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Towards sustainable water quality management

Influencing factors, case studies, exemplary tools, and strategies

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Editorial

The existence of water on Earth is vital to the existence of life on Earth. Clean water nourishes ecosystems, grows food, and powers industry at the same time. Freshwater systems are fed by precipitation from the atmosphere, replenishing natural water storages in the landscape such as soil and groundwater, lakes and rivers. This natural cycle is an important basis for balancing water availability and water demand in natural systems and guaranteeing clean water resources.

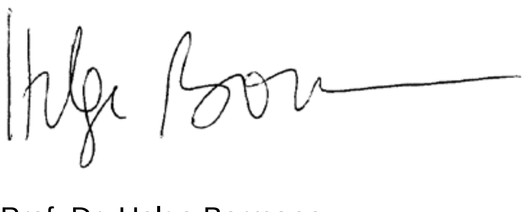
Like all other organisms, humans depend on water availability, as well. Many human activities are linked to water, directly. The increasing human population worldwide has significantly increased the pressure to water resources in general. Increasing pressure to river and groundwater catchments does not only intensify water abstraction but also degrades water quality through intense land use, industrial development and the extension of urbanized areas. Therefore, a sustainable catchment management approach is required, focusing on water quality and water quantity, ensuring availability of clean water. Such water management needs to include some kind of catchment management, as well, in order to manage the entire system which transforms “clean” rainfall into those water resources humans are used to use.

During two expert seminars in year 2012 the chair of “*Water Resources Management*” of the University Siegen has focused on both sides of the water story, on the water abstraction and sustainable water supply (seminar on “Wassergewinnung”, Hof, Germany) on the one hand and on water pollution through diverse uses (seminar on “Water pollution by agriculture”, Santa Maria, Brazil) on the other hand.

This fifth volume of the „*Mitteilungen des Forschungsinstituts Wasser und Umwelt*“ contains contributions of international experts as well as Alumni/Alumnae who actively contributed to the seminars through presentations and discussion. It covers large parts of the above mentioned water related issues, ranging from general water management, monitoring and water supply issues to water quality management tools, soil protection measures and regulations, and to water treatment approaches.

We thank the authors for their contributions, all participants for the lively discussion, the DAAD (German Academic Exchange Service) for the financial support enabling the organization of both expert seminars and, last but not least, the local organizers who took care of all organisational questions during the seminar. We liked a lot to spend the seminars with you! Thanks a lot!

Siegen, August 2013



Prof. Dr. Helge Bormann

Participants of the expert seminar held in Hof (Germany), June 2013.

Participants of the expert seminar held in Santa Maria (Brazil), July 2013.

Contents

Groundwater Management in the RS State: Strategies and Challenges

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Abstract

Estimations of the groundwater demands and availability within water basins are essential for the overall management processes. This study aims to provide a methodological framework in order to cope with this challenge applying it for two different basins of the Rio Grande do Sul State in Brazil. The groundwater demands at the Ijuí River Basin and Ibicuí River Basin were quantified with the information taken from the SIAGAS, CPRM (Water Well Information System kept and operated by the Brazilian Geological Survey). The majority of the water wells are used for domestic supply. The groundwater availability was estimated using mainly hydrological methods and aquifer´s geometries. The balance between actual use and availability gives the stress state of each of the water basin. This information is considered to be very important for the groundwater management and do support all actors involved in the definition of water policies.

Keywords: *Groundwater, River Basin, Management, Aquifer, Rio Grande do Sul.*

1 Introduction

The adoption of the river basin as the geographic and hydrologic water management unit is almost unquestionable. Nevertheless, regarding the groundwater dynamics this assumption unfolds some complexities related to aquifer overall extension, whose borders and/or recharge areas may lie beyond the river basin area. Despite this fact, it´s highly recommended to assure that groundwater assessments are made within the existent legal water management framework. In addition, it is clear that shallow and outcropping aquifers show always strong hydraulic connections with superficial water bodies. According to the existent framework, the civil society participation takes place within the river basin committee and this mediation and democratic space must be strengthened, by definition. This approach is complementary to the classical hydrogeological point of view, which considers the aquifer as the main evaluation object.

Most of the already existing regional water master plans or river basin development plans calculate water availability estimates based only on superficial water bodies through the use of hydrological mathematical modeling and regionalization procedures. The groundwater reserves and the overall groundwater dynamics are traditionally not considered implying in important gaps what the development of more efficient water use policies is concerned.

However, it is important to mention the expressive advances reached in the last years in the field of hydrogeology in the whole country of Brazil. A large number of technical contributions have been published and capacity building has also taken place inside new university research groups engaging young students. Recent groundwater public policies, such as the development of a new comprehensive hydrogeological map for the entire Rio Grande do Sul (RS) State and the setup of a licensing and inventory process for new and old tubular wells, did have a crucial and catalyzing role.

2 Hydrogeological Knowledge of the Rio Grande do Sul State

The geological framework is one of the most important aspects for a proper evaluation of an aquifer system and represent it´s analytical physical basis.

A great part of the RS State (70%) is covered by igneous rocks represented by the volcanic rocks of the Serra Geral formation (55%), building medium to low productivity fractured aquifers. This formation is divided in different hydrogeological units according to their specific capacity, whereas the unit known as Serra Geral I is an exception due to its high productivity. These fractured aquifers host the largest number of tubular wells in the RS State. A large portion of the State is covered by the Gondwanic sequences belonging to the Paraná intracratonic basin. Among them, the sandstones sequences constitute the Guarani Aquifer System (world known as the GAS Aquifer) comprise 13% of the total area of the State. They occur mainly in a central denudated area right opposite to the basaltic highlands front, building the confined and no-confined aquifers.

The coastal aquifer systems from the coastal plains of the RS State represent about 10% of the entire state area. Their high aquifer potential has been recently only understood and extraction rates are drastically increasing. The costal aquifer system I and the marine barrier aquifer system bear enormous potential and huge reserves of fresh water. At last, the permian sediments from the Paraná Basin gondwanic sequences (representing 7% in area) show little regional groundwater potential. Their use is restricted to rural settlements at smaller scale supply systems.

The aquifer systems were obtained from the Hydrogeological Map of the Rio Grande do Sul State (CPRM, 2005) at the scale of 1:750.000. They were identified according their hydrogeological behavior and groundwater yield potential. Their spatial distribution superimposed with the water basin contours are presented in Figure 1. At this map, it is also possible to recognize their production zones according to aquifer´s specific capacity.

2.1 Groundwater Availability Estimates

Considering the inexistence of a regional groundwater monitoring network, historical data sets and the lack of an enhanced knowledge in aquifer behavior (exception given to smaller areas in some of the existent aquifer systems), the estimation of the groundwater availability within the river basin borders is not an easy task. While there is a large number of river gauging stations allowing data collection and data analysis, there is only a limited number of wells, where monitoring procedures are taking place.

The groundwater availability can be defined in terms of their reserves, such as the active (renewable) ones and static (permanent) ones, whereas the total reserve volumes are given by the sum of both terms. The active reserve gives an idea on the renewable amount of fresh water entering the aquifer system in a certain period of time and is also known as dynamic resource or effective recharge. It depends on the aquifer effective porosity or storage coefficient and the seasonal water influxes of superficial water. The permanent reserves correspond to the quantity of water stored in the aquifer which is not affected by the seasonal fluctuation of the potentiometric surface. It´s a nonrenewable resource whose exploitation limits depend mainly on social-economical choices.

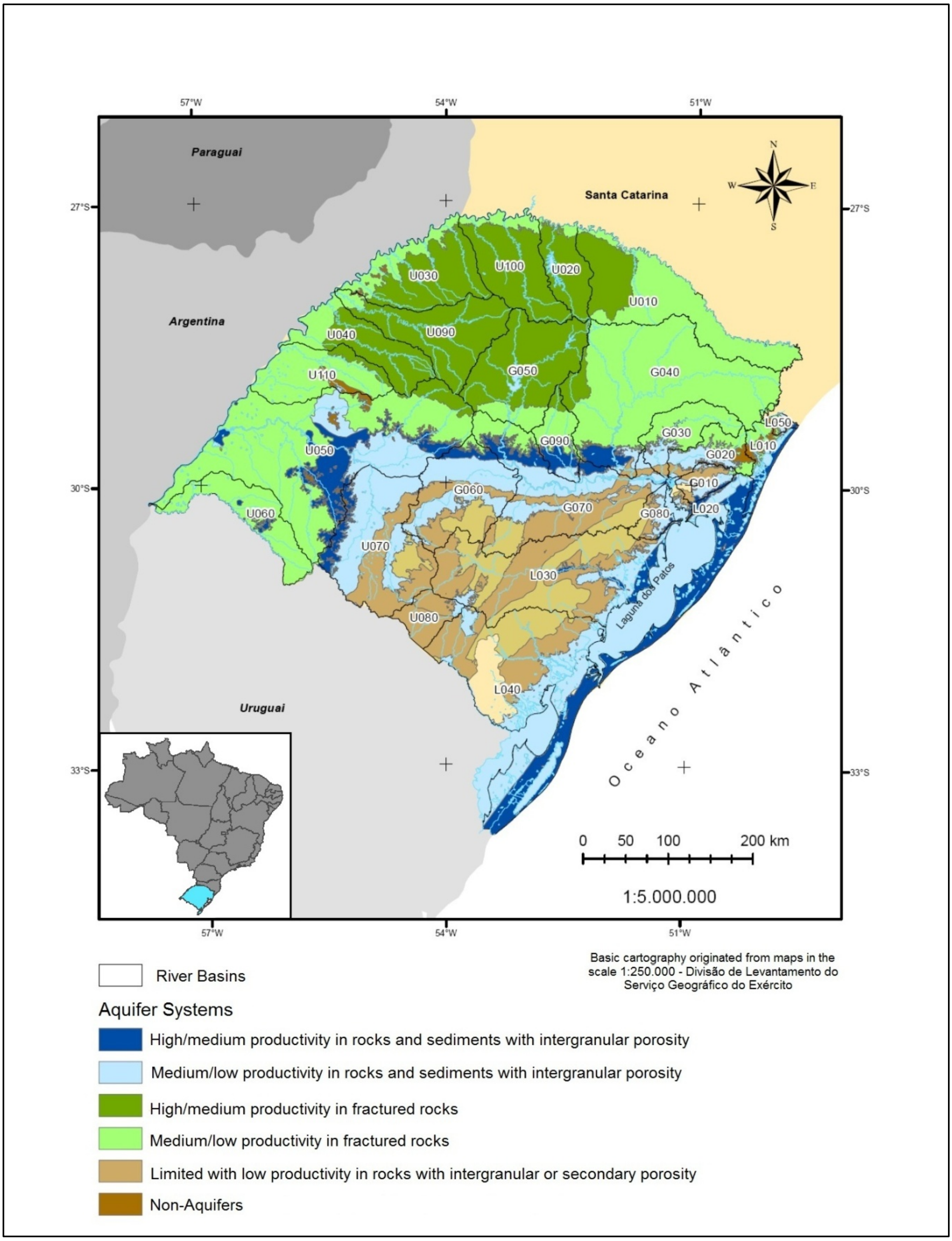

Figure 1: Hydrogeological map with the location of the tubular wells and the river basin boundaries in the RS State.

