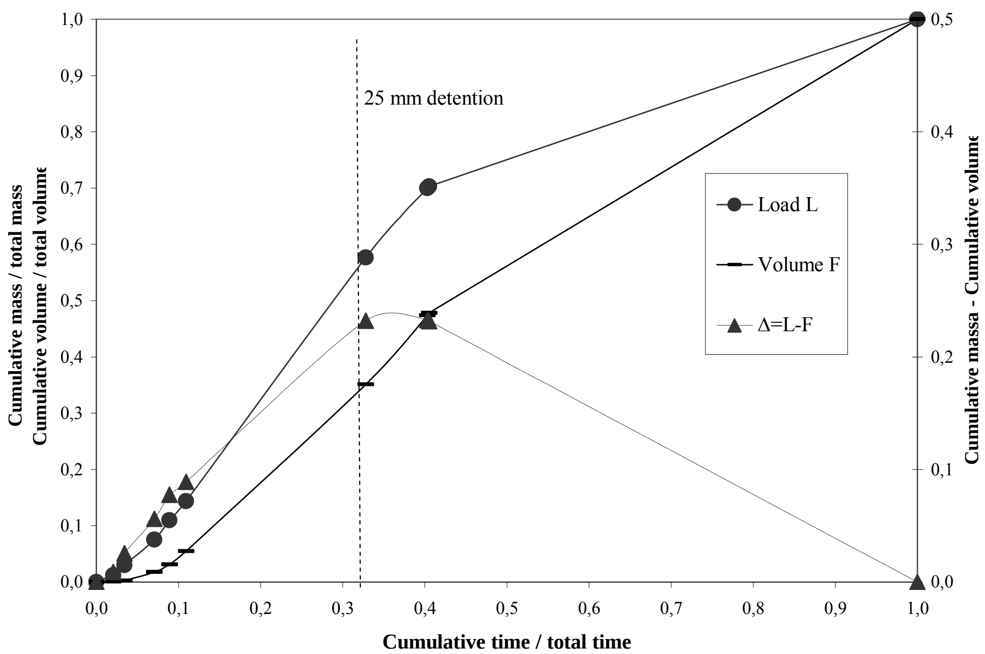


Figure 8: Cumulative discharge volume vs. the cumulative discharge mass of 10/04/05 event.

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The Sanitation challenge for rural and periurban population at Ribeira Valley, Brazil

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1 Introduction

The Ribeira do Iguape River Basin (Ribeira Valley), in southern São Paulo State and eastern Paraná in Brazil, has an area of 25,000 km² and is home to the major intact remnants of Brazil's Atlantic Forest. It is the least developed region of São Paulo, Brazil's most industrialized and wealthiest state. It is the least urbanized, with lowest income levels, the least schooling, highest infant mortality and highest fertility rates. Its economy is based on agriculture (banana and tea), mining and extraction of forest products (palm heart). Industrialization has never gotten underway. In the last 20 years, the valley's participation in the industrial production of São Paulo State never surpassed 0.3% (Hogan, 1999, ISA, 2008). A recent survey, undertaken by the State's Department of Science Technology and Economic Development, indicated that this situation most probably will not change much in the near future. On the other hand, with growing urbanization, flood control is more and more urgent. In last 20 years several floods left more than 20,000 homeless in the region.

This paper analyzes the problem of lack sanitation in area of growing urbanization in spite of being in area of one of most important biomes in world in terms of biodiversity. It addresses some sustainable sanitation approaches and technologies, as a possibility to reduce the public health problem at Ribeira Valley, Sao Paulo State, Brazil. The first is by decentralizing the treatment rather than installing expensive sewer systems that combine and increase the volume of the waste water. The next involve choosing an appropriate treatment technology for the community where several proposed low cost types include lagoons/wetlands, upflow anaerobic sludge blanket (UASB), and dry composting toilet (urine diversion toilets) at household level as a possible solution to address the lack of sanitation in the region. The challenge is also to provide solutions for a region where natural protected areas, cultural and traditional communities interact.

2 The sanitation challenge and regional context

Current reports indicate that great strides are being made in providing access to improved drinking water and sanitation for much of the world (JPM, 2008; UN, 2009). According to recent statistics, 87% of the world's population (5.7 billion people) use drinking water from improved sources, which is an increase of 10% since 1990. Although these statistics indicate that most countries are on track to meet the United Nations Millennium

Development Goal (MDG) for drinking water, 13% of the world's population (884 million people) still do not have access to improved drinking water sources. This statistic is especially startling considering the fact that 84% of the 884 million people without clean water live in rural areas (UN, 2009).

In Brazil, the disparity between urban and rural areas is similarly troubling. Although coverage in urban areas increased to 96% in 2006, only 69% of people in rural areas have access to improved water sources (JPM, 2008b). People without access to improved drinking water sources are more susceptible to water-borne diseases caused by pathogenic microrganisms that can be directly spread through fecal-contaminated water, such as diarrhea, a category that includes more serious diseases such as cholera, typhoid, and dysentery (Cairncross and Feachem, 1993; Prüss-Üstün et al., 2008). 88% of all diarrhea cases are caused by unsafe water, inadequate sanitation or insufficient hygiene, and as a result, over 1.5 million people die every year in the developing world. The World Health Organisation coniders that every 1.00 US$ investment in improving the global water supply has the potential to bring 7.40 US$ in economic benefits and prevent 6.3% of all deaths worldwide (Prüss-Üstün et al., 2008).

While there has historically been much emphasis on water quality, it has been shown by numerous epidemiological studies that water quantity, sanitation and hygiene education are just as important, if not more important, in reducing diarrhea and other water-related diseases (Esrey et al., 1991). It is estimated that at least one billion people lack access to safe water, while over two billion people have inadequate sanitation (WHO and UNICEF, 2000). The United Nations Millennium Declaration adopted in September 2000 was a statement from the world's governments and international agencies that they are committed with the Millennium Development Goals. One of these goals is to halve the number of people without adequate water supplies and sanitation by the end of 2015.

Many studies have shown that human excreta and treated wastewater, if appropriately managed, can be viewed as a major component of the water resources supply and nutrient recovery to meet the needs of a growing economy (Rose, 1999; Wendland, 2003). Thus, the recent strategy in many regions of world is to increase the reuse of treated wastewater effluents for irrigated agriculture which is usually the major sector of water consumption (Sánchez and Subiela, 2007). The improvement of the security and safety of water supply in the developing countries is the best recipe for social, economic and political stability. Implementing this strategy necessitates the needs for a safe, reliable and sustainable use of treated wastewater. The greatest challenges in implementing this strategy are the adoption of low cost wastewater treatment technologies that will maximize the efficiency of utilizing limited water resources, and ensuring compliance World Health Organization Guidelines regarding the health and safety reuse of human excreta. It is crucial that sanitation systems have high levels of hygienic standards to prevent the spread of diseases.

Other treatment goals include the recovery of nutrient and water resources for reuse in agricultural production and to reduce the overall user-demand for water resources (Rose, 1999). Innovative and appropriate technologies can contribute to periurban wastewater treatment and reuse and rural household safety disposal of wastewater.

Currently, in the Brazil, the uncontrolled growth in urban areas has made planning and expansion of water and sewage systems very difficult and expensive to carry out (Nolasco and Pompeo, 2007). It is a common practice to discharge untreated sewage directly into water bodies or to put onto agricultural land, causing significant health and economic risks. The problem associated with the current treatment technologies is the lack of sustainability.

The conventional centralized system flushes pathogenic microorganism out of the residential area, using large amounts of water, and often combines the domestic wastewater with rainwater, causing the flow of large volumes of pathogenic wastewater. In fact, the conventional sanitary system transfers a concentrated domestic health problem into a diffuse health problem for the entire settlement and/or region. In turn, the wastewater must be treated where the cost of treatment increases as the flow increases. The abuse of water for diluting human excreta and transporting them out of the settlement is increasingly questioned and considered to be unsustainable (van Lier et al., 1998). In addition, many treatment systems in mostly developing countries are not successful and therefore unsustainable, since they were simply copied from industrialized countries treatment systems without considering the appropriateness of the technology for the culture, land, and climate. Often local designers educated in universities in developed countries support the choice for the inappropriate systems.

The Valley region contains the largest remnants of Brazil's Atlantic Forest and has been in the national and international environmental spotlight as awareness of the importance of conserving forest resources has grown. The Atlantic Forest is today reduced to less than 5% of its original extension. It is one of the most threatened biomes of the planet. With a biodiversity as rich as Amazon, the Atlantic Forest is currently the object of preservation campaigns, among them UNESCO's Biosphere Reserve Program. As a result of governmental action and the environmental movement over the last three decades, a large part of the Valley's territory is dedicated to preservation, including Areas of Environmental Protection, Ecological Stations and State Parks.

These diverse types of conservation units have different degrees of restriction to the presence of populations and their economic activities. In this sense, they represent obstacles to the populations who live from the extraction of forest products and, according to some compromise, to regional development and efforts to reverse the secular stagnation of this pocket of poverty. Regarding sanitation, the water and sanitation utility company of Sao Paulo Sate (Sabesp), does not provide sanitation to residences located on the rural areas at Ribeira Valley, where traditional communities live. Of the households in the region, 92% use spring water, and the remainder use water from natural caves. The water supplied to residences with access to piped water complies with the quality criteria established by the Ministry of Health. Regarding sewage disposal, 91% of the households included in the study release their sewage into septic tanks, probably in a very rudimentary fashion. Of the remaining households, 4% dispose the sewage on the ground or street, and 5% directly into the river or stream (Giatti et al., 2004). The precariousness of the septic tanks used in periurban areas reflects itself on the pollution of the streams and contamination of local population, imparing the public health of inhabitants.

3 Appropriate treatment technology

Designers should base the selection of technology upon specific site conditions, financial resources and cultural aspects of individual communities. Although site-specific properties must be taken into account, there are core parts of sustainable treatment that should be met in each case. Some of the criteria for sustainable technology (based on Bellagio principles') can be summarized as follow:

- *No dilution of high strength wastes with clean water;*
- *Maximum of recovery and reuse of treated water and by-products obtained from the pollution substances (i.e. irrigation, fertilization);*
- *Application of efficient, robust and reliable treatment/conversion technologies, which are low cost (in construction, operation, and maintenance), which have a long life-time and are plain in operation and maintenance;*
- *Applicable at any scale, very small and very big as well;*
- *Leading to a high self-sufficiency in all respects;*
- *Acceptable for the local population.*

One approach to sustainability is through decentralization of the wastewater management system. This system consists of several smaller units serving individual houses, clusters of houses or small communities. Greywater can be treated or reused separately from the hygienically, more dangerous black water (excreta). Non-centralized systems are more flexible and can adapt easily to the local conditions of the urban area as well as grow with the community as its population increases (Wendland, 2003). This approach leads to treatment and reuse of water, nutrients, and byproducts of the technology (i.e. energy, sludge, and nutrients) in the direct location or nearby of the settlement.

Communities must take great care when reusing wastewater; both chemical substances and biological pathogens threaten public health as well as accumulate in the food chain when used to irrigate crops or in aquaculture. In most cases, industrial pollution poses greater risk to public health than pathogenic organisms. Therefore, more emphasis is being placed on the need to separate domestic and industrial waste and to treat them individually to make recovery and reuse more sustainable. The system must be able to isolate industrial toxins, pathogens, carbon, and nutrients.

There are several options one can choose from in order to find the most appropriate technology for a particular region. This paper discusses sustainable wastewater treatment systems including lagoons/wetlands, upward-flow anaerobic sludge beds/blankets (UASB), and urine diversion toilet technologies for example.

3.1 Lagoons and wetlands

In wetland treatment, natural forces (chemical, physical, and solar) act together to purify the wastewater, thereby achieving wastewater treatment. A series of shallow ponds act as stabilization lagoons, while water hyacinth to accumulate heavy metals and multiple forms of microorganims, plankton act to further purify the water. Wetland treatment technology in warm climate countries offers a comparative advantage over conventional, mechanized treatment systems because the level of self-sufficiency, ecological balance, and economic viability is greater. The system allows also for resource recovery. Lagoon systems may be considered as low-cost technology if sufficient, non-arable land is available. However, the availability of land is not generally the case in highly urbanized areas. The demand of flat land is high for the expanding urban development and agricultural purposes (van Lier, 1998). The decision to use wetlands must consider the climate. There are disadvantages to the system that in some locations may make it unsustainable. Some mechanical problems may include clogging with sprinkler and drip irrigation systems, particularly with oxidation pond effluent. Biological growth (slime) in the sprinkler head, emitter orifice, or supply line cause plugging, as do heavy concentrations of algae and suspended solids.

3.2 Anaerobic digestion

Another available treatment option is anaerobic digestion if there is little access to land. Anaerobic bacteria degrade organic materials in the absence of oxygen and produce methane and carbon dioxide. The methane can be used as an alternative energy source (biogas). Other benefits include a reduction of total biosolids volume of up to 50–80%. A final waste sludge that is biologically stable can serve as a rich humus for agriculture. In addition, the construction and operation of such technology is quite simple and affordable, even for developing economies. So far, anaerobic treatment has been applied in Colombia, Brazil, and India, replacing the more costly activated sludge processes or diminishing the required pond areas. Various cities in Brazil show an interest in applying anaerobic treatment as a decentralized treatment system for “sub-urban”, poor, districts. The beauty of the anaerobic treatment technology is that it can be used at small and large scales (van Lier, et al., 1998). This technology, developed by Professor Gatze Lettinga from the University of Waggening in Netherlands, become very popular during the 1980 and 1990 decades in Brazil and could be considered as one of the sustainable option for a growing community.

There are different types of digesters available of which some have been proven to be effective over time. One of the most suitable digesters for tropical conditions is the UASB. In warm climate, there are reductions in BOD of 75–90%. The UASB technology is feasible in an urban and periruban developing world context because of its high organic removal efficiency, simplicity, low-cost, low capital and maintenance costs and low land requirements.