Basically, regarding this paper, the renewable reserves or recharge volumes were estimated by: (a) correlation to the volumes obtained by base flow separation from hyrographs at representative gauging stations; (b) direct correlation to the volumes obtained by base flow separation solved by the MGB model (Collischonn, W. 2001). This statement is true on the basis of the continuity equation applied for a steady state system, where the regional annual recharge rates equal the regional discharge into the drainage system.

The permanent reserves were estimated throughout the aquifers geometry and known potentiometry (including its pressure component). However, the heterogeneity of the variables related to the estimation of the permanent reserves of thick volcanic sequences is unquestionable leading to the necessity of more simplified approaches. In such cases, permanent reserves are estimated as a proportion of the annual recharge volumes. Table 1 indicates estimations for the groundwater availability for the river basins of the RS State.

2.2 Groundwater Use Estimates

One of the greatest challenges faced by water management authorities deals with the high degree of no-notification in water well drilling and completion. An unknown proportion of tubular wells are operating without the necessary legal pemits, sometimes jeopardizing sustainability extraction criteria.

About 17.000 tubular wells located in the RS State are registered within the SIAGAS (Groundwater Management System) operated by the Brazilian Geological Survey. The data given by the SIAGAS are extremely useful for any regional/sub-regional groundwater analysis and, in fact, it represents the only data bank available. It includes public wells and private owned wells. Since the water well licensing process has been established by the water management institution, the SIAGAS started to be fed constantly, increasing it´s well registration number and also data quality. Regarding the SIAGAS system, some aspects need to be stressed:

- *A large number of registered wells are out of operation, due to the lack of institutional coordination, leading to unnecessary economic losses and civil society frustration;*
- *Despite the representativity of the SIAGAS, there are still innumerous data omissions and failures. About 50% of the registered wells miss information on the water extraction rates just to mention one of the existing problems;*
- *The larger number of wells are used for fulfilling potable domestic needs in urban and rural areas; many of them are used for multiple uses. Groundwater extractions rates for industrial use are already significant and are expanding extraordinarily thanks to cheaper well drilling and electricity costs;*
- *Right in opposite to what it seems, considering its media exposure, the mostly used aquifer system in the RS state is not the GAS, but the fractured aquifers of the Serra Geral formation, holding 40% of the total well registers;*
- *The SIAGAS coverage in the State is not homogenous. There are areas where the registration task forces form the CPRM did not reach. This is also a fact that must be taken into account when dealing with overall river basin extraction rates.*

The table 1 indicates estimation for the groundwater extraction volumes for every single river basin of the RS State.

Table 1: Estimates of the groundwater renewable reserves, extraction rates (according to SIAGAS) and general budgets for the river basins of the RS State. Source: SIAGAS (CPRM), November 2012.

River Basin	Renewable Reserves (hm^3/year	Extractions (hm^3/year)	General Budget (%)
G010 – Gravataí	214.07	86.55	40.4
G020 – Sinos	558.17	297.31	53.3
G030 – Caí	518.79	442.73	85.3
G040 – Taquari – Antas	3388.47	2691.77	79.4
GO50 – Alto Jacuí	2022.7	982.39	48.6
G060 – Vacacaí – Vacacaí-Mirim	568.17	314.13	55.3
G070 – Baixo Jacuí	1741.33	220.02	12.6
G080 – Lago Guaíba	651.46	134.03	20.6
G090 – Pardo	464.9	110.03	23.7
L010 – Tramandaí	827.54	372.65	45.0
L020 – Litoral Médio	1946.28	269.98	13.9
L030 – Camaquã	2045.69	142.61	7.0
L040 – Mirim – São Gonçalo	1445.48	293.28	20,3
L050 - Mampituba	206.08	36.79	17.9
U010 – Apuaê – Inhandava	2168.08	857.08	39.5
U020 – Passo Fundo	1006.32	335.33	33.3
U030 – Turvo – Santa Rosa – Santo Cristo	1977.16	599.71	30.3
U040 – Piratinim	1039.55	94.26	9.1
U050 – Ibicuí	2973.88	1012.66	34.1
U060 – Quaraí	881.91	153.83	17.4
U070 – Santa Maria	1476.28	567.82	38.5
U080 – Negro	134.58	53.96	40.1
U090 – Ijuí	2662.13	253.51	9.5
U100 – Várzea	1976.92	508.08	25.7
U110 – Butuí - Icamaquã	1369.97	108.45	7.9

2.3 Availability and General Budget

The comparison between the groundwater availability and actual use for each river basin leads to the groundwater budgets, which are illustrated by the table 1. Since there is a great number of wells which have not been registered and do not have been licensed, the total extraction rates need to be multiplied by a no-notification factor of 10x. This approach clearly gives rise to an overestimation of the extraction rates, which can be understood as a critical scenario assessment. The results have allowed the identification of potential conflictive river basins which, by the end, were considered as targets for specific groundwater policies within the State Water Masters Plan (Plano Estadual de Recursos Hídricos). According to the results, the river basin Caí and Taquari-Antas have showed the highest groundwater use proportion in contrast to the Camaquã and Butuí-Icamaquã River Basins, with the lowest use proportion.

This methodology is only valid for a long term steady state. Until now the overall groundwater extraction volumes for most of the RS State river basin are still low. It does not mean that local conflicts (overexploitation with localized potentiometric level decreases) may not arise. They may happen and their effects are visible at restricted surrounding areas. The loss of the steady state implies in the establishment of a transient regime, where the extraction Q is compensated after a time gap by: (i) a variation in storage or, (ii) an increase in recharge rates or, (iii) a loss in discharge rates. After a certain period of time, a new steady state is reached when there is no variation in storage anymore and the recharge equals the discharge. If not, a permanent loss of storage of the aquifer body is foreseen.

3 Case Studies

The general groundwater balance scenarios for the whole group of river basins in the State of Rio Grande do Sul proofed to be an useful information on the context of general policy target identification. But still, considering the water management processes and the information demands which are being placed within river basin committees, a suitable scale assessment needs to be handled. This is basically the main objective of the two case studies that follow. The Ibicuí and Ijuí river basin were chosen for a more detailed assessment. For both river basins, a better geological and hydrogeological assessment allowed the determination of the renewable and permanent reserves. An enhanced tubular well data base was available for the estimation of the actual water extractions. Therefore, better use scenarios could be set considering a refined spatial discretization, such as at the sub-basin scale. This effort aims to make some steps forward on the bumpy way to more efficient groundwater management policies.

3.1 The Ibicuí River Basin

The Ibicuí River Basin (BHIb) is located in the southwest corner of the RS State close to the border with Uruguay, like it is shown by the figure 2. The geological framework of the BHIb consists in large areas of outcropping gondwanic sedimentary sequences, namely the Pirambóia formation, followed by the Sanga do Cabral, Santa Maria, Caturrita, Guará and Botucatu formations (CPRM 2008). Among those sequences, the sandstones belonging to the Guarani Aquifer System (SAG) comprise 21% of the basin´s surface. The whole set is covered by volcanic sheets from the Serra Geral formation comprising 56% of its surface. At last, the clastic cenozoic alluvial sedimentation associated to the river beds covers about 13% of the basin´s surface. In the context of the State, water wells from this region are considered to be very productive bearing very high specific capacity. The SAG appears as an unconfined to semi-confined aquifer building up regional discharge and recharge zone as well. It´s one of the most groundwater rich basins turning it into a regional strategic area.

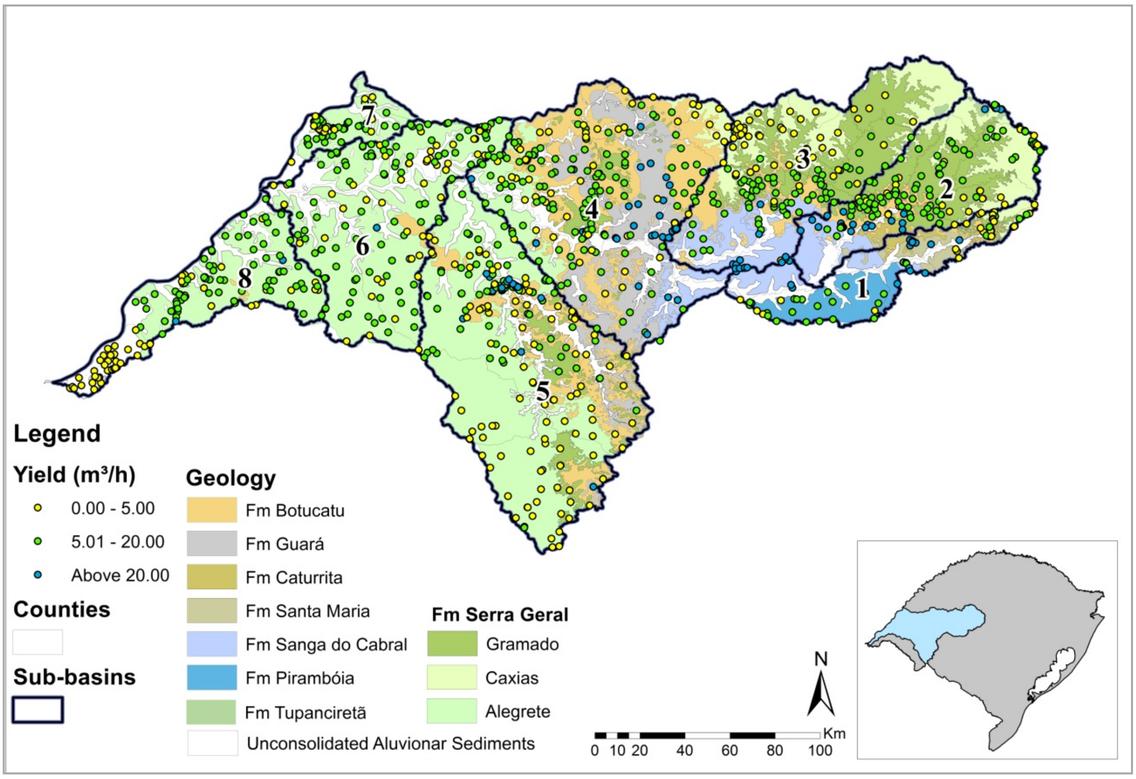

Figure 2: The geological map for the Ibicuí River Basin (BHIb) and its sub-basins and location of the known tubular wells.

3.2 The Ijuí River Basin

The Ijuí River Basin (BHIj) is located in the northwest corner of the RS State, close to the border with Argentina, according to the figure 3. It drains directly towards the transboundary Uruguay River. The geological framework is considered to be very homogenous with eolic sandstones of the Botucatu formation being completely covered by thick volcanic sheets (around 700m of thickness) of the Serra Geral formation. It means that the SAG aquifer is under highly confined regime.

3.3 Groundwater Extraction Rates

The majority of the water wells in both river basins are used for urban and rural domestic supply, as shown in the figure 4. The groundwater use for irrigation schemes represents about 9% of the overall volumes in the BHIb and there is a clear increase in this tendency, especially considering its economical agribusiness model. Regarding the BHIj, this tendency is less remarkable. Next to the large urbanized centers, the industrial use of the groundwater is expanding, spatially along development axis, such as Santo Ângelo and Ijuí cities in the BHIj. For the BHIb in sub-basins located on the hilly upper zones the groundwater is being used for rural multipurpose uses at familiar agriculture production schemes. This is also the case for the BHIj. The table 2 presents the extraction volume estimations for each one of the sub-basins for the BHIb and BHIj as well.

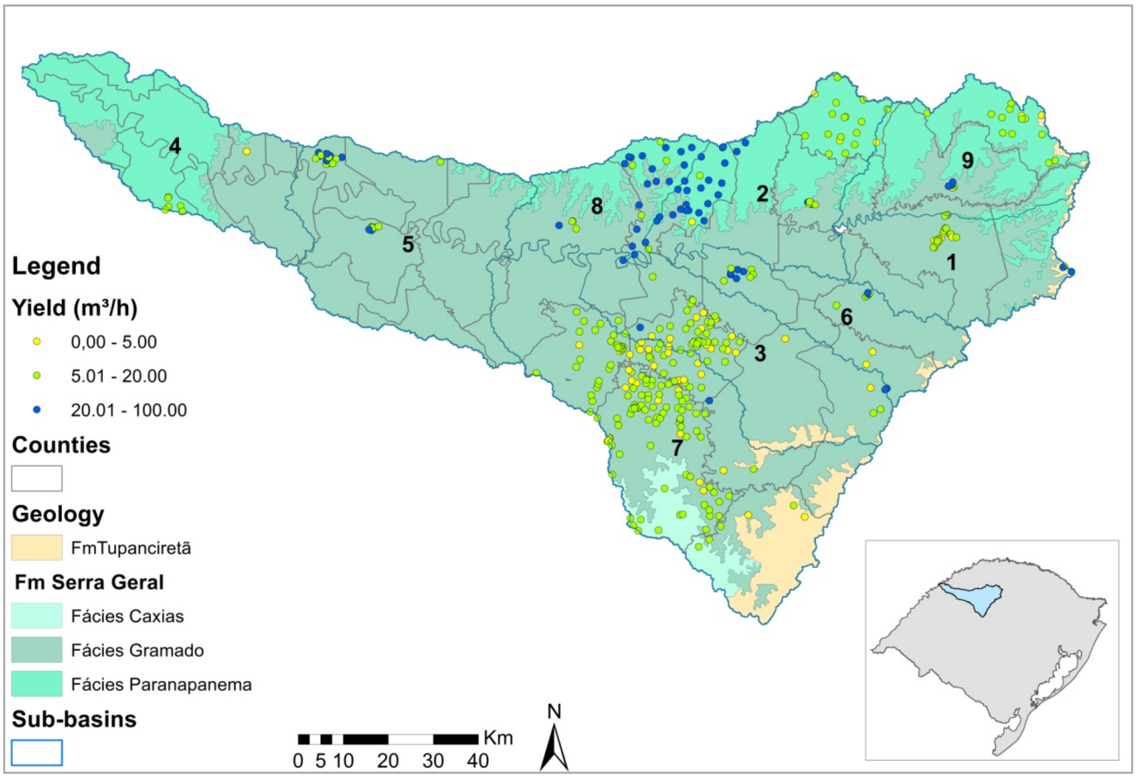

Figure 3: The geological map for the Ijuí River Basin (BHIj) and its sub-basins and location of the known tubular wells.

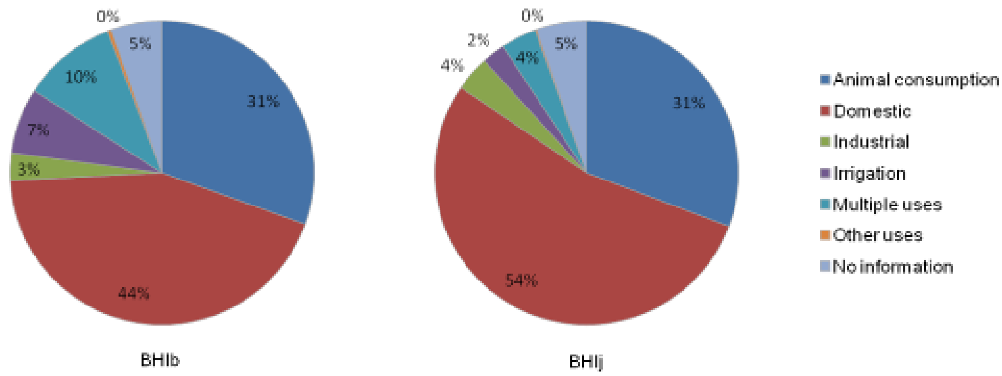

Figure 4: Water use distribution in the BHIb and BHIj.

3.4 Groundwater Availability

According to the methodologies discussed above the renewable reserves were calculated by means of hydrograph separation techniques from river discharge series and from modeling. The permanent reserves were determined for every single aquifer body according to their geometries and potentiometric surface. After all, the confined SAG is responsible for the contributing with the largest volumes of water, adding up to 98,5% for the total availability at the BHIb. For the BHIj, the SAG and the fractured aquifers together sum up to 93,4% of the total reserves. The explorable reserves can be dimensioned throughout different criteria, based on the maximum drawdown assumption. The following scenarios were selected: (i) Explorable reserves equals to the reguladora reserves, and (ii) Explorable reserves equals the reguladoras reserves plus 10% of the permanent reserves for each aquifer body.

Table 2: Estimates for the Groundwater extraction rates for the BHIb and BHIj.

Sub-basins	∑ Wells	Q (m³/h)			∑ Vol.
		Medium	Maximum	Minimum	(hm³/year)
1 - Ibicuí/Mirim	86	14.79	80.00	0.30	4.64
2 - Toropí	146	13.50	50.00	0.20	7.19
3 - Jaguarí	155	7.87	48.65	0.15	4.45
4 - Médio Ibicupi/Itú	219	11.16	75.00	0.60	8.92
5 - Ibirapuitã	209	14,53	120.00	0.10	11.09
6 - Baixo Ibicupi/Ibirocaí	147	8.61	37.60	0.20	4.62
7 - Afluente lado esquerdo	80	12.50	75.00	0.77	3.65
8 - Afluente lado esquerdo	147	8.89	105.00	1.00	4.77
Total	1189				49.34

Sub-basins	∑ Wells	Q (m³/h)			∑ Vol.
		Medium	Maximum	Minimum	(hm³/year)
1 – Fiuza and Caxambu	21	11	55	1	0.8
2 - Alto Ijuí	49	21	78	3	3.7
3 - Rio Conceição	54	9	24	3	1.7
4 - Baixo Ijuí – Lower Part	7	13	14	4	0.3
5 - Baixo Ijuí – Center Part	31	19	51	6	1.8
6 - Rio Potiribu	25	26	66	4	2.0
7 - Rio Ijuizinho	151	7	74	1	4.1
8 - Médio Ijuí	26	22	38	9	2.1
9 - Rio Palmeira	25	12	42	2	1.1
Total	389				17.6

3.5 Groundwater Budgets

Knowing groundwater exploitable reserves under both scenarios (A and B) and the annual withdrawals in each of the case studies river basins allow the development of coefficient of use (annual withdrawals / groundwater exploitable reserves). The table 3 synthesizes this data for both regions. As the results are showing the overall budget for both scenarios in the two river basins are very positive. The BHIb has slightly higher coefficients, but still on the comfort range. Considering the scenario A, some sub-basins of the BHIb, such as the 7 and 8, may be the main targets for a more restricted groundwater use policy or the establishment of a well monitoring networking. Besides this fact, it's possible that in some dense urbanized areas with an expressive number of production wells, some cone of depressions may develop. But still, at present no overexploitation effects have been registered in both river basins.