Typically, UASBs have low sludge production and low energy needs. Since nitrogen and phosphorus are not effectively reduced in anaerobic technologies, this primary treatment approach works well with agriculture or aquaculture. However, they are not completely effective at removing all pathogens; the wastewater needs a post-treatment option to meet discharge standards such as composting digested sludge, wetland systems, or stabilization ponds (Rose 1999). The UASB reactor has been used in Brazil as a sanitation system for medium and large periurban areas. The UASB reactor reduces the organic load dramatically and post-treatment reduces pathogens and nutrients loads. The necessity of post-treatment is necessary in order to attend the legal requirements of discharge into the rivers and also to be safe for agricultural irrigation.

3.3 Treatment at household level: Urine Diversion Toilet (UDT)

Besides the above mentioned low cost treatment (lagoons, wetlands and UASB), there are several authors noting that all of them are conventional wastewater treatment systems. They are not sustainable since they usually do not provide the valuable nutrients contained in human excreta to agriculture, and hence to food production. The design principle of those technologies is mixing all types of wastewater produced and disposing it afterwards.

When the systems designed fail to reconvert the waste back into resources, they don't meet the important criteria of sustainable sanitation (Esrey, 2000). Thus, the future sanitation designs must aim for the production of fertiliser and soil conditioner for agriculture rather than waste for disposal (Otterpohl, 2001). Nutrients and organic matter in human excreta are considered resources, food for a healthy ecology of beneficial soil organisms that eventually produce food or other benefits for people. One person can produce as much fertiliser as necessary for the food needed for one person (Niemcynowicz, 1997).

Therefore, new approaches should be designed in such a way that they are able to reconvert the produced waste into resources free of pathogens on reasonable costs without polluting aquatic environment. Ecological sanitation bases on the concept of source control. High levels of nutrient recovery is possible with the concept of source control in household (figures 1 and 2).

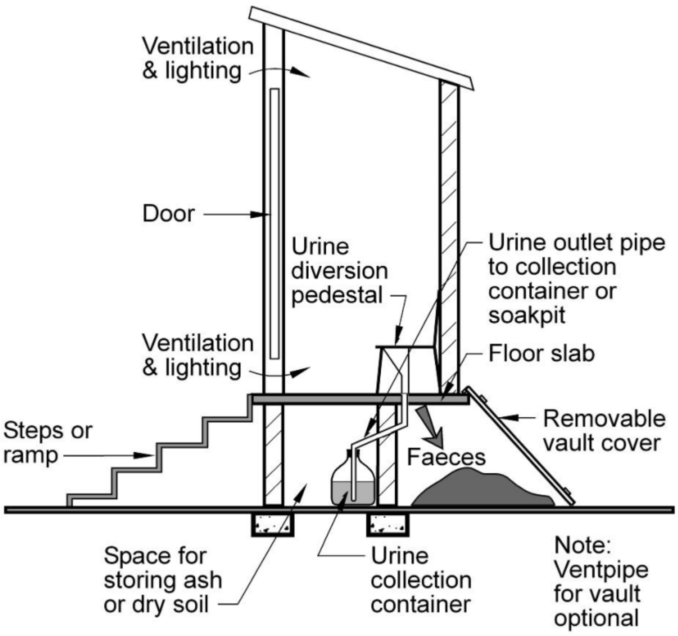

Figure 1: Typical low cost system for UDT.

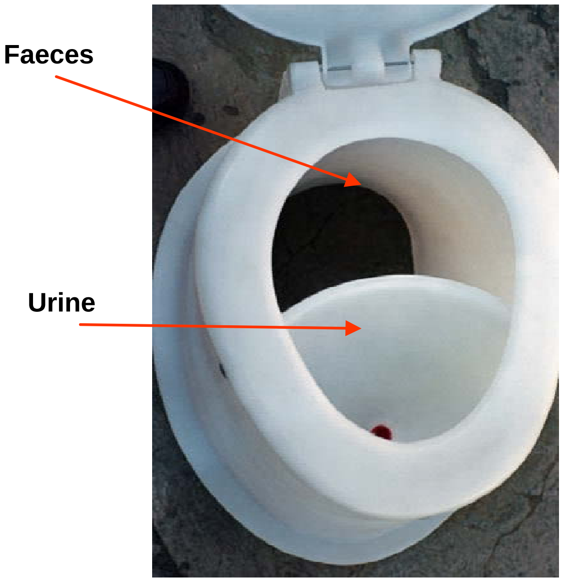

Figure 2: Urine diversion toilet

A vision of source control for household wastewater is based on the fact of very different characteristics and composition of grey, yellow and brown water (Table.1). The typical characteristics of the flows of household wastewater reveals that urine contains most of the soluble nutrients, whereas grey water, despite a very large volume compared to urine, contains only a small amount of nutrients.

Furthermore, faeces, which are about ten times smaller in volume than urine, contain nutrients, high organic load and the largest part of pathogens. Although greywater due to personal hygiene and yellow water due to contamination in sorting toilet contain pathogens, they can easily be eliminated. But, faeces contain as much as 100 million bacteria per gram; some of them are pathogen to human.

Table 1: Definition of wastewater fractions in households.

Wastewater fraction	Description
Grey water	Washing water from kitchen, shower, wash basin and laundry
Black water	Toilet wastewater (urine, faeces, toilet paper (if used and put in the bowl) and flush water
Yellow water	Urine with or without flush water
Brown water	Faeces, toilet paper (if used and put in the bowl) and flush water (toilet wastewater without urine)

If urine is separated and reused in agriculture, not only nutrients will be reused, but also a high level of water protection will be reached. Unlike wastewater containing urine and faeces, grey water can be treated with simple and low cost processes and reused. If faeces are separated and kept in small volumes with non or low-flush toilet, it will provide a good condition for sanitization of faeces. These sanitized faeces can be used as a soil conditioner in agriculture (Gajurel and Wendland, 2007).

4 Strategies for implementing new treatment technology

A wastewater treatment developer must perform an appropriate risk assessment before carrying out the reuse of wastewater. Proper consideration of the health risks and quality restrictions must be a part of the assessment. Source-point measures rather than end of pipe solutions are essential. Source-point measures require extensive industrial pre-treatment interventions, monitoring and control programs, and incentives to the community not to dispose of any harmful matter to the sewers (SIDA, 2002).

For the implementation and promotion of new technology, strategies must include local participation as well as municipal. The importance of local participation is a positive growing trend in many governmental projects in developing countries. The participation must fit with the local population to meet particular local needs. Agreement on key issues between design engineers and the local residents are necessary early in the project, and if local participation is extensive, capital costs can ultimately be reduced. Citizen participation, properly channeled, generates savings, mobilizes financial and human resources, promotes equity and makes a decisive contribution to the strengthening of society and the democratic system.

Furthermore, there is a strong sense of ownership by members of the community in their projects. This pride in the new development helps to ensure the sustainability of the water supply and sanitation systems. Once the project is implemented, local participation contributes to the community's confidence in the new technology and allows them to take on other challenges such as accessing financial aid for other infrastructure projects.

A key feature in some of the most successful simplified sanitation systems must have the community participation, at all stages. The local sanitation authority has to be engaged with residents from the start regarding the choice of system. For simplified sewerage for example, system known as "condominial system", the householders can be responsible for unblocking the length of sewer laid on their own plots. This system can be introduced gradually to a community block by block, such that a relatively small number of householders need to be on board initially for a demonstration project, and others can join once they can see that the system has proved to be successful.

Low cost and community involvement help to ensure, even in low-income settlements, that a high proportion of households are connected to the system. The community based approach to sanitation has been shown to be effective on a large scale, for example in Brazil (Katakura and Bakalian,1998)

Despite significant successes, some simplified sewerage systems in Brazil suffered from low-connection rates, poorly constructed networks and inadequate operation and maintenance (Watson, 1995). The unsatisfactory performance was attributable to the same problems that plague conventional systems: lax construction practices and inadequate or inappropriate efforts to involve customers in project planning and implementation. In cases where customers were not fully informed how to use or maintain their systems, connection rates were less than 40 percent of the intended beneficiary population. The community approach may appear difficult to reconcile with classical project management techniques.

The professional designers usually are more reluctant to deal with low-income communities than to deal with low-cost technologies. Professional engineers often have little experience of community work, so negotiations with the community are best undertaken by a multidisciplinary team. Negotiations may be lengthy, but neglecting the opinions of the community has proved to be a false economy (Watson, 1995). Local knowledge is required to ensure understanding of cultural norms, which can require particular sensitivity regarding toilet practices. Maintaining good relationships between sanitation providers and the community after a system has been implemented is also important, particularly in areas with a high turnover of residents such is the poor regions with inadequate habitations. In many countries, the practical experience has shown that sanitation systems have worked well when authorities, engineers and users have been able to learn how to interact productively.

5 Conclusions

This paper approached the sanitation problem in Brazil, particularly in a region of traditional communities in Ribeira Valley, Sao Paulo State, and discussed several options to achieve sustainability in domestic sewage treatment. The first option is decentralizing the treatment rather than installing expensive sewer systems that combine and increase the volume of the waste. A second options involves choosing an appropriate treatment technology for the community where several types proposed included lagoons/wetlands, UASB and UDT (urine diversion toilet). The common characteristic of all the described types is that they encourage “zero-discharge” technology. This cyclical, rather than linear, approach includes the reuse of the treated effluent for agricultural irrigation and soil conditioner.

The reuse of the wastewater decreases the money spent on fertilizers and it is considered safe since it has been treated for pathogens. The closed-loop treatment system is recommended to achieve ecological wastewater treatment. Currently, many systems are a “disposal-based linear system”. The traditional linear treatment systems must be transformed into the cyclical treatment to promote the conservation of water and nutrient resources. Using organic waste nutrient cycles, from point-of-generation to point-of-production, closes the resource loop and provides an approach for the management of valuable wastewater resources. Thus, the diversion and use of urine in agriculture can aid crop production and reduce the costs of and need for advanced wastewater treatment processes to remove phosphorus from the treated effluents.

Failing to recover organic wastewater from urban areas means a huge loss of life-supporting resources that, instead of being used in agricultural for food production, fills rivers with polluted water. The development of ecological wastewater management strategies will contribute to the reduction of pathogens in surface and groundwater to improve public health. Ecological sanitation systems are one of most promising approaches to deal with sanitation lack. They are sustainable, can adapt and grow with the community’s sanitation needs considering also the area’s climate, topography, and socioeconomic factors and cultural aspects. There are still plenty of needs in this area for research to improve or optimise the current methods of wastewater treatment including community level and household scale. The result of increased attention to this topic will improve the health, economic, and agricultural factors of a developing community.

To conclude, the solution for the lack of sanitation at Ribeira Valley, must be tied with local communities at all phases of the process, otherwise it has large chance to fail, similarly of what happened in many sanitation projects in Brazil and in other developing countries.

6 Acknowledgement

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Comparative study of small wastewater treatment technologies under special operation conditions - COMPAS

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Abstract

In rural areas, small wastewater treatment plants (SWWTP) are a cost-efficient solution to sewage disposal issues. In Europe, SWWTPs are defined as plants for treating domestic wastewater up 50 person equivalents (PE). In Germany, about 2.2 million SWWTPs are in operation or are being installed. In France about 10 to 12 million people are served by decentralized systems.

There are many different technical solutions on the market, ranging from artificial wetlands, reed bed filters to activated sludge systems. All systems available on the European market have to meet the EU-Certification EN 12566-3 [1], which regulates a minimum standard of operation reliability and purification limits. Furthermore, additional guidelines have to be considered, depending on national and regional specifications. There is still a lack of information about performance, operation reliability and maintainability of the different types of SWWTP under real operating conditions. These parameters are however, of particular importance to both customers and service providers. To fill this gap, during a duration time of 14 month in this study 12 different treatment systems were simultaneously compared and evaluated under real operating conditions. The study delivers now detailed information about the performances of different plant models with regard to purification capacity, effluent values, operating expenditures, sludge treatment etc.

The study was performed at the Training and Demonstration Centre for Decentralized Sewage Treatment (BDZ) in Leipzig with a special range of small wastewater treatment plant, already installed at BDZ for training purposes as well as two additional plants, which has been installed there especially for the COMPAS study..

Keywords: *small wastewater treatment technologies, decentralized wastewater treatment, rural areas, realistic operating conditions*

1 Introduction

For more than 100 years, central wastewater disposal with gravity sewer systems or with conveyance by pumps to wastewater treatment plants has stood the test of time in urban settlements, particularly for hygienic and economic reasons. Still, these systems are subject to continuous modification.

New developments have been advanced particularly with regard to the separation of part-streams and to rainwater infiltration in order to monitor and control the discharge situation. In rural areas, however, differing frame conditions necessitated special solutions at very early stages in the planning of wastewater treatment. Such conditions are, among others (cf. [1]):

- *low settlement concentration of up to 25 PE/ha of settlement area,*
- *large settlement lots due to loose open development, single houses,*

- *settlements with scattered buildings,*
- *small villages and districts far apart from each other,*
- *low ratios of covered surface (up to 20% of the settlement areas),*
- *low implementation of sewage and treatment systems,*
- *high ratio of areas under environmental protection,*
- *seasonal variation of the wastewater amounts due to tourism.*

Often decentralized small wastewater treatment units can fulfil these requirements under those conditions. Inquiries of water authorities and manufacturers of SWTP's have shown that in Germany the people (9.5%) who were not connected to a centralised water treatment organisation (WTO) up to 1996 have caused a COD-emission of maximum 44% of all wastewater discharge. In some areas for example Bavaria it was calculated that only 7% of the inhabitants discharged 70% of the COD-load (COD = chemical oxygen demand).

2 Central or local wastewater disposal

There are no standard definitions of „centralized" and „local". In this paper, the terms are used as follows:

Central wastewater disposal

The wastewater is collected within a larger settlement area and mostly treated at some distance from where it was produced. A disposal network with one central WWTP is established (Figure 1).

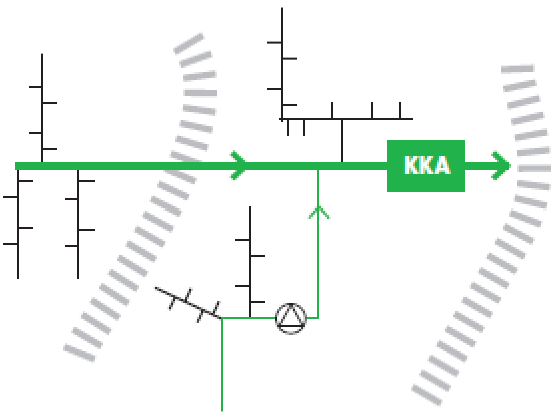

Figure 1: Centralized Wastewater Disposal (KKA = WWTP).

Decentralized wastewater disposal

The wastewater of single houses is locally treated on site; the connection of neighbouring houses is possible, too. On the other hand, the term "local" is also used for the treatment of wastewater from single districts or single villages which are situated near the areas where the wastewater is produced (Figure 2).

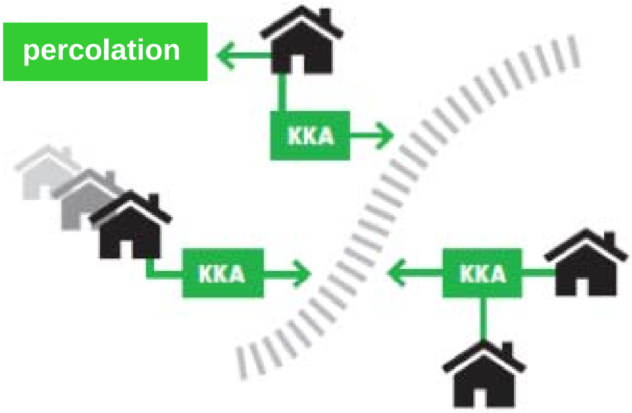

Figure 2: Decentralized Wastewater Disposal (KKA = WWTP).

Local wastewater disposal systems in residential areas with small WWTP'S directly on the sites (< 50 PE or < 8 m³/d) can provide a sustainable solution especially if public sewage systems would lead to unacceptably high costs. Choosing local solutions you have to regard the hygienic conditions, monitoring and maintenance problems and the sludge disposal.

If the authorities have to decide whether for a given disposal area a central or local solution should be developed, they have to check first if the overall situation (protection areas, receiving waters, insufficient gradients, lack of infiltration opportunities) generally allows for a local solution. On the other hand the costs of both variants have to be compared on the same planning level.

3 Motivation and objectives of the comparison of SWWTP's

All small wastewater treatment systems sold on the European market must be certified to European standard EN 12566-3 [1]. As such, they all meet uniform minimum requirements for operating safety and treatment efficiency. In addition, each system must meet any national or regional standards that may apply. However, these minimum requirements say little about the treatment efficiency, stability, ease of maintenance and wide range of different technological features of SWWTP's under realistic operating conditions, although this information would be of particular interest, not only to consumers but also to wastewater service providers.

Therefore, it was an explicit objective of the COMPAS study to test a wide range of SWWTP's under as real as possible operation conditions for more stringent than those defined in design approval procedures and EU certification throughout a test period of one year. In particular, operating conditions were to be simulated, that the principal "VEOLIA" had determined as representative for one-family-households in France, meaning comparably high specific water consumption and high temporal fluctuation of usage within a year.

The test took place on the Demonstration field of the BDZ with 10 already installed plants, those are provided by the manufacturers, organized in the BDZ for demonstration and training purposes. In addition, two Canadian SWWTP's were to be installed for the COMPAS study, to be able to compare the results of this study with an almost contemporaneously carried out study in France (CSTB, Nantes). The operation conditions of this French study consisting of a test field with 8 SWWTP's, mainly soil filter systems, were identical.

The test program was to be carried out in accordance with EN 12566-3 [1] (daily schedule, etc.) with additional load charges. Throughout the year of testing, the following process variables were to be assessed

- *Treatment efficiency,*
- *Technical and maintenance requirements,*
- *Operational stability,*
- *Power consumption,*
- *Consumables*
- *Sludge accumulation, etc.:*

To facilitate interpretation of the results in regard to the effluent values not only the German limiting values but the French limiting values were taken into account as references as well.

4 Overview of the 12 small wastewater systems investigated

Under the guidance of the Steering Committee and in collaboration with the BDZ, we selected a group of small wastewater treatment systems representing the most commonly used procedures on the German and European market for testing in the scope of the COMPAS project. The selected SWWTP's included systems using sessile biomass, different types of soil filters and membrane bioreactors with suspended biomass, sequencing batch reactors and combined technologies (see Figure 3). The type of technology determined the sequence of the presentation of results. In the majority of cases, the SWWTP's tested in the scope of this study had already been installed previously for demonstration purposes. Therefore, possibilities to modify the systems to meet the more stringent test conditions of the study were generally very limited. Two systems were replaced to be able to compare with another study (CSTB, Nantes).

5 Test conditions

The aim of the COMPAS study was to test a broad scope of small sewage treatment plants under as extreme as possible operation conditions that exceed the specifications of the construction admission procedures and the EU certification within in a whole year operation period. Especially conditions were to be simulated that the principal VEOLIA has established as representative for typical households in France which have comparably high specific water consumption and strong seasonal fluctuations of the intensity of usage throughout the year. This includes regular bath tub water discharges as well as additional loading through guests but also holiday idle and power blackouts. Furthermore, no design values exist in France, so that small sewage treatment plants have to be tested under strict conditions to cover as many extreme situations as possible.

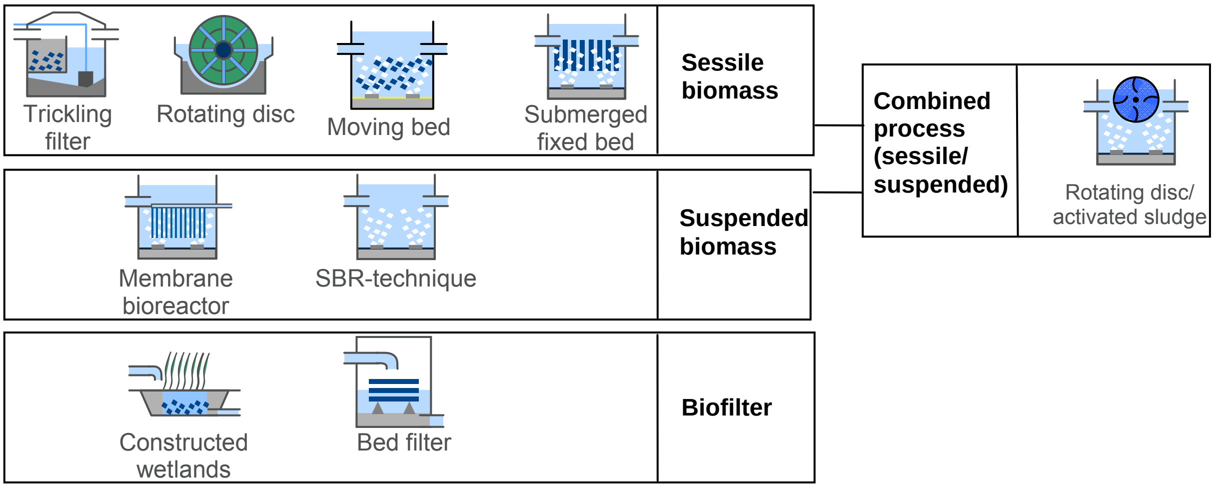

Figure 3: Processes of the 12 small wastewater systems investigated.

The test program was based on the specifications of EN 12566-3 [1] with increased waste water quantities at intermittent intervals (VEOLIA- test program: “Protocole en conditions sollicitantes®”). The charging program is summarized in the following, changes compared to EN 12566-3 [1] are written bold:

- *Phase 1: Inoculation: 100 % hydraulic and pollution load (7 weeks)*
- *Phase 2: Obtaining a permanent state with 100% (4 weeks)*
- *Phase 3: Normal operation with a load of 100% (21 weeks)*
- ***Phase 4: Operation with 100% except for 3 days at the end of the week with 200% (4 weeks)***
- ***Phase 5: operation with 200% (3 weeks)***
- *Phase 6: No load (3 weeks)*
- ***Phase 7: Normal operation again, except for the last 3 days of the week with 200% (2 weeks)***
- *Phase 8: Normal operation (4 weeks)*
- *Phase 9: Operation with 50% load* ***(4 weeks)***
- ***Phase 10: Operation with normal load (4 weeks) with three simulated electric breakdowns of 24 hours with 48 hour intervals***

Phase 3 had to be extended due to an oil accident from a nearby factory, which also affected the test facility. This additional time was needed to allow the systems time to restabilize and to ensure that the further course of testing was not impaired.

Before starting phase 4, manufacturers of the SWWTP's were given the opportunity to modify and adapt their systems to the increased hydraulic load conditions.

6 Overview of Results

Figure 4 contains the influent curves and the maximal and minimal concentrations in the effluent of all SWWTP's for entire study period. The mean influent COD concentration was 456 mg/l, with values ranging from 830 mg/l maximum down to 180 mg/l minimum. Overall effluent COD for the respective small wastewater systems ranged from 14 mg/l (minimum) to 741 mg/l (maximum), with mean values ranging from 34 mg/l to 196 mg/l. By comparison, the mean effluent COD for Class 1 to 5 wastewater treatment plants in Germany was only 28 mg/l in 2007 [2]. This suggests a significantly better treatment performance of large WWTP's. All but two of the investigated SWWTP's yielded an average effluent COD below the German and French maximum limit of a mean 150 mg/l and 125 mg/l, respectively.

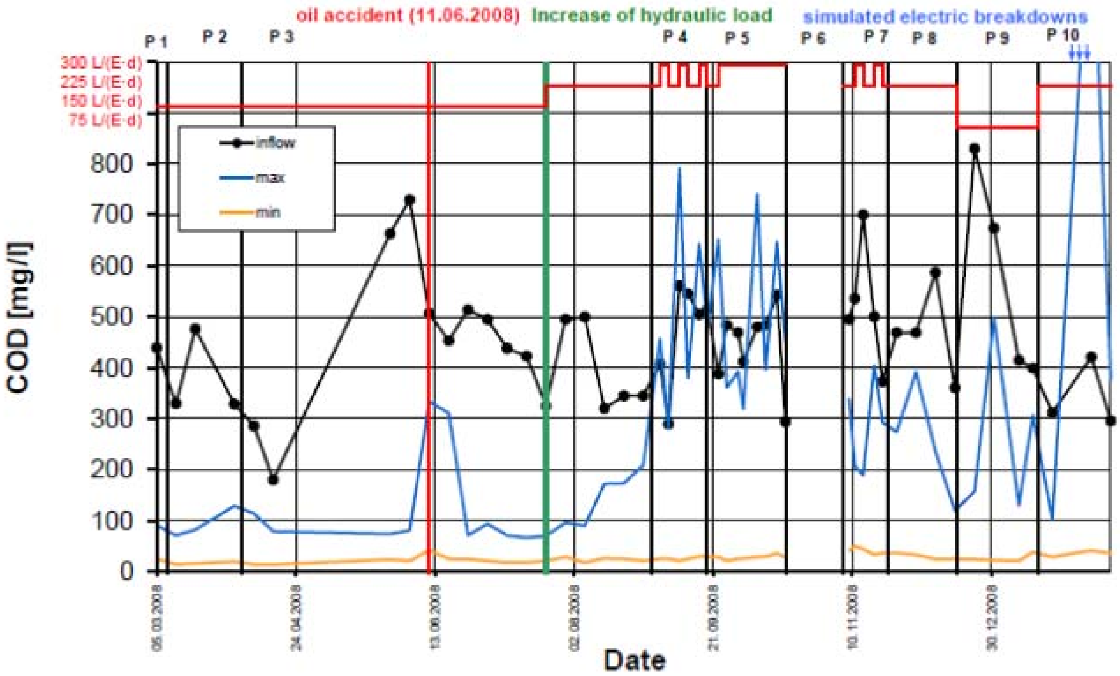

Figure 4: COD curves for influent and the maximal and minimal effluent of all systems.

In most of the SWWTP's, effluent values were below 100 mg/l during most phases of testing. The oil accident led to increases, albeit delayed in some cases, in all of the SWWTP's. Nevertheless, all of the concentrations remained below 150 mg/l during this time except in one case. Fourteen days after the oil accident, effluent concentrations in all of the SWWTP's had returned to the original baseline levels. Starting in Phase 4, overloading resulted in concentration, increases of variable extent. Three of the SWWTP's (suspended biomass and trickling filter) exceeded the 150 mg/l limit at that phase. At the 200% hydraulic load level (Phase 5), peak effluent values far exceeding the 150 mg/l limit and, in some cases, even higher than the influent concentrations, were observed in four of the investigated systems (suspended biomass, trickling filter, and combined processes). Increased effluent COD concentrations (mean 28.6 to 102.9 mg/l) were detected in the remaining SWWTP's. After Phase 6 (no load), the concentrations stabilized in nearly all SWWTP's. COD peaks were observed directly after system restart, particularly in suspended biomass systems. During the four-week 50% load phase (under-loading), effluent COD concentrations in nearly all SWWTP's were less than 100 mg/l. Higher concentrations occurred in only two SWWTP's (see above). During the simulated electrical breakdowns, concentrations rose in all of the systems. A temporary increase in hard-to-degrade substances in the influent could be the cause of this phenomenon because it was observed at the same time in nearly all of the SWWTP's studied.

Table 1 presents the results of the statistical analysis of overall mean influent and effluent concentrations for the target parameters, COD, NH4-N and SS. The number of samples for almost all test systems was n = 50.