Table 3: **Groundwater budget between explorable reserves and total annual extaction volumes for BHIb and BHIj.**

Sub-basin	Explotable Reserves Scenario A (hm^3/year)	Explotable Reserves Scenario B (hm^3)	Total Annual Extractions (hm^3/year)	E/R(A) Coefficient (%)	E/R (B) Coefficient (%)
1 - Ibicuí/Mirim	305	710	46.4	15.21	6.54
2 - Toropí	168	2141	71.9	42.80	3.36
3 - Jaguarí	473	5052	44.5	9.41	0.88
4 - Médio Ibicupi/Itú	1.654	25831	89.2	5.39	0.35
5 - Ibirapuitã	586	8138	110.9	18.92	1.36
6 - Baixo Ibicupi/Ibirocaí	859	6774	46.2	5.38	0.68
7 - Afluente lado esquerdo	64	704	36.5	57.03	5.18
8 - Afluente lado esquerdo	147	2003	47.7	32.45	2.38
Total	4.256	51352	493.4	11.59	0.96

Sub-basin	Explotable Reserves Scenario A (hm^3/year)	Explotable Reserves Scenario B (hm^3)	Total Annual Extractions (hm^3/year)	E/R(A) Coefficient (%)	E/R (B) Coefficient (%)
1 - Fiuza and Caxambu	220	3506	8	3.64	0.23
2 - Alto Ijuí	195	3070	37	18.97	1.21
3 - Rio Conceição	141	3964	17	12.06	0.43
4 - Baixo Ijuí – Lower Part	170	3018	3	1.76	0.10
5 - Baixo Ijuí – Center Part	242	4699	18	7.44	0.38
6 - Rio Potiribu	362	8602	20	5.52	0.23
7 - Rio Ijuizinho	69	2114	41	59.42	1.94
8 - Médio Ijuí	217	6986	21	9.68	0.30
9 - Rio Palmeira	157	6025	11	7.01	0.18
Total	1773	41986	176	9.93	0.42

4 Conclusions

The main idea behind this study was to develop an easy and robust methodology for generating groundwater budgets on the river basin scale using existing information. The application for the two selected pilot river basins proofed to be a useful contribution in order to anchor water management policies. They were directly incorporated in the main state wise water masters plan, still under development. The SIAGAS, despite some deficiencies, is still an indispensable groundwater tubular well data bank for the future regional and sub-regional projects dealing with groundwater assessment and management. The next step will be the application of this methodology for the entire group of river basin of the RS

State. While new information is generated, new and more consistent values for the renewable and permanent reserves are going to be estimated allowing more realistic budgets.

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Analysis for implementing a comprehensive groundwater monitoring system for Forestal Oriental in Uruguay

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Abstract

Fast growing Eucalypts are known for their relatively high rates of water use. The 100,000 hectares of Forestal Oriental SA eucalyptus plantations (in 2009) to supply its owner, Botnia's pulp mill (now UPM), are distributed across the western parts of Uruguay, over a very large geographical area of 36,000 km² (3,600,000 ha). The plantations are located on the recharge zones of two regional aquifer systems, the North Basin Aquifer System and the Guarani Aquifer System. The apparent concentration of plantation on the recharge zones of these aquifers is largely a function of the prioritisation of land for forestry purposes by the Uruguayan government. In addition, groundwater systems in Uruguay are highly complex and there is little hydrological baseline data available (both for river flow and groundwater dynamics). Collectively these factors indicate that monitoring water impacts at the level of each individual plantation is considered impractical and of limited scientific value. Given the constraints identified above, requirements and commitment to sustainable practices, a number of complementary methods to assess the impact of Forestal Oriental (FO) plantations on water resources have been identified and will be implemented.

This paper seeks to address the challenge of designing a monitoring system that meets the conditions of comprehensivity while recognising the practical demands of the large spatial spread of plantations. By means of a risk assessment and by attributing numeric values to the consequences and likelihoods of the loss of surface and groundwater resources on social, economic and environmental assets, it is possible to identify those assets at greatest possible risk. Besides, at a macro-catchment scale we assessed the vulnerability of aquifer systems by determining the proportion of their recharge zones afforested by FO. We conclude that the possible effect on recharge is small and undetectable. The study then concludes with priority additions to a monitoring infrastructure to keep track of the water resources critical to the sustainability of the assets identified. No assets were identified as being at high risk. However, the risk assessment identified domestic water supplies to some hamlets and small settlements close to FO operations as being somewhat at risk. Dairy operations near FO operations are the only identifiable economic activities potentially at risk although the risk rating is moderate to low. Low levels of risk were found to apply to most environmental assets as these depend on the maintenance of habitats that are neither riparian nor groundwater related, but we recommend monitoring at the one protected area.

1 Introduction

Botnia (now UPM), a large international pulp manufacturing company, established a pulp mill on the banks of the Uruguay River at the city of Fray Bentos, western Uruguay, and began production in November 2007. Running at full capacity, this mill uses about 3.5 million cubic meters of wood a year to produce one million air-dried tonnes of bleached short-fibre eucalyptus pulp. The majority of the feedstock is harvested from eucalyptus plantations owned by Botnia's subsidiary in Uruguay, Forestal Oriental (FO).

Fast growing Eucalypts are known for their relatively high rates of water use. The World's Bank International Finance Corporation (IFC) has provided funding to the Botnia mill and has made the implementation of a comprehensive groundwater monitoring scheme by FO a condition for financing and a compliance requirement of the Environmental and Social

Action Plan. Besides, FO also maintains a long term commitment to the sustainability of its operations and the need to monitor all possible significant aspects, a requirement of the Forest Stewardship Council (FSC) standard to which FO subscribes.

Many studies show that the conversion of grassland to tree plantations generally reduces streamflow and recharge to groundwater, which has the potential to affect both human use and aquatic ecosystems (Bosch and Hewlett, 1982; Brown et al. 2005). In 1997 de Paula Lima undertook an independent assessment for the Uruguayan government on the potential hydrological impacts of extensive eucalypt plantations and the implications for water resources. He concluded (in respect with hydrology) that as the average rainfall for the country is about 1,200 mm, and the potential maximum evapo-transpiration (water use) in the regions where the plantations were envisaged is about 1,152 mm, it was highly unlikely that the water balance (macro scale) is drastically altered with increased afforestation (Lima, 1997).

This paper describes a risk assessment approach for determining the extent, location and intensity of groundwater monitoring that may be required, taking into account the widely distributed nature of Forestal Oriental plantations, the differing groundwater systems on which these are located and the variety of groundwater-dependent entities. The monitoring actions that result from this objective approach and that are appropriate to the levels of concern are also defined.

2 Objectives

There are many practical and resource constraints to meeting the over-arching goals of a comprehensive water monitoring system that observes the impact of about 130,000 ha of plantable land distributed over a large region in Uruguay (Figure 1). FO’s specific objectives are therefore:

- *To define a groundwater monitoring program to achieve compliance with IFC and FSC requirements;*
- *To better understand the potential impacts of afforestation and forest operations on water balance (surface water flows, groundwater storage, changes in flow patterns, etc.) and water quality in Uruguay, and thereby to identify desirable additional monitoring or management actions.*

3 Background

3.1 Biophysical environment

FO has its holdings in Uruguay, South America in a subtropical to temperate humid climate zone, with its plantations located between approximately latitudes 31°28'S and 33°37' S, and longitudes 55°22' W and 58°8' W. FO operations are spread over a large region in the Litoral (North-western Uruguay - 3,221,200 ha) and in the Tacuarembó Department (North-central Uruguay - 1,543,800 ha) (Figure 1).

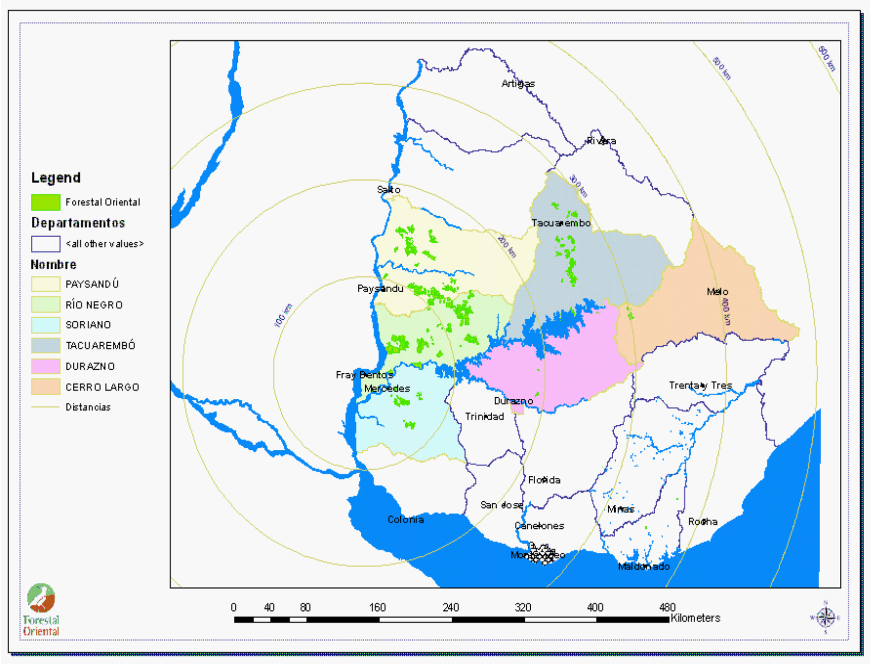

Figure 1: Location of FO plantations (2008); Radial lines refer to distance from the pulp mill in Fray Bentos.

Uruguay has a humid sub-tropical climate, classified in the Köppen climate classification system as Cfa. ("C" temperate and humid, "f" precipitation throughout the year and "a" hottest month temperature is greater than 22 ºC; see Figure 2). Winters are mild while summers are hot. Median temperatures between 7.1°C and 32°C. Extreme temperatures can reach 42°C (mid-January) and -4.5°C (early July), which implies frost occurrence in low-lying areas. Mean annual precipitation is about 1,300 mm/yr in the Litoral region and greater than 1,400mm/yr in Tacuarembó, is fairly uniformly distributed throughout the year, with less rainfall during winter months (Figure 4). There is a strong north-south precipitation gradient (Figure 3).

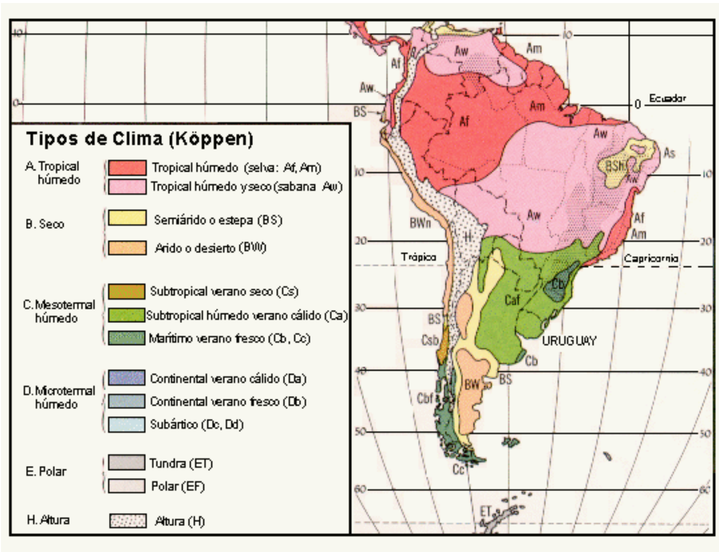

Figure 2: Köppen climate classification system (Source: DNM - National Meteorological Office).