Table 1: Results of the statistical analysis. [1)]German limiting value as specified in AbwV; [2)]French limited value as specified in "arête du 22/6/2007".

Technique	Mean effluent			
	COD [mg/l]	SS [mg/l]	NH_4-N [mg/l]	Δ E.coli [log]
Mean inflow	456	269	35	
Limiting values	150[1)]	35[2)]	(10)	
Combination of rotating disk and activated sludge	196	117	20	0.6
Moving bed	53	16	9	0.8
Rotating disc	78	21	16	0.8
Trickling filter	92	29	18	0.8
Trickling filter (textile)	45	9	8	0.9
Submerged fixed bed	56	11	20	1.2
Bed filter	60	14	17	1.1
Constructed wetlands	34	5	12	Effluent: 0 MPN/ml
Filter with coco material	52	13	9	0.8
Membrane bioreactor	77	25	19	Effluent: 0 MPN/ml
SBR I	163	93	23	0.8
SBR II with control panel	70	20	24	0.8

The mean influent SS (suspended solids) concentration was 269 mg/l, with values ranging from 730 mg/l maximum and 120 mg/l minimum. Overall effluent concentrations for all systems ranged from < 1 mg/l (minimum) to 1,100 mg/l (maximum), with mean values ranging from 5 mg/L to 117 mg/l. On average, two of the SWWTPs exceeded the French maximum limit of 35 mg/l. Currently, there are no statutory limits for effluent SS concentrations in Germany.

The mean influent NH4-N concentration was 35.1 mg/l, with values ranging from 54.5 mg/l maximum and 11.6 mg/l minimum. Overall effluent concentrations for all systems ranged from < 0.5 mg/l (minimum) to 49.9 mg/l (maximum), with mean values ranging from 8.1 mg/l to 23.7 mg/l. By comparison, the mean effluent NH4-N concentration for Class 1 - 5 wastewater treatment systems in Germany was a mean 1.18 mg/L in 2007 [2]. Two systems using sessile biomass achieved effluent NH4-N concentrations < 10 mg/l (stabile nitrification).

Due to the lack of guidelines on monitoring parameters for microbiological testing of small wastewater systems without hygienization, Directive 2006/7/EC of the European Parliament and of the Council of 15 February 2006 concerning the management of bathing water quality and repealing Directive 76/160/EEC [3] was consulted for reference. Only those SWWTPs with specific hygienisation systems (UV irradiation and MBR technology) achieved the rating of "excellent bathing water quality for coastal waters and transitional waters", as determined based on the parameters "intestinal enterococci" and "Escherichia coli".

7 Summary and perspectives

The twelve small wastewater systems installed at the Training and Demonstration Centre for Decentralized Sewage Treatment (BDZ) facility in Leipzig, Germany represent the wide range of technical solutions available for small-scale wastewater treatment problems, including SWWTP's with sessile biomass, different types of soil filters, suspended biomass membrane bioreactors, and sequencing batch reactors. In the COMPAS study, these state-of-the-art small wastewater systems were evaluated and compared under realistic operating conditions far more stringent than those associated with the EU certification or design approval procedures. To better reflect local conditions, the test conditions used for assessment of the small wastewater systems investigated in COMPAS were more stringent than those specified in EN 12566-3. The effects of additional loads attributable to guests and regular bath water discharges, low-flow conditions occurring during vacation and holiday periods and electrical power outages were simulated in appropriately designed test phases.

The results of the COMPAS provide useful data on the performance characteristics of the different small wastewater systems, including their treatment efficiency, effluent concentrations, technical requirements, sludge accumulation and power consumption rates, etc. Data gathered in this study will make it possible to identify the most reliable small wastewater treatment systems.

Because influent concentrations at 100% design load were in the lower ranges for "standard European wastewater", as specified in EN 12566-3, the nominal hydraulic load was in-creased to 150%. Relative COD ratios, or the ratio of COD concentration to that of other parameters, were consistent with the reference values.

Chemical and physical parameters in the influent and effluent of the SWWTP's analyzed each week. In addition, three samples were collected for microbiological analyses, the results of which served as the basis of a treatment efficacy assessment.

Nearly all of the SWWTP's reduced effluent COD and TSS to concentrations below the German and French statutory limits. Some of the SWWTP's did not exhibit stable operation. Some of the systems with suspended biomass developed problems under high hydraulic load conditions.

In almost all of SWWTP's studied, increases in effluent concentrations of the target parameters during simulated electrical breakdowns could be attributed to the electrical breakdowns themselves or to the presence of hard-to-degrade substances in the influent. In the study in Nantes [4], however, similar peaks were observed during simulated electrical breakdowns in almost all SWWTP's independent of whether they operated using electricity or not. The researchers in Nantes also could not find a plausible explanation for this phenomenon. This issue requires further investigation.

Only those SWWTP's with targeted hygienisation systems achieved the rating of "excellent bathing water quality for coastal waters and transitional waters", as determined based on the parameters "intestinal enterococci" and "Escherichia coli".

Overall, the results of this study support the further establishment of small wastewater treatment plants as a permanent solution to decentralized wastewater treatment problems in rural areas. The data from this study make it possible to compare the treatment efficancy, stability, and ease of maintenance of different small wastewater treatment systems under realistic operating conditions and provide further insight into the planning and operation of such systems.

An additional research program investigating the effects of specific local conditions for example in Germany should be performed in the future. Examples include:

- *Extreme underload conditions (e.g. 1 PE);*
- *Holiday apartment conditions (changing loads, summer and winter periods);*
- *Effects of disinfectants;*
- *Effects of household cleaning agents;*
- *Effects of medications.*

8 References

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[2] DWA, 2008; Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V., 20. Leistungsvergleich kommunaler Kläranlagen 2007, Hennef 2008.

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Considerations on sanitary barriers for cisterns aimed at drinking water supply in rural areas – Northeast Brazil

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1 Introduction

The main difference between rural and urban areas is that many infrastructures which are often taken for granted by the urban residents do not exist in the rural environment. When the rural area has a serious problem with the climate, the situation is even more complicated. In the Northeast Region of Brazil, there is an area, which is the Semi-Arid Region, with severe restriction on water availability. North-eastern Brazil is the most densely populated Semi-Arid region in the world and around 11 million people do not have a permanent supply of drinking water. This region, extending over almost one million square kilometers, has an annual rainfall below 800 mm, an aridity index of less than 0.5 and a drought risk of above 60%. Due to this irregular rainfall regime, the region is affected by periodic droughts, partly with less than 200 mm rainfall per year. Consequently, the inhabitants of this rural area need to impound the largest quantity of rainfall that is possible, and the cistern is the usual solution. In fact, a rainwater storage cistern coupled with a rainfall catchment area can be an effective way to attain a source of water for a home. Although the quality of water from rainfall is usually very good, the users sometimes do not have sanitary conditions, or hygiene habits, or level of knowledge to keep this quality level. Therefore, to reduce health problems due the water quality, it is necessary to investigate different ways of changing the traditional handling of water in rural areas.

2 Northeastern Brazil's Semi-Arid region

The territory of Brazil is divided in five regions: North, Northeast, Central, Southeast and South (Figure 1). The gathering of states was performed based on similar cultural, economical, historical and social aspects. This division is the most widely used in Brazil because official information given by the IBGE uses this system.

The Semi-Arid region of Brazil in the Northeastern part of the country, extending over almost one million square kilometers, has a annual rainfall below 800 mm, an aridity index of less than 0.5 and a drought risk of above 60%. This Region has a predominant native vegetation of deciduous thorn forest or thorn bush savannah, locally known as caatinga (Sampaio et al., 1995).

Inhabitants in Semi-Arid areas in developing regions are amongst those most vulnerable to climate variability and potentially most vulnerable to climate change. The vulnerability to climate variability emerges from a combination of the level of availability of natural resources and the human dependency on these resources (Krol et al., 2004). According to the authors, in Semi-Arid regions, the limited availability of water and the low reliability of this availability pose strong restrictions on the use of natural resources. In addition, population is often of high density, and is strongly dependent on natural resources with little short-term options to reduce the dependency.

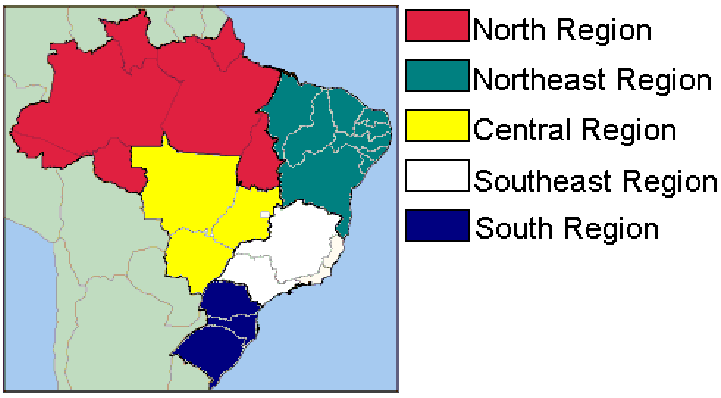


Figure 1: The different regions of the territory of Brazil.

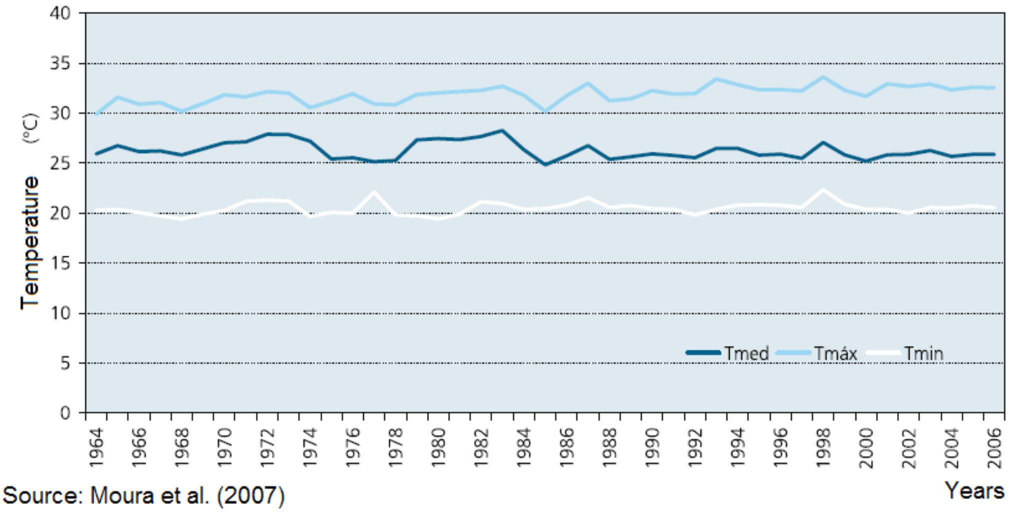
2.1 Climate

In general, climate can be understood as encompasses the statistics of temperature, rainfall, evaporation, and numerous other meteorological elements in a given region over long periods of time. Figure 2 shows that the climate of the Semi-Arid region is characterized by continuous high temperatures, high evaporation rates and a highly time-variable rainfall regime. Due to this irregular rainfall regime, the region is affected by periodic droughts, with partly less than 200 mm rainfall. The inter-annual rainfall variations in the Semi-Arid region constitute a key problem which importance worsens each year with population growth and the consequent demand for water resources.

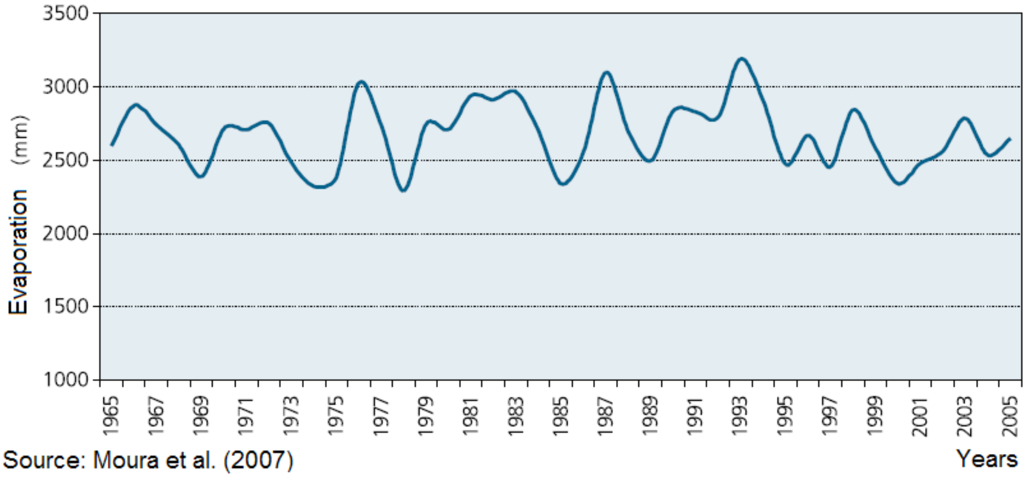
2.2 Water supply and sanitation

According to Costa (2006), the current situation of water supply and sanitation in Brazil is demonstrated by the following access indicators: the water supply index in urban areas reaches 95.4%; the sewage collection index in urban areas reaches 50.3%; regional contrast can be described as follows:

- *in the south region, the water supply index in urban areas is 98.9%, while in the north region it is only 69%;*
- *the sewage collection index in the southeast region is 70.7%, while in the north region it reaches only 8.5%;*
- *the treatment index of sewage produced in the whole country is 31.3%;*
- *the treatment index of sewage collected in the whole country is 61.2%.*



Source: Moura et al. (2007)



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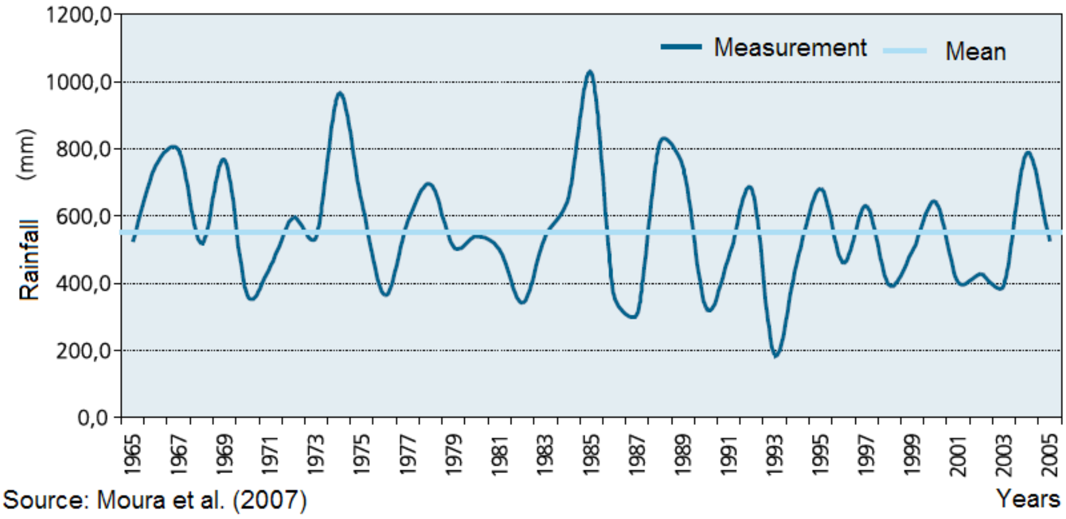

Source: Moura et al. (2007)

Figure 2: Climate elements of the Semi-Arid Region of Brazil. Top: Air temperature: Tmed = mean temperature, Tmax = maximum temperature, Tmin = minimum temperature. Mid: Annual Evaporation rates. Bottom: Annual Rainfall rates.

These numbers serve as basis for some reflections about the situation of water supply and sanitation in Brazil. The situation is more critical when analyzing rural and urban areas separately. Figure 3a shows that less than 20% of the rural area has water supply by public service. In rural areas of the Northeast of Brazil, a large amount of water supply is not covered by public service or by wells. In this case, cisterns can be an alternative solution.

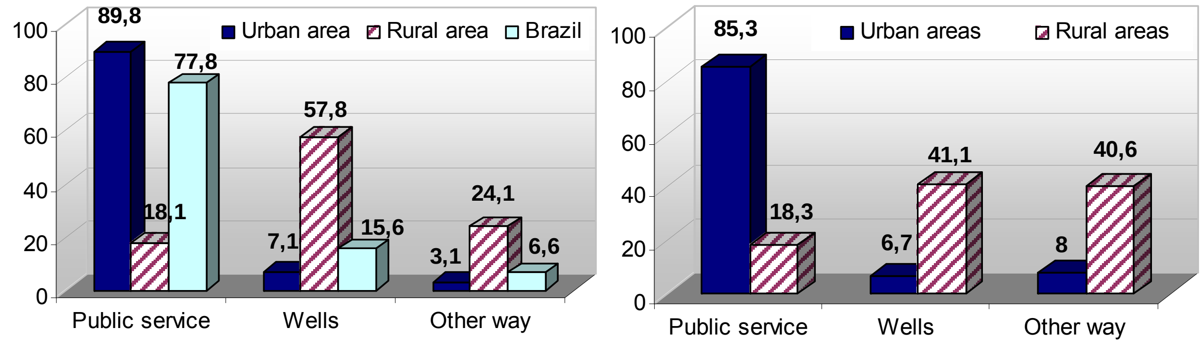

Figure 3: Overview of water supply service (Source: IBGE, 2002). Left: Overview of Brazil; right: Overview in Northeast of Brazil.

For sanitation service, Costa (2006) presents the following indicators:

- *around 84.5% of the municipalities have services, mainly only collection, provided directly by municipal services; they partly do not provide these services regularly;*
- *approximately 14.5% of the municipalities have the services provided by State companies in a regular or irregular manner and without any control and regulation system;*
- *less than 1% of the municipalities have passed the services to private companies.*

According to IBGE (2002), in the largest part of the Northeast of Brazil the sanitation services reach less than 30% of the region. It can be observed that the coverage is significantly higher in urban areas, where 84% of the Brazilian population lives, than the coverage in rural areas, where 16% of Brazil’s population lives. Consequently, most of people have to walk long distances in search of alternative sources of water supply.

2.3 Health

More than 4 million children up to an age of 6 years live in the semi-arid region of Brazil. This amount represents more than 15% of the population who lives in this region usually from excavated wells and contaminated by animals. An important indicator of the reality of these children is the infant mortality rate, which represents the number of deaths of children less than 1 year old per 1000 births. The infant mortality rate of the municipalities in the Semi-Arid Region is 65 per 1000 births, which is higher than the Brazilian quantity 29.7 per 1000 live births (Gomes Filho, 2003). According to information from Brazilian Heath Service (Sistema Único de Saúde), the main reasons for the amount of children less than 1 year entrance in hospital are diarrhea, pneumonia and prenatal sickness. Gomes Filho (2003) informs that a greater part of these occurrences in the semi-arid region is linked to bad sanitary conditions and to water scarcity or water contamination.

3 Alternative action

The climate characteristics and the existing deficiencies in the water supply and sanitation systems are the reasons for many problems of the inhabitants of semi-arid regions. Gnadlinger (2006) pointed out that the water problem in the semi-arid region of Brazil has to be managed in different ways, according to the available sources of water supply (groundwater, surface water, soil and rainwater). Gnadlinger (2006) presents a brief list of some possibilities:

- *Managing water in and for the environment based on the watershed, protection and revitalization of springs and riparian vegetation, pollution prevention, wastewater treatment, reuse and recycling of water, looking for the balance of land use, water use and the health of ecosystems, helped by a broad application of Integrated Land and Water Resources Management (Falkenmark et al., 2007).*
- *Taking care of community water for laundry, bathing, livestock consumption, supplied by ponds, ground catchment rockcisterns, riverbed-cisterns, shallow wells, etc.; community organization for planning, construction and maintenance is necessary.*
- *Assuring blue and green water for agriculture, hence rainwater harvesting techniques are indispensable for supplying water to plants, or as “green water” or as “blue water” (Frankenmark and Rockström, 2004).*
- *Supplying emergency water for drought years, guaranteed by deep wells and smaller dams strategically distributed.*
- *Providing drinking water for every household supplied by cisterns, shallow wells, etc.*

According to Gnadlinger (2006), following these different alternatives of water management, decentralized and participative plans of water supply must be elaborated by communities, districts, municipalities and river basin committees of Semi-Arid Region.:

3.1 Cistern: a popular solution

For thousands of farming families in northeastern Brazil’s semi-arid region, cistern is a simple, low cost water storage system that dates back thousands of years and has made life much easier. In fact, the cistern is a solution for drinking water supply in semi-arid regions and it is intended to use large enough to store rainwater collected during the rainy season for using during the long dry season. Taking into consideration the fact that in the Northeastern Brazil around 11 million people do not have a permanent supply for drinking water, the Program of 1 Million Cisterns – P1MC was launched by the Federal Government. P1MC has been executed by the civilian society in a decentralized manner. The goal is to supply safe and drought proof drinking water for 1 million rural households, which represent around five million people. Each cistern from P1MC holds 16,000 liters and can supply a family of five people with enough water for washing, cooking and mainly drinking for the dry period of the year. In the scope of the program training is provided for local people to build the cisterns by themselves, consequently the community involvement is essential.

3.2 A brief outline on cistern users

P1MC selects the communities considering the following criteria (Lopes and Lima, 2005):

- *communities with lowest Human Development Index (HDI),*
- *communities whose heads of the families are women,*
- *communities with highest quantity of children, old people (more than 65 years old) and people with handicap,*
- *communities with the highest levels of water scarcity,*
- *Communities with more quantity of children and teenagers in risk situation (infant mortality).*

Gomes et al. (2002) investigated hygiene habits of many people from Northeastern Brazil and they concluded that the studied population presented very poor sanitary conditions, as well as inadequate hygiene habits (Table 1). According to the authors, only 18% of the houses had indoor plumbing and 46% had bathroom facilities. It was reported that in 77% of the residences, hogs were being raised and they were often in contact with human. One point of concern is related to the population awareness on drinking water quality, since only 8.8% of the families boil water for drinking purpose.

When new cisterns are built, the inhabitants no longer face more water quantity problems. But if they continue with inadequate hygiene habits and handling of rainwater of storage and catchment system, a new problem, arises relate to water quality, which can increase the cases of sickness by water contamination.

In the Semi-Arid Region of Brazil, there are more than one hundred thousand families supported by the P1MC, thus the quality of water provided by these cisterns is an important factor. Therefore, some studies have been investigating the quality of water from cisterns (Ceballos et al., 1998; Crabtreea et al., 1996; Kahinda et al., 2007).

Brito et al. (2005) evaluated physic-chemical and bacteriological parameters of cistern water in five municipal districts of the Semi-Arid Region of Brazil. The results showed that the physic-chemical variables were within existing water quality standards; however, the bacteriological analysis results indicated the presence of coliforms in more than 40% of cisterns, contravening water potability legislation. These findings underline a need for water treatment and training of health inspectors in advising families on water management and treatment, aimed at achieving adequate human consumption standards.

Table 1: Frequency of basic sanitation conditions and hygiene habits, Northeastern Brazil; n = number of families surveyed. (Source: Gomes et al., 2002)

Characteristics	n	[%]
Indoor water plumbing	166	18.1
Bathroom facilities	162	45.7
Familiarity with cysticercosis	165	93.9
Familiarity with tapeworm	131	26.7
Has raised hogs	155	77.4
Raises hogs presently	155	30.3
Boils drinking water	159	8.8
Throws out faeces outside the home	165	47.3
Washes hands prior to eating or when going to bathroom	165	63.6
Washes food products	164	84.1
The hogs consume excrement	119	72.3
Has eaten or eats pork contaminated by cysticercosis	153	45.8

3.3 Sanitary barriers: some possibilities

Figure 4 exhibits a typical scheme of rainwater storage and catchment system, identifying two main potential points for contamination: downpipe, which is used to do the first flush rejection and the water outlet. The procedure of first flush discard is appropriate to remove suspended solids and animals excrements that are carried from the catchment surface (here: the roof) during the first few minutes of a rainfall event and the common way to let the first flush rejection is disconnecting the downpipe. There are two problems with this procedure: the first problem is that sometimes the people forget to do it, and the second, and most important, is that it is necessary to use the hands, and sometimes people do not have adequate hygiene habits to do it. Otherwise, the common way to take water from cistern is using buckets, and therefore here the hygiene habits are also an important issue. In order to reduce the water contamination from inadequate hygiene procedures, some alternatives were studied by Souza (2009): first flush rejection automatic devices and hand pump.

In order to investigate both proposed sanitary barriers, Souza (2009) performed specific experiments. The first experiment was performed considering two models of first flush rejection devices; one was based on communicant vases principle and the other on siphon. The main goals were: investigation of an efficient device to apply to communities, providing the people with the automatic first flush rejection (no hands), and building a simple and cheap (material and labour) device. In both models of devices investigated, the methodology was: collecting the water samples (from three points – water used for the experiment prior to reaching the roof, point A; inside the first flush device, point B; and inside the cistern, point C), transporting the samples to the laboratory, analyzing the samples at the laboratory and comparing the results.

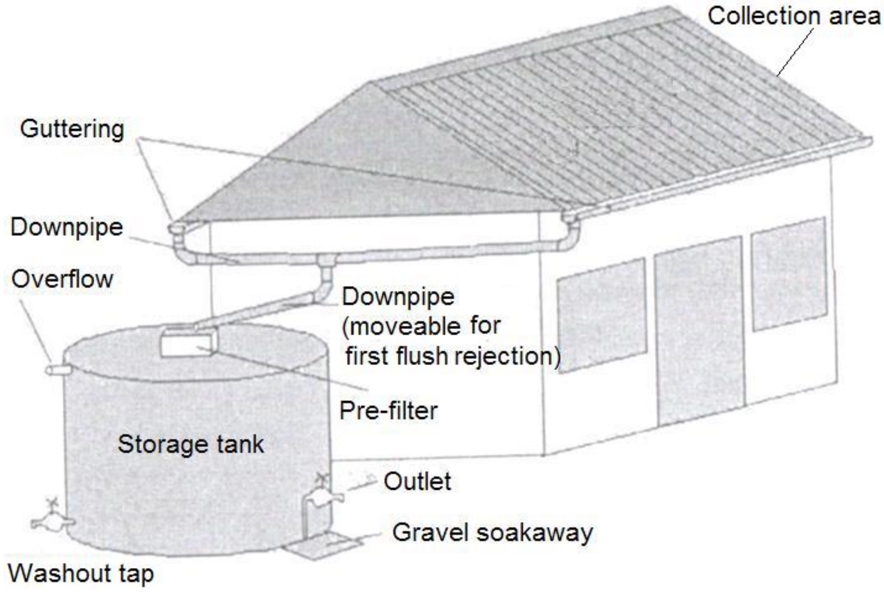

Figure 4: Typical scheme of rainwater storage and catchment system (Source: Tomaz, 2005).

Based on the results of Souza (2005), two parameters can be analyzed: turbidity and coliform. Turbidity is a parameter that measures of the amount of particulate matter that is suspended in water. Coliform are bacteria that are always present in the digestive tracts of animals, including humans, and are found in their wastes. They are also found in plant and soil material. If coliform bacteria are present in drinking water, the risk of contracting a water-borne illness is increased. Both models of automatic first flush rejection are able to reduce the quantity of suspended particulate matter (Figure 5a) while the same behavior was observed with regard to coliforms (Figure 5b). Both models of automatic first flush rejection are also able to reduce the quantity of coliforms.