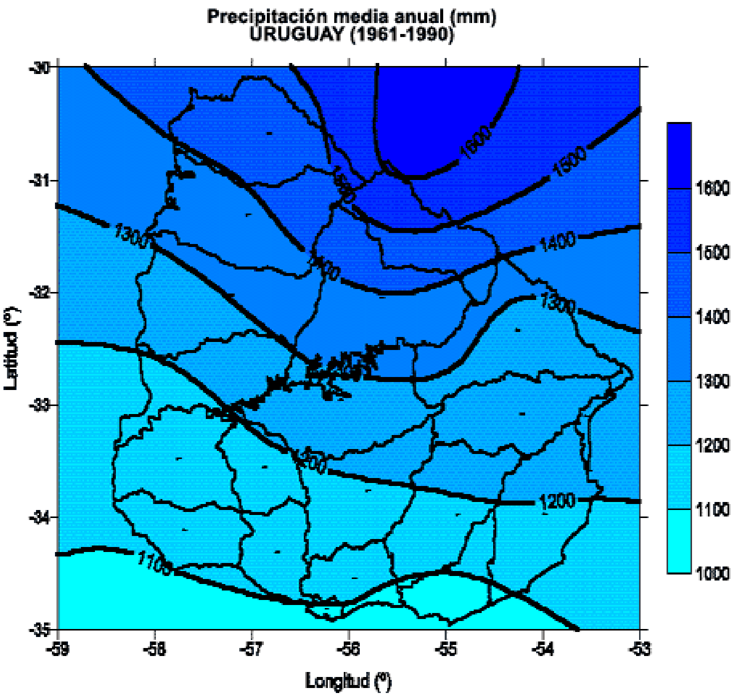

Figure 3: Uruguay annual average precipitation (mm) (1961-1990) (Source: DNM).

The FO land base encompasses a wide range of site types, especially regarding lithology and soils. The Uruguayan landscape does not have large topographic features, particularly in the west where the landscape does not rise above 180 m above sea level. In contrast the Tacuarembó region gradually rises from southeast (80 m a.s.l.) to the northwest (400 m a.s.l.). Plateaus extend from the northwest in a series of long broad ridges, becoming narrower and lower to the southeast, and forming numerous south- and north-facing side valleys on their flanks. (Herbert, 2008).

The Litoral has clay-rich subsoil, which has some important influences on the hydrological characteristics of the region (Scott, 2000). Tacuarembó soils are dominated by sandy loam and sandy clay material of varying depth over sandstone. The higher elevations area shows outcroppings of basalts and sandstone with thin layer topsoil above. Another feature is the riverine and swamp native forest occurring in the lower portion and flood plains of the Tacuarembó River.

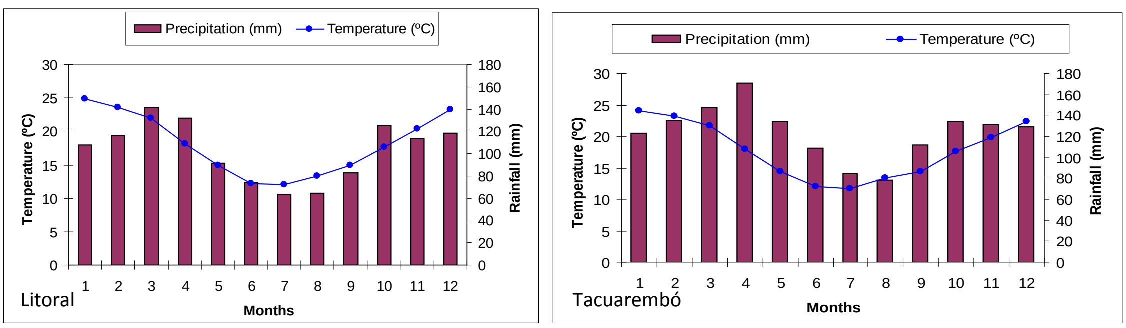

Figure 4: Climate diagram (Climagraph) for both regions, showing median precipitation and temperature throughout year (Source: DNM).

Uruguay is part of the system denominated Pampa Biome formed mainly by open areas covered with natural grasses, with a minor presence of other kinds of vegetation such as natural forests, which occupy 4% of the whole Uruguayan territory (remnant riparian forests - swamp native forest), palm trees, bushes, wetlands, which are generally not suitable for Eucalyptus plantations and are not planted by FO. Uruguayan climax vegetation is evergreen grassland and its natural state is a tall grass prairie (Panario and Bidegain, 1997). At mean annual rainfalls of 1,200 to 1,300 mm per year, the climax vegetation should be one of forest and Panario and Bidegain (1997) note that seasonally evenly distributed rainfalls of the quantities (as seen in Uruguay) are elsewhere in the world usually associated with forest. They also observe that the most plausible hypothesis for the existence of grasslands in Uruguay, and not forests, is that a) most soils are saturated for much of the year with high clay or lime contents (grassland is usually a climax vegetation of leached sandy soils), and b) the abundance of thin soils, low topography and relatively high wind speeds (3.5–5 m/s) reduces water availability relative to other regions of similar rainfall.

Regarding the groundwater systems of relevance to FO operations, these can be divided into two parts, which have very different aquifer characteristics and behaviours: The North Basin Aquifer System (NBAS) and the Guarani Aquifer System (SAG). The NBAS, located in the litoral area, overlies the SAG. They are separated by a layer of basalt (the Arapey Formation) up to 900 m thick in the west. Regional aquifers (or even international ones, like the SAG) are extremely large (covering thousand to 10s of thousands of square kilometres), so it is impossible to model them as a whole without assuming absurd simplifications (for example homogeneous internal structure, planar and parallel contacts, hydraulically isotropic). Real aquifers (that can deliver more than 500 l/hr) are extremely complex when studied at large scales (a 1/50,000 map scale is hard enough) because of their internal heterogeneities and the lateral and vertical changes of geological facies.

The NBAS, of approximately 130 to 150 m thick, outcrops to the East and is made up of several parallel, tilt units of sedimentary and chemical weathering origin, from upper cretaceous period; all of them aquifers. Tertiary sediments (aquiclude) form subsequent coverings; these are not part of the recharge zone. The recharge area of NBAS is coincident with the outcropping area, and the regional groundwater flux is towards the west towards the main discharge area along the Uruguay River, but there is very little data regarding groundwater recharge through the upper (top) units of the aquifer-bearing geological units.

The SAG (Figure 5) is a very large transboundary aquifer system located to the SE of South America, between 12º and 35º latitude S and between 47º and 65º long W, extending to more than 1,2 million km², underlying large parts of Brazil (840,000 km²), Paraguay (71,700 km²), Uruguay (58,500 km² – 3.8%) and Argentina (225,500 km²). It is bounded in the north near Brasilia in Brazil, with its south-western extent becoming undefined in Argentina. The north-west quarter of Uruguay is underlain by the SAG and it occupies about 25% of the total Uruguayan territory. The SAG has an estimated average thickness of 250 meters, varying from a few meters at it extremities to about 800 m in its central parts (in Brazil). This is known as the freshwater unit of the SAG as opposed to the underlying salty SAG. The depth below land surface varies from zero in outcropping areas in Brazil to more than 1,800 meters in Argentina. In Uruguay the SAG dips to the west such that it reaches some 600-900m depth in the western parts of the country, overlapped by basalts in most of its extension.

The SAG is estimated to contain about 40,000 km³ of fresh water (permanent reserves) with annual natural recharge occurring in the outcrop areas and through discontinuities in the confining rock estimated in 160-250 km³ (5,000 – 8,000 m³/s) (active reserves). About 90% of the total volume of fresh water is potable, although, locally, potability can be reduced due to salinity and high fluoride content. The exploitable reserves are estimated at 40 km³ per year (25% of the estimated annual recharge).

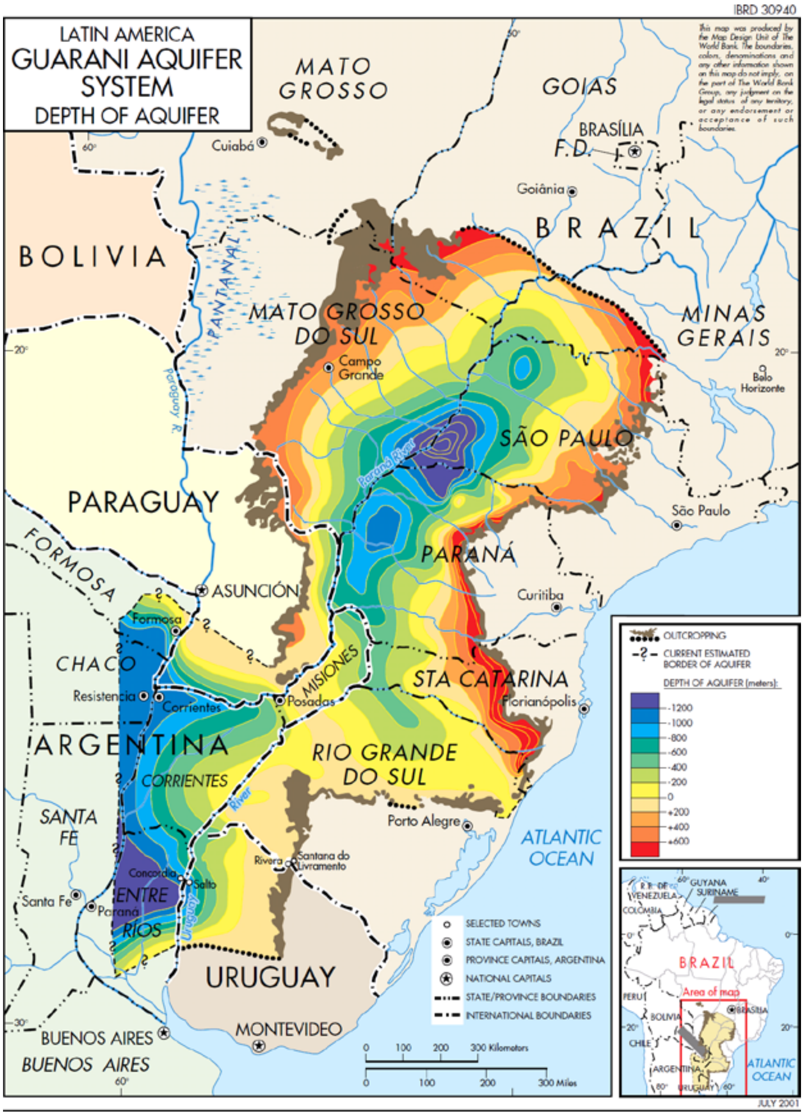

Figure 5: The Guarani aquifer. Brown: outcrop in Uruguay - Tacuarembó Formation. Pink zone: thinner, fractured basalts on high ground where some indirect recharge is thought to also take place. Source: World Bank.