4 Conclusions

The water scarcity in the Semi-Arid Region of Northeast of Brazil is not only a water quantity problem but also a water quality problem. The population searches for alternative water supply sources which sometimes can increase the cases of sickness by water contamination. Cisterns represent one possible solution for the water quantity problem while the water quality parameters have to be monitored continuously. Devices for automatic first flush rejection can be a good option to reduce the contamination of the rainwater in storage and catchment system.

5 Acknowledgement

The authors would like to acknowledge the National Counsel of Technological and Scientific Development (CNPq/CT-Hidro) and the Research and Projects Financing Agency (FINEP) for financial support. Research project partners of Federal Rural University of Pernambuco (UFRPE), Federal University of Campina Grande (UFCG), State University of

Paraíba (UEPB) and Brazilian Agricultural Research Corporation (EMBRAPA) are also greatly acknowledged.

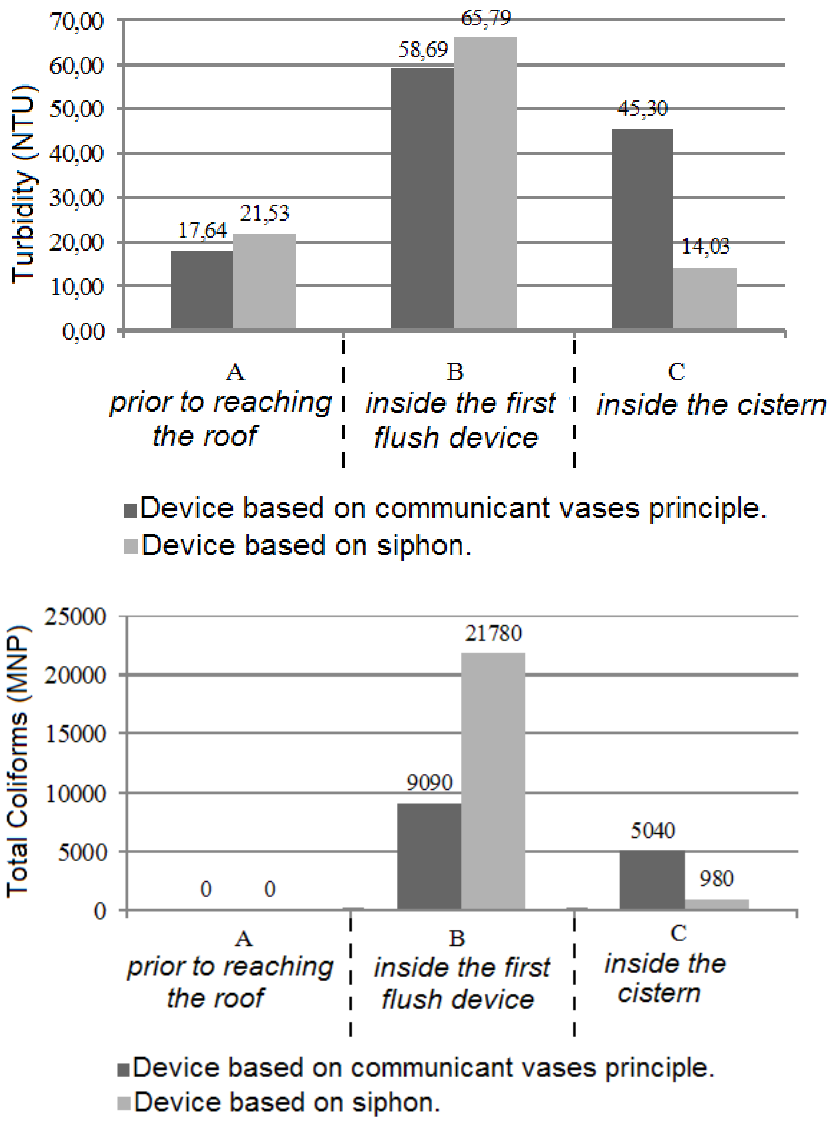

Figure 5: Results of water quality parameters. Top: Turbidity on three points in the catchment-storage system. Bottom: Total Coliforms on three points in the catchment-storage system.

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Treatment of well water contaminated with arsenic and water network modeling

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1 Introduction

The presence of arsenic as a natural contaminant in groundwater used for drinking by humans and animals is a problem that affects large parts of America, and it involves different countries, including Argentina, Chile, Mexico, Peru, Bolivia, USA, Canada, Nicaragua, El Salvador and Brazil. It is estimated that in Latin America at least four million people are exposed to high concentrations of arsenic through drinking water, usually the dispersed rural population is the most affected by this problem by lack of access to safe drinking water. It is further estimated that in Argentina, the population exposed to drinking water with high content of arsenic, is 2 million inhabitants.

In this area, the most important health problem, caused by the ingestion of varying doses of arsenic for long periods of time, is the ERCHA (Endemic Regional Chronic Hidroarsenicism). The ERCHA is associated with several chronic effects, including skin disorders such as melanosis, keratosis and skin cancer. The time that it takes to manifest the HACRE is variable and is related to the health of the person, individual susceptibility, nutritional status, arsenic exposure time and arsenic concentration (Trelles et al., 1970). Usually it takes several years before the onset of clinical symptoms. The effects of arsenic on human health, has also described his relationship with the occurrence of bladder cancer, kidney cancer, lung cancer, blood vessels diseases of the legs and feet, and possibly also diabetes, hypertension and reproductive disorders.

There are around 14 technologies to remove arsenic from water with efficiencies of 70 to 99%. The coagulation-flocculation and lime softening are most commonly used in large systems, not only to remove arsenic (Sandoval, 2000). Small systems can be applied for ion exchange, activated alumina, reverse osmosis, nanofiltration and reverse electrodialysis. The use of Phytoremediation would help remove up 90% of arsenic from water at low cost. In recent years, differents tests with phytotechnologies have been carried out involving the use of aquatic plants to remove toxic elements from the water. The main adsorption mechanism of uptake is through the roots (Miretzky et al., 2004, Denny and Wilkins, 1987).

The aim of this paper is to apply this method in a simple way to a rural affected area and then distribute the water efficiently, using aquatic plants in a water treatment plant and the design of a water distribution network. In order to apply these methods, a rural area of the province of Buenos Aires near Carlos Casares (Buenos Aires) has been selected which is affected by both problems:

- *Contamination of arsenic in water and*
- *Inefficient distribution of aquatic resources in the area*.

We will introduce and apply the following tools to treat well water polluted with arsenic and to improve the water distribution in the rural area:

- *The aquatic plants technique: treatment with aquatic plant to remove the arsenic from ground water;*
- *Subsequently, we design the drinking water network efficiently through EPANET 2.0.*

These two proposed methods may contribute to solve the existing problems and improve quality of life for the inhabitants (Figure 1).

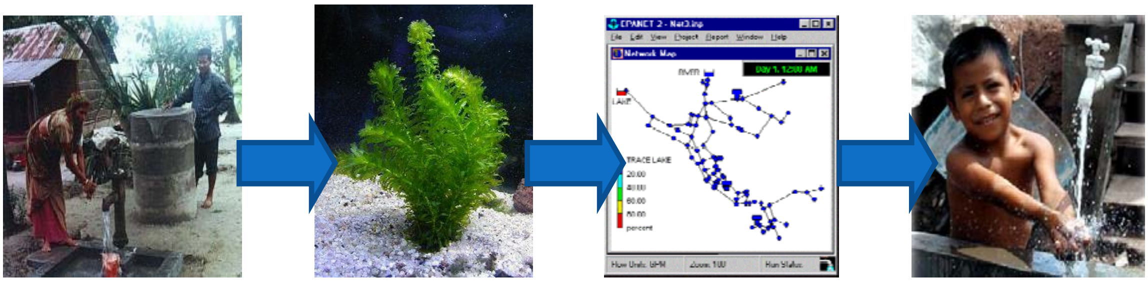


Figure 1: Steps performed in this study.

2 Elimination of arsenic in groundwater contaminated through the use of aquatic plants

Recent solutions focus on the problem of contamination of well water with arsenic, consisting of implementing the technique of phytoremediation at a treatment plant, which has proven to remove up to 90% of inorganic arsenic from water. Phytoremediation has been known for years by the absorption of heavy metals, including arsenic. But until today, this technique has not been implemented in drinking water treatment plants, although in many countries it has proven its effectiveness at laboratory. The development is based on a drinking water treatment plant with aquatic plants. It is planned to implement this method in a treatment plant to reduce arsenic concentration to a level below the tolerable limit for the human body (minimum value established by World Health Organization: less than 10 µg/l).

In general, these plants are able to retain in their tissues a variety of heavy metals (like cadmium, mercury and arsenic). The mechanism is assumed to work through complex formation between heavy metal with amino acids present in cell, after absorption of these metals through the roots (Yeddy Metcalf, 1995). Another possible mechanism suggests that the microorganisms present in the roots produce flocculated solids, which then sediment by gravity (Novotny and Olem, 1994). There are many types of aquatic plants that can absorb heavy metals, but the best absorption of arsenic are the following genus of plants: Ceratophyllum, Myriophyllum, Chara and Elodea.

2.1 Description of plants

Table 1 describes the main characteristics of plants suitable phytoremediation of arsenic.

Table 1: plants suitable phytoremediation of arsenic.

Illustration	Name, description and habitat
	***Ceratophyllum*** *Description:* A brittle, rootless, entirely submerged perennial herb. Leaves bright green, stiff, coarse-textured, sessile, in whorls of 5-12 at each node, once or twice forked, ¼"-1¼" long. *Habitat:* Quiet water of lakes, ponds, marshes, and streams, where it is common, often abundant. A good pond oxygenator, it usually grows submerged in the water but is sometimes found floating on the surface. All Ceratophyllum species are obligately submerged aquatics and cannot tolerate periods of emergence.
	***Myriophyllum*** *Description:* It has leaves submersed and emergent. The submersed leaves are 1.5 to 3.5 centimeters long and have 20 to 30 divisions per leaf. The emergent leaves are 2 to 5 centimeters long and have 6 to 18 divisions per leaf. The bright green emergent leaves are stiffer and a darker green than the submersed leaves. *Habitat:* Is found in freshwater lakes, ponds, streams, and canals and appears to be adapted to high nutrient environments. It tends to colonize slowly moving or still water rather than in areas with higher flow rates.
	***Chara*** *Description*: It is often called muskgrass or skunkweed because of its foul, musty almost garlic-like odor. Chara is a gray-green branched multicellular alga. However, it has no flower, will not extend above the water surface. Chara has cylindrical, whorled branches with 6 to 16 branchlets around each node. *Habitat*: The plant is found in shallow water to depths over 20 ft depending on water clarity. The plants can also thrive in ponds that are completely dry part of the year.
	***Elodea*** *Description*: Elodea is a rooted multi-branched perennial plant but can survive and grow as floating fragments. The dark green blade-like leaves (3/5 inch long and 1/5 inch wide) are in whorls of three with finely toothed margins. The flowers of Elodea have three white petals with a waxy coating that makes them float. *Habitat*: Quiet waters of marshes, lakes, and streams, to depths of 25' or more. Also the Great Lakes. Typically found in calcareous, "hard" water. Often forms large masses.

Under ideal conditions of light, pH and temperature, the plants get the maximum retention of arsenic. The best result was the Elodea. It has an elimination of 90%.

2.2 Toxicity of Arsenic

The toxicity of arsenic depends on:

1) *The state of oxidation;*

2) *The chemical structure of the compound to be studied;*

3) *The solubility in biological medium.*

The scale of arsenic toxicity decreases in the following order:

Arsine (H3As) > As+3 Inorganic (Arsenite) > As+3 Organic > As+5 Inorganic (Arsenate) > As+5 Organic > Arsenic elemental and Arsenical compounds.

The plants convert inorganic arsenic into organic arsenic and arsenical compounds that are less hazardous to health.

2.3 The pilot plant

The pilot plant process begins with the taking of water from wells with submersible pumps, which sends the water to a primary tank where are taken samples to determine the concentration of arsenic in water (Figure 2). According to the Arsenic concentration, it is decided whether the plant enables the pools with aquatic plants in parallel (water with lower concentration of arsenic) or in series (water with higher concentrations of arsenic).

In order to monitor the system performance, samples are taken periodically at the output of each pool. Then, the water flows directly through a filter to remove impurities from the aquatic plants or the environment, and it is stored in a secondary tank where chlorine is added and sends it to the drinking water network.

In function of the arsenic concentration in well water and the water flow required for consumption, the system decides to spend part of the water flow through this system which reduces considerably the arsenic level, and then it is mixed with the flow of raw water, to reduce the arsenic concentration less than 10 µg/l.

3 Drinking water network design and water distribution by EPANET 2.0

EPANET is a computer program that performs extended period simulation of hydraulic and water quality behavior within pressurized pipe networks. A network consists of pipes, nodes (pipe junctions), pumps, valves and storage tanks or reservoirs. EPANET tracks the flow of water in each pipe, the pressure at each node, the height of water in each tank, and the concentration of a chemical species throughout the network during a simulation period comprised of multiple time steps. In addition to chemical species, water age and source tracing can also be simulated.

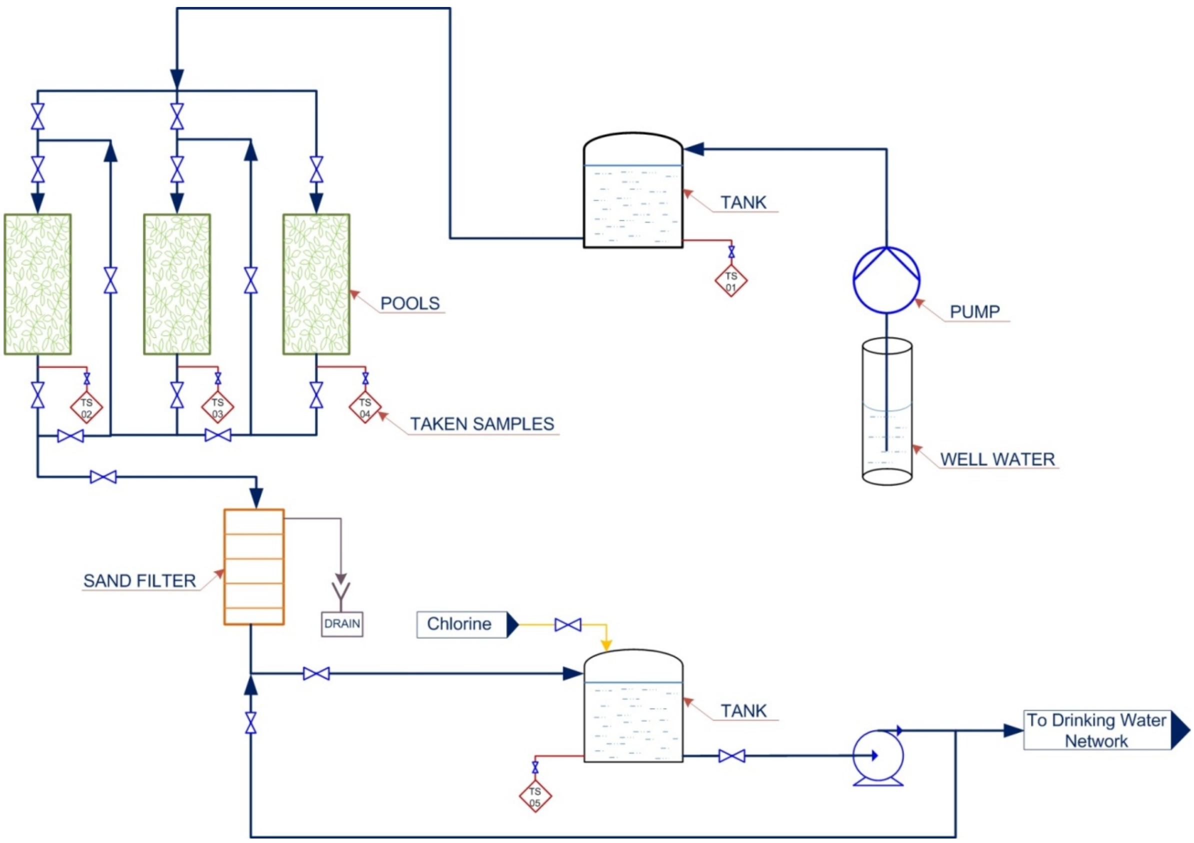


Figure 2: The pilot plant.

Sampling program design, hydraulic model calibration, chlorine residual analysis, and consumer exposure assessment are some examples. EPANET can help assess alternative management strategies for improving water quality throughout a system.

EPANET's Windows user interface provides a visual network editor (Figure 3) that simplifies the process of building piping network models and editing their properties. Various data reporting and visualization tools are used to assist in interpreting the results of a network analysis.

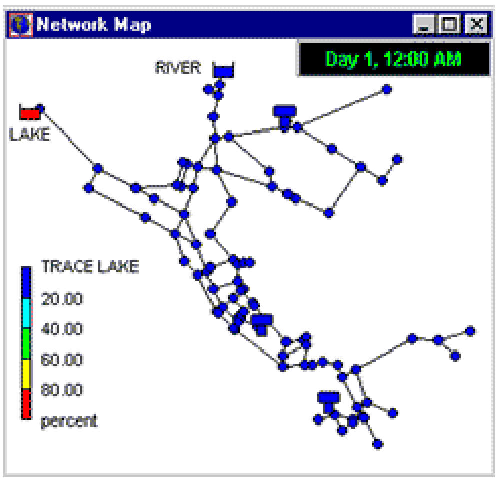


Figure 3: EPANET visual network editor.

3.1 Applications

EPANET was developed to help water utilities maintain and improve the quality of water delivered to consumers through distribution systems. It can be used to design sampling programs, study disinfectant loss and by-product formation, and conduct consumer exposure assessments. It can assist in evaluating alternative strategies for improving water quality, such as altering source use within multi-source systems, modifying pumping and tank filling/emptying schedules to reduce water age, using booster disinfection stations at key locations to maintain target residuals, and planning cost-effective programs of targeted pipe cleaning and replacement. EPANET can also be used to plan and improve a system's hydraulic performance. The software can assist with pipe, pump, and valve placement and sizing. Further goals can be energy minimization, fire flow analysis, vulnerability studies, and operator training. Figure 4 shows the EPANET workspace.

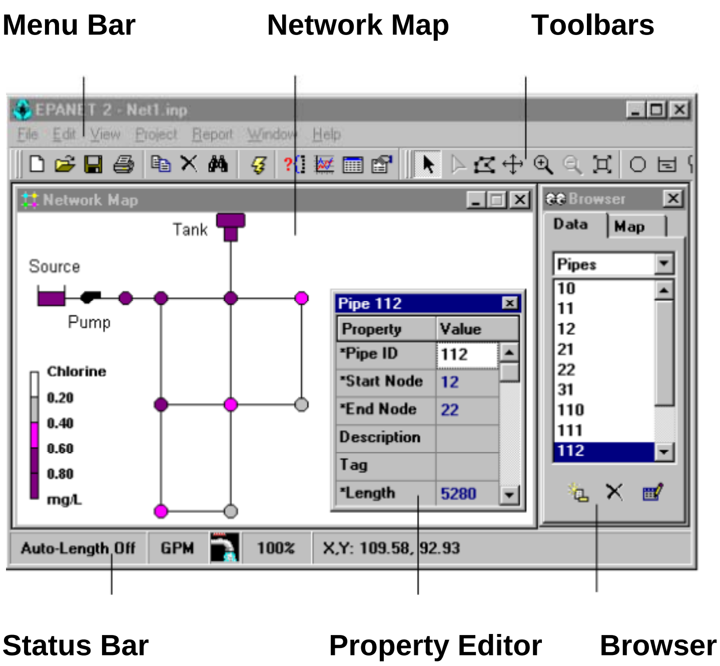
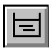
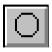


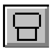
Figure 4: EPANET workspace.

3.2 Drawing the network

The network (Figures 5,6) is drawn by making use of the mouse and the buttons contained on the Map Toolbar.

First the reservoir  is added. Then click the mouse on the map at the location of the reservoir (somewhere to the left of the map).

Second, the junction nodes  are added. Click the Junction button and then click on the map at the locations of nodes.

Then the tank  is added by clicking the Tank button and clicking the map where the tank is located.

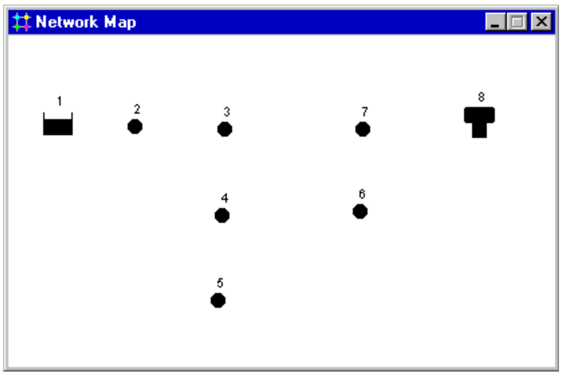
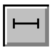


Figure 5: EPANET Network Map after adding nodes.

As next step, the pipes are added . Start with pipe 1 connecting node 2 to node 3. First click the Pipe button on the Toolbar. Then click the mouse on node 2 on the map.

Finally the pump is added . Click the Pump button, click on node 1 and then on node 2.

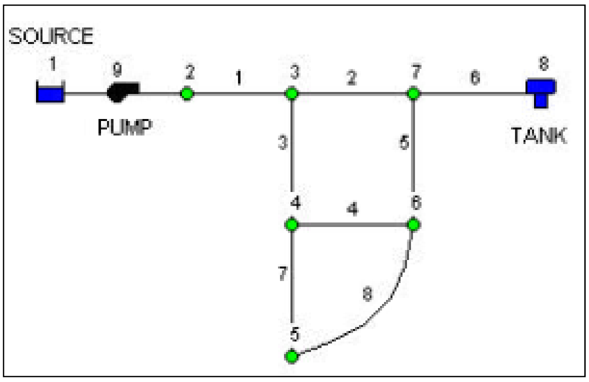


Figure 6: EPANET Network Map after adding pipes and the pump.

3.3 Setting object properties

The Property Editor is used to edit the properties of network nodes, links, labels, and analysis options. It is invoked when one of these objects is selected. When objects are added to a project, a default set of properties is assigned. To change the value of a specific property for an object, the object must be selected in the Property Editor (Figure 7).

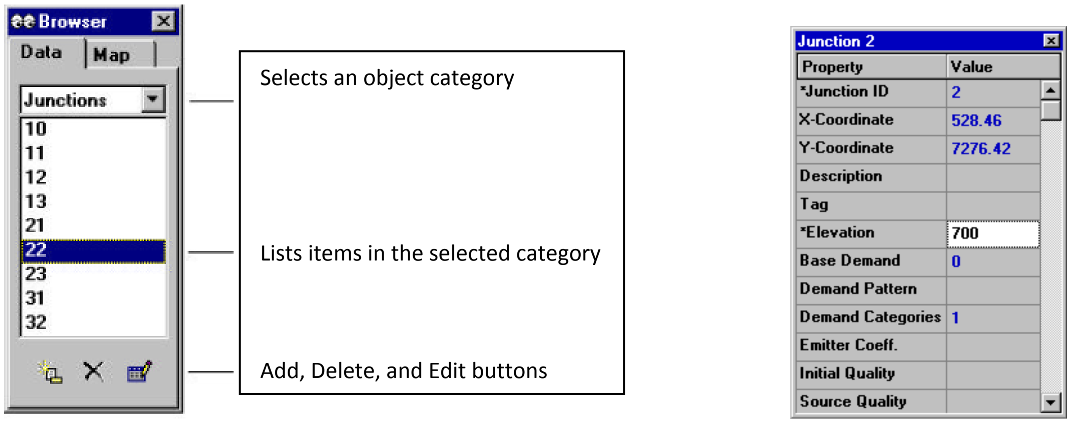


Figure 7: EPANET Property Editor; left: selection of the object; right: modification of properties.

3.4 Pumps

Pumps are links that impart energy to a fluid thereby raising its hydraulic head. The principal input parameters for a pump are its start and end nodes and its pump curve (the combination of heads and flows that the pump can produce). Additionally, EPANET is able to compute the energy consumption and cost of a pump. Each pump can be assigned an efficiency curve and schedule of energy prices.

The principal output parameters are flow and head gain and we need to assign a pump curve (head versus flow relationship; Figure 8).

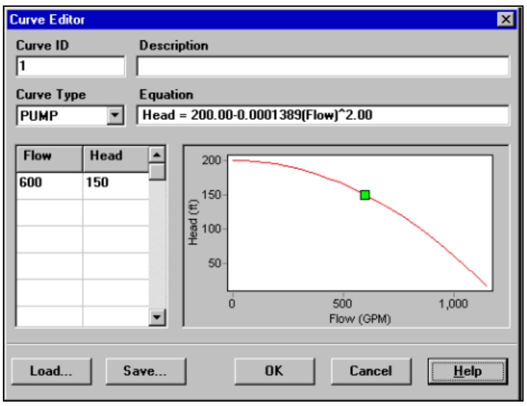


Figure 8: EPANET Curve Editor.

3.5 Running an extended period analysis

To make the network more realistic for analyzing an extended period of operation, a Time Pattern is created that makes demands at the nodes vary in a periodic way over the course of a day (Figure 9). This example uses a pattern time step of 6 hours thus making demands change at four different times of the day.

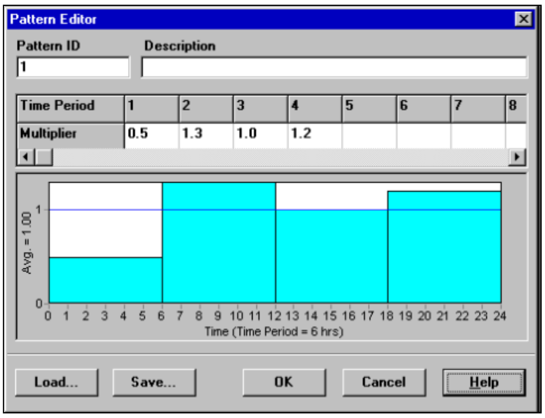


Figure 9: EPANET Pattern Editor.

3.6 Time options

While we have the Time Options available we can also set the duration for which we want the extended period to run (Figure 10).

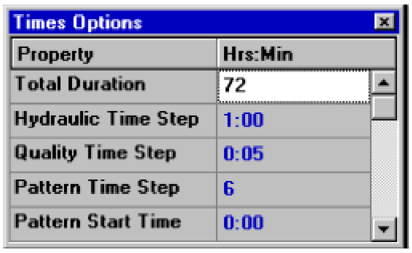


Figure 10: EPANET Time options.

3.7 Map browser

The Map Browser (Figure 11) is accessed from the Map tab of the Browser Window. It selects the parameters and time period that are viewed in color-coded fashion on the Network Map. It also contains controls for animating the map through time.

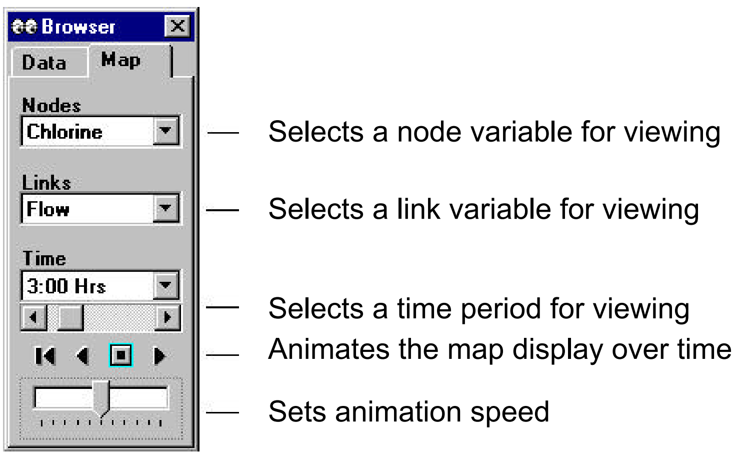


Figure 11: EPANET Map browser.