In Uruguay the SAG outcrops in the Tacuarembó and Rivera departments (Figure 6). Recharge to the SAG in Uruguay takes place through direct infiltration of excess rainfall and stream-flow into the outcropping Tacuarembó formation.

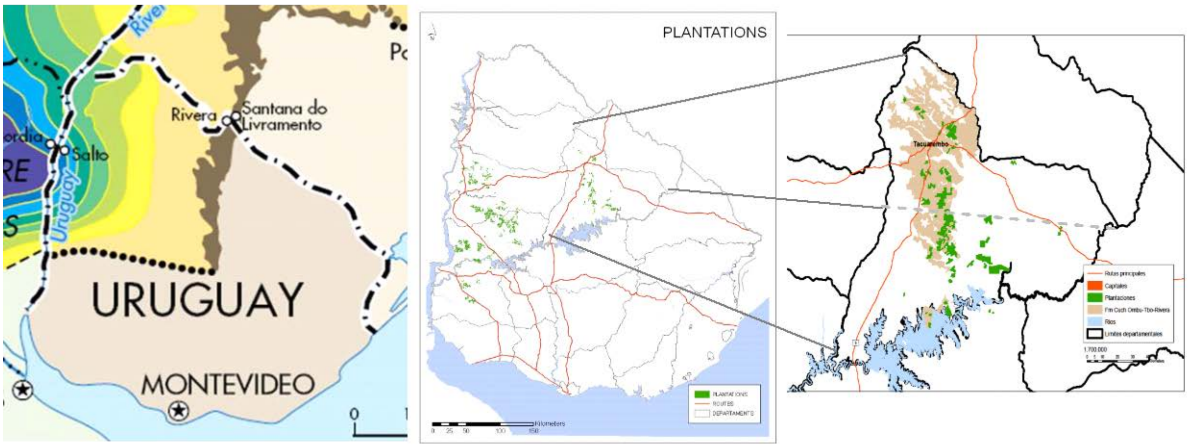

Figure 6: FO plantations located on the Uruguayan portion of the recharge zone.

Or indirectly through the overlapping formations that include the thin and fractured flood basalts in the eastern part of the Uruguayan Arapey Formation (Cretaceous basalt cover related to the opening of the southern Atlantic basin during the breakup of the Gondwana supercontinent), in an arc of about 10-15 km wide and 240 km long. Towards the centre of its structural basin, the SAG groundwater becomes progressively more confined by the thickening overlying basalts and exhibits an artesian overflowing head over large areas. With increasing depth and confinement the groundwater temperature also increases substantially (can be up to 65ºC) through the natural geothermal gradient.

Aquifer flows from boreholes in Uruguay can vary from 5 to 600 m^3 per hour or more. Known utilization of the SAG in Uruguay (135 wells for public water supply), is either through low-yielding boreholes into the shallow parts of the aquifer outcrop or high yield deep boreholes, drilled through the basalts, supplying artesian water to geothermal spas (7 boreholes) that have been developed in the north-west of Uruguay. These produce water at rates of between 2.5 and 7.5 m^3 per minute, on average. The elevated temperature of the water rising to the surface is more a reflection of the depth at which the water is abstracted rather than any anomalous subterranean heatflow that could be of magmatic origin.

3.2 Socio-economic environment

Uruguay is highly urbanized, and there is a continuing trend of depopulation from the smaller rural settlements and movement to the larger urban centres (especially to the capital city Montevideo which at 1.6 million contains almost 50% of the population). Data taken from the 2005 National Statistics Institute census show the population density of many areas within many rural departments to be less than 1 person per km^2. Higher population densities are clustered around the western edge of the litoral region, close to the Rio Uruguay. Visually, much of the countryside appears empty of people. Most FO plantations occur where population densities average about 3 persons per km^2.

Apart from forestry (brown in Figure 7), there are five key economic activities that occur in the rural areas of Uruguay - listed in descending order of area used:

1. *Extensive beef cattle rearing (light greens), mostly on unimproved pasture;*
2. *Dairy herds (dark green and greys), especially where soils are shallow or poor and could not support arable crop production;*
3. *Arable agriculture (pink and red) – wheat, maize, sunflower and soybeans;*
4. *Rice production (blue and light blue), mostly located in the Merín lake basin (Eastern Uruguay) and in the NE part of the country;*
5. *Citrus (yellow) and other fruit growing and at a still smaller scale, horticulture and viticulture (violet).*

The Litoral soils, because of their sedimentary origin, are more fertile and support a higher intensity of farming operations than the central part of the country.

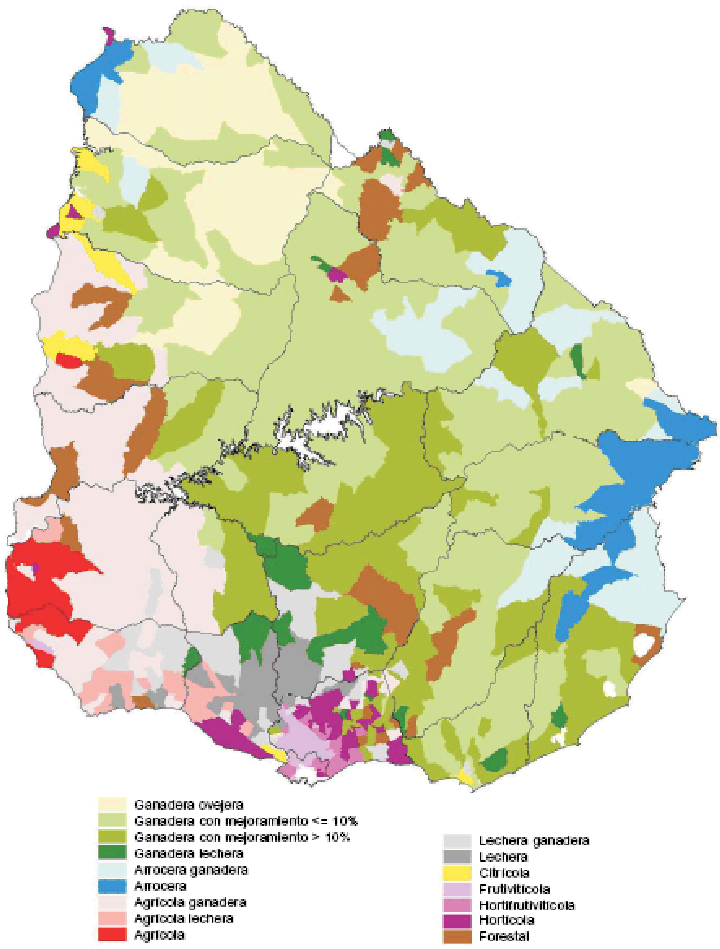

Figure 7: Agropecuary regions, 2006 (Source: MGAP-DIEA).

3.3 Forestry development in Uruguay

The distribution of plantations across the Uruguayan landscape has been determined by the combination of political objectives and soil type (or land productivity type). The

Uruguayan government classified the country into land types which are largely based on a soil classification, but which is more accurately described as homogeneous soil units defined by their wool, sheep and cattle production capacity. These classes were legislated as Art. 65 of Law Nr. 13695, 1968 as a means for tax assessment purposes.

The policy of creation of a commercial forest sector developed in the 1980's as a means of a) integrating the sector with traditional agricultural activities, b) establishing a platform for a new industrial sector, c) generating new employment in rural areas and d) creating a sustainable energy resource. Priority was given to afforestation of particular soil groups, specifically those with low natural fertility but relatively good drainage. Soils that are suitable for forestry and simultaneously have low productivity for farming were declared as "Forestry Priority Soils". The plantings on forest priority soils were promoted by subsidies, tax exemptions and access to soft loans until 2005, when all new subsidies were removed. Then in 2006 the list of forest priority soils was reduced (Figure 8) and in 2007 most tax exemptions were terminated.

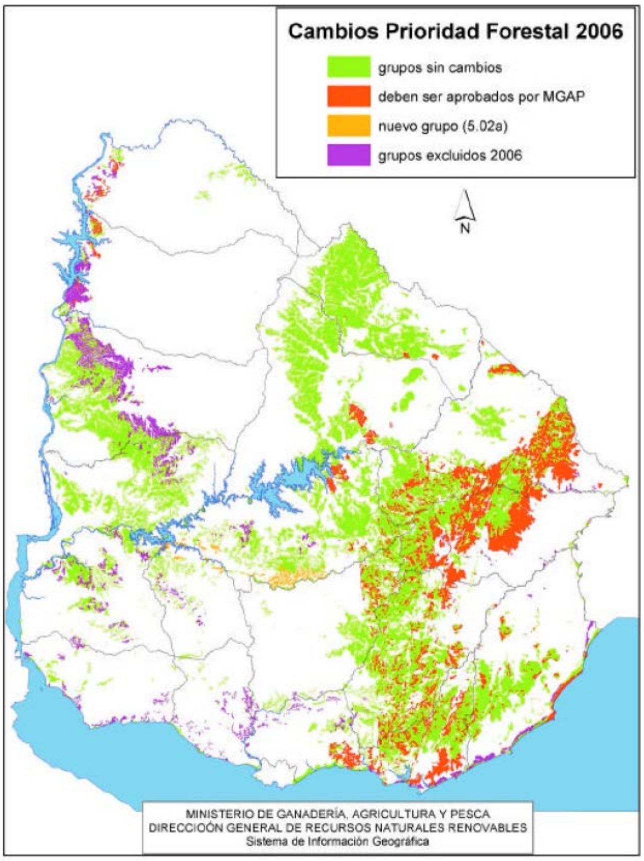

Figure 8: Forest Priority Soils, with changes introduced during 2006 excluding some areas previously favoured for afforestation (purple) and adding small areas (orange).