The animation control pushbuttons on the Map Browser work as follows:

- Rewind (return to initial time)
- Animate back through time
- Stop the animation
- Animate forward in time

3.8 Viewing results

Tables

A Network Table (Figure 12) lists properties and results for all nodes or links at a specific period of time.

Network Table - Nodes at 4:00 Hrs

Node ID	Demand GPM	Head ft	Pressure psi	Chlorine mg/L
Junc 10	0.00	1010.67	130.28	1.00
Junc 11	210.00	992.42	122.37	0.85
Junc 12	210.00	980.17	121.40	0.78
Junc 13	140.00	977.08	122.23	0.30
Junc 21	210.00	977.24	120.13	0.74
Junc 22	280.00	976.29	121.88	0.49
Junc 23	210.00	975.76	123.82	0.30
Junc 31	140.00	970.32	117.13	0.53

Figure 12: EPANET Network table.

Map query

A Map Query (Figure 13) identifies nodes or links on the network map that meet a specific criterion (e.g., nodes with pressure less than 20 psi, links with velocity above 2 ft/sec, etc.).

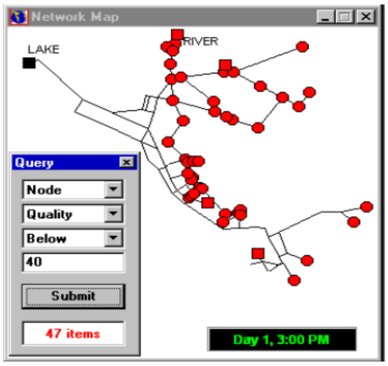


Figure 13: EPANET Map query.

Graphical results

Analysis results, as well as some design parameters, can be viewed using several different types of graphs (Figure 14). Graphs can be printed, copied to the Windows clipboard, or saved as a data file or Windows metafile.

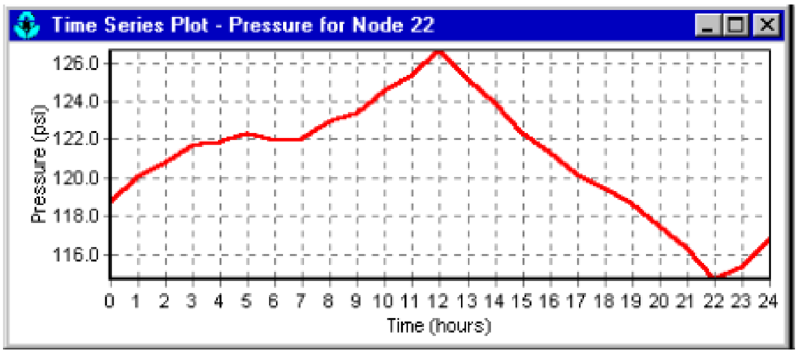


Figure 14: EPANET Time series graphics.

3.9 Backdrop map

EPANET can display a backdrop map (Figure 15) behind the pipe network map. The backdrop map might be a street map, utility map, topographic map, site development plan, or any other picture or drawing that might be useful.

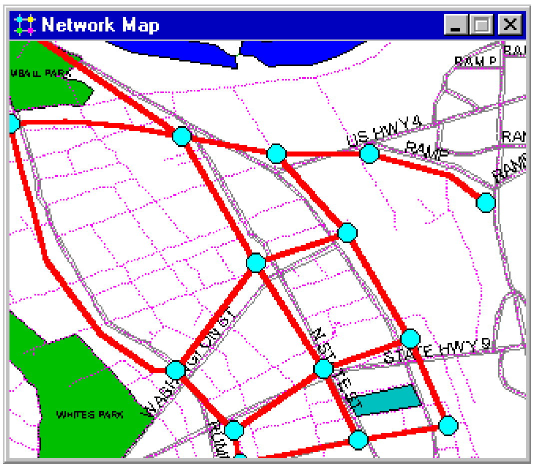


Figure 15: EPANET Backdrop map.

3.10 Energy report

EPANET can generate an Energy Report (Figure 16) that displays statistics about the energy consumed by each pump and the cost of this energy usage over the duration of a simulation.

Energy Report

Table | Chart

Pump	Percent Utilization	Average Efficiency	Kw-hr /Mgal	Average Kwatts	Peak Kwatts	Cost /day
10	58.33	75.00	314.07	62.01	62.73	0.00
335	29.51	75.00	394.83	309.49	310.86	0.00
Total Cost						0.00
Demand Charge						0.00

Figure 16: EPANET Energy report.

4 Scenario

Our application consists of water abstraction from different wells (Figure 17). These wells deliver water with a high arsenic concentration. Each is accompanied by a treatment plant, which contains Elodeas. Each treatment plant can have different performance.

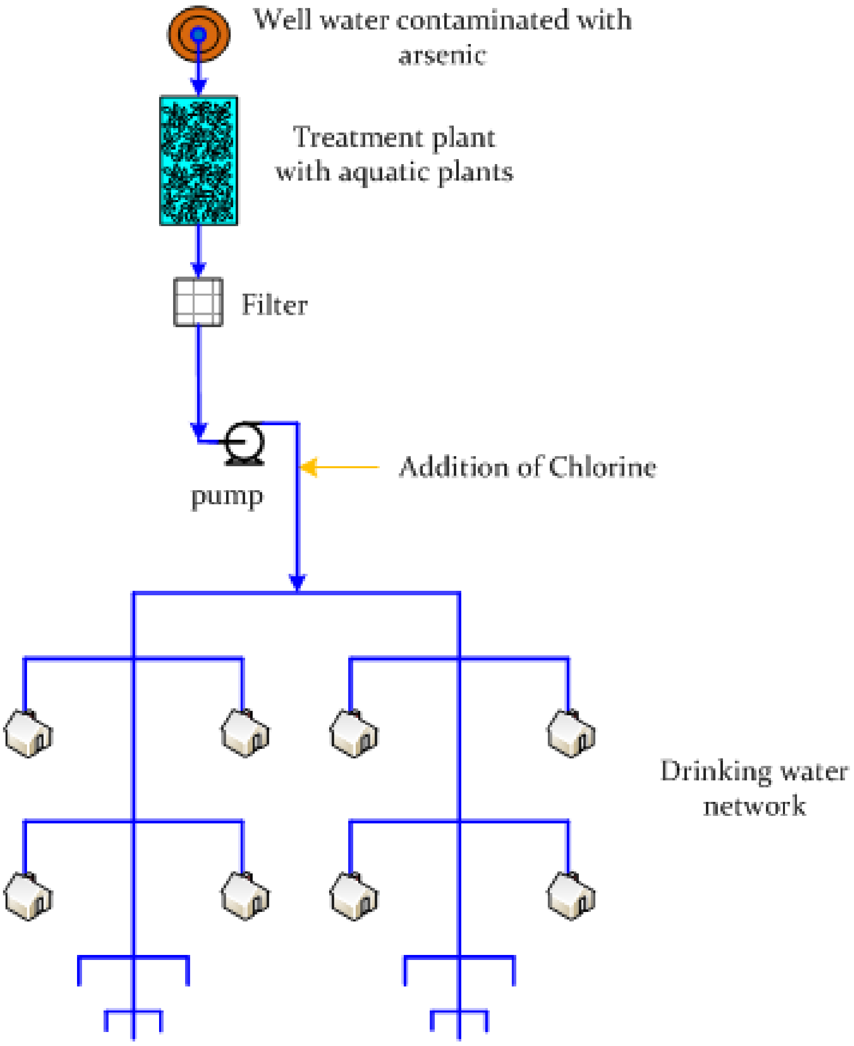


Figure 17: EPANET structure for water abstraction, treatment and the supply network.

After this process, the water is conveyed into the drinking water network.The software EPANET 2.0 is used to check the arsenic concentration for each pipe or for each node, as well as different parameters such as pressure, demand or flow.

EPANET 2.0 is applied to present the results to the user who can analyze the behavior in the net as a basis for taking the right decisions.

4.1 Application

First, the area of application needs to be selected where the both methods will be applied. The target area is a rural area where the arsenic concentration in each well is very high. In this example two wells and two treatment plants are assumed. In the middle of the net, a mix between the different flows can be observed.

The water is abstracted from the wells and flows directly to treatment plants. Afterwards, it is conveyed into the drinking water network. Figure 18 shows the target area within the EPANET environment.

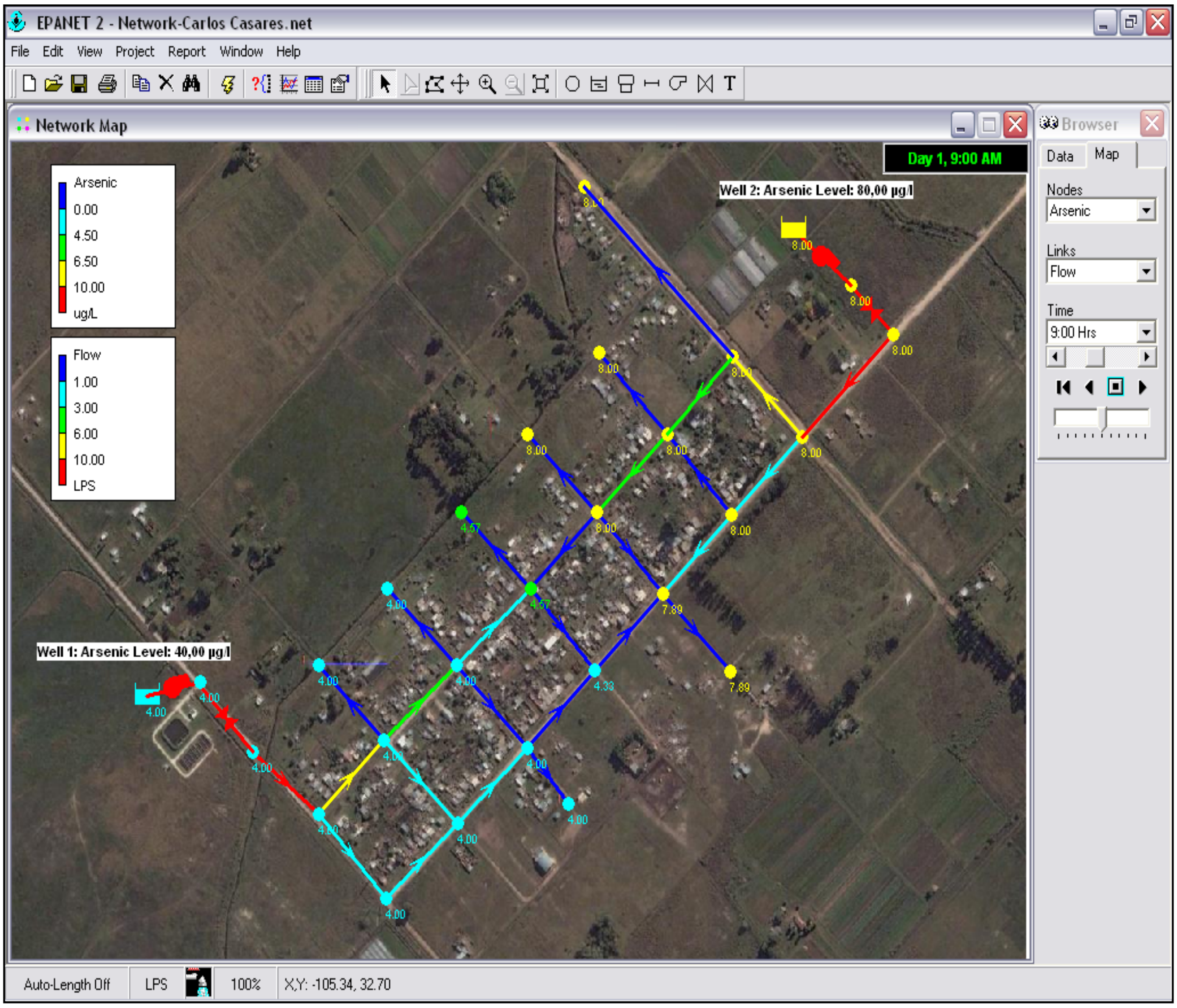


Figure 18: Representation of the rural area with EPANET.

The first well provides water with 40 µg/l arsenic, the second well provides water with 80 µg/l. During the water treatment, the high arsenic concentrations decrease by 90%. After the process, the arsenic concentration in water, which comes from the first well, is 4 µg/l. In the other water with 8 µg/l of arsenic is obtained. These values satisfy with the minimum established value by World Health Organization (less than 10 µg/l).

EPANET shows the behavior within the net. It can be used to analyze the different parameters and, based on such analysis, to improve the network.

4.2 Results

These processes discussed above were applied at small scale. Currently the working group is looking for financial support to apply them on a big scale. The major impediment is to have sufficient funds for effective implementation of this research. The results obtained after the tests are the followings:

- *Reduce arsenic levels in drinking water (< 10 µg/l)*
- *Less disease risks*
- *Low-cost treatment*
- *Simple handling*
- *Constant water flow*
- *Optimization of drinking water distribution.*

5 Conclusion

The most important feature of this method is that this is a low – cost and easy handling solution for rural areas. The use of aquatic plants to remove arsenic from water is an effective, easy implementation, and particularly economical with possibility of use in rural areas disperses, since our country is the population most affected by this problem.

This solution could be applied in different cities or places, where there aren't resources to build an expensive and big treatment plant. This new technology is believed to be very important for developing countries, where the low cost of operation makes it advantageous compared to other technologies.

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