The essence of the original Forestry Law was to preserve the best agricultural land for crop growing while also encouraging rural development through the establishment of a forestry industry in a way that avoids a conflict for soil and water resources. The unintended consequence of this policy was to concentrate the establishment of plantations on the recharge zones of the NBAS and the SAG in particular.

4 The Risk Assessment (RA) Method

4.1 General Approach

Given the large geographical coverage of FO plantations (distributed over 35.000 km² of Uruguay), the paucity of hydrological baseline data available (for river flow and groundwater dynamics) and the complexities of the local aquifer characteristics, the design of a comprehensive monitoring system capable of providing meaningful and appropriate information was quite a difficult undertaking. Therefore, in order to evaluate the possible effects and focus for monitoring of FO plantations on ground and surface water resources in general, a risk assessment has been undertaken. The results of the risk assessment were then used to specifically identify and to select locations and entities to be monitored as well as the type of monitoring required.

Table 1: Risk estimate matrix.

SEVERITY \ LIKELIHOOD	1	2	3	4	5	6
6	6	12	18	24	30	36
5	5	10	15	20	25	30
4	4	8	12	16	20	24
3	3	6	9	12	15	18
2	2	4	6	8	10	12
1	1	2	3	4	5	6

Risk estimate:

I High	All situations, that cause effects, should immediately get below this level.
II Moderate	All situations, that cause effects, should be below this level in next few years.
III Low	All risks, that can be removed or decreased, should be taken into account when planning other activities.
IV Negligible	Risk is not substantial and there is no present need to evoke actions for mitigation

Likelihood/ Severity	Description of likelihood	Description of severity
1	Extremely unlikely, not ever expected to occur.	No effect, no identifiable impact on assets.
2	Very rare, could occur once during facility life, 1/1000yrs.	Intermittent impacts on assets but tolerable
3	Low likelihood, could occur during facility life given scale of operation	Identifiable impacts on assets
4	Possible, could occur once in ten years, 1/10yrs.	Persistent and occasionally severe impacts on assets
5	Probable, could happen annually, 1/yr	Severe impacts on assets.
6	Regular, could happen as often as ten times per year, 10/yr.	Total loss of flow permanently/irreparably damage assets and possibly leads to total loss.

The principle of this risk assessment is to start with the end in mind – and to focus in identifying those assets possibly at risk if a reduction in water supply (as a result of plantation water use) is observed. In this way, the risk assessment has less to say about absolute quantities of water involved and more to say about the consequences of reductions of water supply. The risk analysis approach inherently acknowledges the complexity of the situation and tries to reduce the uncertainty about what may or may not happen. Risk is measured in terms of a combination of the likelihood of occurrence of the hazard and the severity of the consequences. This is performed using a risk evaluation matrix (table 1), which integrates the information generated by the previous steps.

4.2 Methodology

The following sequence of actions describes in more detail the method:

1) Identification of assets: The first challenge is to identify what entities could be affected by the impact of eucalypt plantations on water resources. These can be grouped as:

- *Social: domestic water supplies, human settlements;*
- *Environmental: wetlands and associated ecosystems, protected areas, rare and endangered species or groundwater-dependent ecosystems that contain these species;*
- *Economic: money-generating entities using surface water or groundwater - cattle grazing, agriculture irrigation, industries requiring high quality water and others.*

2) Hazards identification: possibility of reduction in groundwater supplies and flows in streams in the affected area to the social, economic and environmental assets or receptor earlier identified. In these circumstances two key types of hazards may eventually be a) the loss of a portion of streamflow through reduced soil moisture and runoff, and b) reduction of recharge to aquifers which may result in insufficient replenishment and a drawdown of the water table or piezometric surface.

3) Evaluation of the likelihood of the hazard occurring: the extent of the plantation area at the catchment above where streamflow is required as the prime determinant of the likelihood of occurrence. It is the probability of streamflows being reduced or water tables falling, in which event the assets could become affected. Such impacts are related to the scale of the forestry operation in the catchment in proportion to the total water-supplying area, i.e. the proportion of the catchment that is afforested. Another factor that may affect likelihood is the weather pattern, in drought periods trees use relatively more water and have greater impact on low flows than during wet periods. There are both spatial and time components to the likelihood of hazard occurrence.

4) Determination of the exposure or vulnerability of the asset to possible impacts: Relates where the assets are located in relation to the plantation (upstream/ downstream/surrounded by the hazard/closeness) and the hydrological functioning of the place.

5) Determination of the consequences of exposure of the assets to the hazard (severity): Possible severity of the potential impact is material. For instance, the water supply to a small community could be threatened, which has human health consequences and therefore the severity would rate quite high. The effect would be long term (increasing the severity effect) although of only local spatial extent, it would still require ameliorative actions. The effect is not cumulative, but if it is assumed that the plantations are permanent features of the landscape, then the effect is irreversible. While life in the town would not

become unviable, if the effect were to take place, it would require other means of water supply.

If severity and likelihood are high it can be concluded that the risk is also high. However, even if the likelihood is low, but the severity of exposure to that hazard is high, then the risk can still be high (see Table 1). If the likelihood and consequence produce a moderate or high risk score then those assets so identified will be priority target for monitoring by FO.

4.3 Application of the Risk Assessment to water risks of FO plantations

Before applying the general risk assessment approach described above, the location, extent and age-class of the FO plantations were mapped. As the risk assessment is hydrologically based, a first important task was to understand how Forestal Oriental plantations are located in the different catchments.

As there is no existing classification of Uruguayan catchments, we have chosen a classification of stream channels and basins according to the Strahler schema (Strahler, 1952) and considered the Strahler Order 3 catchments as a base case because Order 1 and 2 partition the study area into too many sub-catchments of meaningless detail. However, at Order 4, important detail is lost and this level is not useful for discriminating differences between catchments.

It is broadly considered from international research and literature that few negative effects can be detected on water downstream when the basin area is afforested up to approximately 20%. “Reduction in flow from forest cover of less that 20%,(…), apparently cannot be detected by measuring streamflow” (Bosch and Hewlett, 1982). Research in Australia also found a similar result, in that anything less than 20% of the catchment planted would have little measurable impact (Brown et al, 2005).

Thus this risk assessment is specifically focused at the Order 3 level of catchment aggregation and in catchments in which FO has more than 20% afforested. So the argument is that, using this simplifying assumption, no further detailed assessment is required in catchments with <20% of the total area covered by FO plantations, because no hydrological effect is likely be detected anyway and therefore there is little justification to monitoring. [Note in addition that FO does not plant the important lower parts of the topography and has plantations covering only 60% of the total owned land area].

For each Order 3 basin, its total area, the gross area and percentage of the basin owned by FO, the total plantable area of FO holdings and its percentage within the catchment were studied for both regions (Litoral and Tacuarembó). Based on afforested areas greater than 20% of total catchment area five catchments have been identified to study within this risk-based assessment. See tables 2a,b.

The risk assessment approach is a means of reducing the complexity of the way in which plantations might interact with the groundwater systems. Or where there is only limited understanding of all the complexities involved in such systems. It can also help inform FO (and others considering conversion of grassland to plantations) about areas of high sensitivity to additional planting and the potential need for alternative management practices.

Following the general risk assessment approach described before, each asset identified in the vicinity of all FO planted areas, was located and mapped.

Table 2a: FO lands, plantations and % of afforestable lands in each Order 3 catchment. Litoral zone.

Catchment name	Catchment area (ha)	FO gross area (ha)	FO % area of catchment	Plantable area (ha)	FO % plantable area of catchment
Coladeras	23674	10111	43%	6625	28%
Del Talar	8104	3131	39%	1957	24%
Sarandí Grande	11267	3818	34%	2200	19%
Sarandí	13994	4280	31%	3070	22%
Grande	53855	14803	27%	7271	13%
Quebracho Grande	37040	7537	20%	4957	13%
Sánchez Chico	16838	3361	20%	2272	13%
Bacacuá	31020	6103	20%	4073	13%
Ñacurutú	18213	3140	17%	1972	11%
Sánchez Grande	21376	3631	17%	2786	13%
Guayabos	29093	4867	17%	3101	11%
Negro Superior	54407	7976	15%	5312	10%
Román	20834	2928	14%	1781	9%
Molles de Porrúa	15600	2105	13%	1063	7%
Averías Chico	17874	2364	13%	1369	8%
Capilla Vieja	18218	2273	12%	1353	7%
Guaviyú	85438	9554	11%	5314	6%

Table 2b: FO lands, plantations and % of afforestable lands in each Order 3 catchment. Tacuarembó zone.

Catchment name	Catchment area (ha)	FO gross area (ha)	FO % area of catchment	Plantable area (ha)	FO % plantable area of catchment
Blanquillo	3511	1131	32%	414	12%
Furtado	8513	2470	29%	1758	21%
Del Sauce	13484	2884	21%	1975	15%
Viraró	5413	1066	20%	775	14%
Bañado de Rocha	8249	1480	18%	1007	12%
Molles	5611	921	16%	644	11%
Corral de Piedra	8852	979	11%	625	7 %

Social assets include the domestic use of water, by individual homesteads or settlements of varying size. These may obtain their water from shallow wells (<15m deep) or from deeper boreholes. Modes of supply can include self-operated (homestead well or borehole) or that supplied by the state water company OSE. This organisation may abstract water from boreholes or from surface water. Large settlements obtain water from deeper boreholes and even larger obtain their water from surface water resources (or a mixture of boreholes and surface water).

Risk to social assets is partly a function of settlement size. It is expected that with the low population density, the risks of adverse effects by the plantations on domestic water resources will be relatively low (the consequences of a loss of water will be low, even if the likelihood of an impact is somewhat higher).

As FO forests are concentrated mostly onto similar soils the proportion of a catchment that can be planted is fairly high, as micro-catchments are small. This may result in the local impact on streamflow having an important effect if there are downstream neighbours that rely on the small streams for water supply (Scott, 2000). To assess whether there are specific problems, the downstream water use and estimated streamflow reductions were assessed on a catchment by catchment basis. For domestic and industrial supplies of water, though, there are large alternative sources of water that will not be affected by forestry.

Unlike urban dwellers, who usually pay for the water and therefore volumes consumed are perfectly known, the rural population is typically not supplied with metered water. Rural population take water directly from surface waters or unregistered underground sources and therefore the quantities consumed are typically not available. Because of this, it is very difficult to estimate the behaviour of water demand of rural settlements.

From data taken from 2006 National Home Survey for water used for drinking and cooking in rural areas, 12.6% is supplied by the public network (OSE), 69.4% through boreholes, 11.4% from wells and just 1.7% from rivers or streams. Other type of water supplies totals 4.9%.

In small settlements under 100 people, often the inhabitants are responsible for their own water supply. Usually they are too poor to own and operate deep boreholes (of depth > 30m) for high quality water from the confined aquifers and they have shallow wells of depth <15m into the unconfined aquifer. Such shallow sourcing can result in temporal issues of water quantity, quality and contamination with domestic effluent and waste. These communities that are very close to FO plantations (within 2-3 hundred metres) are potentially exposed to the hazard of loss of groundwater supplies. If the water source is a borehole through the unconfined aquifer and aquitard and into a regional confined aquifer, then the community is unlikely to be exposed to the impacts of FO on groundwater recharge. If the water source is a surface water supply and the community is located downstream a plantations, then exposure should be considered.

Environmental assets: FO has 3,160 hectares voluntarily allocated to the protection of ecosystems of high interest. These areas were identified during the environmental characterization process carried out by FO prior to the establishment of the plantations. Each of these protected areas has a specific management plan which takes into account the resources of conservational interest and the peculiarities they may have.

The relationship of surface-water with its dependent ecosystems was determined through detailed mapping of the riparian zones, river banks (aluvions), lowlands, wetlands, discharge zones (springs) and all those areas in the region where the water table has a direct influence on the nature and/or density of water dependant species.

Regarding water dependency species, there is just one amphibian in FO lands (Pleurodema bibrobi – frog) considered NT (almost at risk) from the Conservation Category. There are no species on FO lands considered EN (in danger) or VU (vulnerable).

Economic assets: The key economic activities in the rural areas that depend on water abstraction are cattle grazing, dairy farms and irrigated arable agriculture. The area sown to arable crops is not in competition with plantation forestry for water because: a) as with forestry, it relies on precipitation directly onto the crop canopies and soil, and b) it is spatially separated from forestry areas as both activities are located in different soil groups (with particular reference to the application of “Forest Priority Soils” designation).

The key economic activities in the rural areas specifically dependant on water abstraction usually use borehole water or shallow wells. Irrigation by water extracted from borehole is used for citrus crops and vineyards, not in close proximity to FO operations. Irrigated agriculture takes place in an area where the nearest FO operations are more than 15 km distant and therefore there is no possible influence.

The largest economic activity specifically dependent on water in the rural areas near FO operations include both small scale, unspecialised subsistence dairy farms consisting of a small number of animals, and larger specialised farms producing milk and cheese on a commercial basis. Apart from the usual stock watering, milking parlours require water for cleaning purposes. The small subsistence farmers may be exposed to the hydrological impacts of FO plantations where they exist very close to, or just downstream of these plantations.

4.4 Groundwater monitoring

The monitoring of groundwater resources, as well as the determination of groundwater recharge remains one of the most difficult problems in hydrological research, because this recharge varies spatially and temporally. It depends also on a wide variety of factors such as vegetation cover, precipitation, topography, geology, and soil type. Therefore, groundwater monitoring is full of uncertainties and complexity. Fluctuations in the water table are not always indicative of groundwater recharge or discharge and changes in water levels occur over different time scales. There may be long-term fluctuations, which can be attributed to naturally occurring changes in climate, land use changes, pumpage, as well as seasonal fluctuations, which are very common in many areas and are due to changes in evapotranspiration and precipitation. Barometric pressure changes, on the other hand, can also cause short-term water table fluctuations (Healy & Cook, 2002). So how can we possibly be certain whether a change in water table level over time was a result of the plantation establishment?

To seek to discover (by measurement and/or monitoring) the relationship between afforestation and the regional aquifers (SAG, NBAS), we cannot model the whole aquifer system. However it is possible to examine the behaviour (apportionment) of rain fall between water run-off and percolation in the first 10m below a maturing tree crop (from literature assumed to be the rate of highest water usage) and compare that with the behaviour without trees (in a similar underground condition at an adjacent grassland or once the trees have been harvested). If this behaviour can be established it will be possible to extrapolate to compare the infiltration loss (or gain) caused by the forestry over a big area like the outcropping zone of SAG or NBAS, and then extract some conclusions about regional aquifers impacts of afforestation (i.e. we can only scale up our conclusions). Real data can only be collected by restricting the area of observation and analysis regarding the internal system variables (such as permeability and composition).

Entirely separately from the RA we assessed aquifer vulnerability of the NBAS and SAG by mapping the area of FO plantation onto each aquifer’s recharge zones. We expect in this way to determine, by looking at the proportion of the recharge zone that has been afforested, and to establish, in a broad way, the likelihood of an impact on aquifer recharge. Tables, maps and assessment conclude this section.

In the Litoral FO plantations (57,000 ha) are preferentially located on a NBAS layer formation (350,568 ha in this area) where less than 7% (23,440 ha) of the total aquifer recharge zone is covered by FO plantations. It can be safely assumed that any hydrological impact of FO plantations on this area at a regional level will be undetectable.

Less than 6% of the total SAG aquifer recharge zone in Uruguay (811,432 ha) is covered by FO (48,612 ha). At a regional level, any impacts of FO plantations on recharge to the SAG will be undetectable. Also the thinner western boundary of the Arapey formation which overlies the SAG can also be considered a recharge zone through fractures in the basalts. FO forests have not been planted on the basalts and if this zone is included as a recharge zone, then total FO coverage will be reduced to substantially less than 6%.

The groundwater level monitoring systems in each of the units described above will be implemented under a mature forest, with harvesting date at least one year from the time of the monitoring network establishment. The affected region will occupy between 50 and 100 hectares in such a way to evaluate the regional groundwater performance.

5 Conclusions - Recommended Monitoring Programme

Groundwater levels in parts of the NBAS are already known to be declining, caused by over-use of the aquifer by borehole owners who do not know how to manage their groundwater resources. Since the advent of electrically-powered pumps and rural electrification, groundwater levels have been in decline. This trend represents a significant threat to FO because the possibility exists that these trends will be attributed to the company's plantations. The risk assessment did not identify assets at high risk. However, as a result of this study, the following recommendations were made:

1) The monitoring of water levels in pre-existing wells in FO plantations near where human habitation occurs. Specifically from the risk assessment results it is recommended to install monitoring points at five settlements close to the plantations, which rely mostly on groundwater, are co-located on ridge-tops with the plantations and situated mostly on the NBAS system. At these locations, water levels in wells within the plantation area and at a distance of more than 200 metres outside the afforested area should be monitored over time. The comparison of phreatic surface variations between the locations will help indicate if changes are a result of normal climatic variations or tree water impact.

2) Despite few economic assets seem to be threatened at all by the plantations, monitoring at one dairy farm whose borehole is within 100m of FO plantations is recommended.

3) Conducting a limited study that seeks to assess the direct recharge impacts of the plantations on the four important aquifers in the FO land base (three in the NBAS and one in Tacuarembó). The study will measure the phreatic surface and rainfall event responses inside and outside (grassland within some hundreds of metres) maturing plantations.

The selected locations should have FO plantations that will be harvested in 12 to 18 months from the time of the monitoring network establishment. The affected region will occupy an area between 50 and 100 hectares (400 to 550m radius to the central monitoring drilling) in such a way to evaluate the regional groundwater performance. The monitoring will require single piezometers equipped with automatic water level recorder. This approach would involve a web of six piezometers scheme. Five of them installed under a plantation stand in specific geomorphological positions (one central drilling, one upstream, one downstream and two more on notable sites) and the data of the water table level position will be downloaded together with the key agro-climatic parameters (precipitation, barometric pressure). The remaining piezometer will be installed in a nearby open area. In the period between the monitoring system installation until the harvest date, the water table baseline will be monitored, along with precipitation and atmospheric pressure. The governing hypothesis will be that plantations are actively influencing the water table position at a specific forest-age. At the time of felling, the governing hypothesis of active impact ceases and the monitoring system should assess for the rebound of the water table to initial conditions prior to afforestation. The analysis of data collected during the second phase (after felling) should allow the measure of the magnitude of the impact caused by an adult forest in the vadose zone and piezometric surface in an inverse way. The advantages of the proposed method are related to the economy of time and resources for obtaining quantitative data of afforestation impacts on groundwater. This makes the method applicable to various levels of study (supports duplication of the technique quickly and easily). It is flexible and is short-term, allowing redesign of monitoring plans without wasting time. It also can be applied to different geological formations, soil/geology combinations, plantation densities and species.

4) In order to establish a long term baseline for afforestation impacts on runoff and groundwater levels, and to study water dynamics associated to forest plantations at catchment scale in western Uruguay, FO established, in late 2006, a paired catchment experiment on unplanted land in Western Uruguay (see Chapman, 2007). The monitoring infrastructure implemented includes two flow measuring devices (v-notch weirs) with time-height recording instruments, six boreholes (three of them with automatic water depth sensors and data-loggers) and an automatic weather station. Monitoring of the already established (classic forest hydrology assessment methods) paired-catchment experiment should continue, as a means of developing evidence based knowledge of plantation forest hydrology in western Uruguay.

5) Given the scale of the FO plantation area in Tacuarembó, the fact these overlie a different geology and the recharge zone of the SAG, of main concern to the IFC, a second paired-catchment experiment should be established in this area.

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Use of Water from the Guarany Aquifer System as Drinking Water by Dilution with Surface Water

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Abstract

This paper presents a viability study for the use of the water from the Guarany Serra Geral Aquifer System (GSGAS), which is located in the extreme west of the State of Paraná (in the southern region of Brazil), for drinking water purposes. The GSGAS is connected to the Guarany Aquifer System (GAS) through geological faults and diabase dykes of structural compartments so that in some regions of the aquifer a sample of water of the GSGAS can present very similar characteristics to the GAS, examples include: high content of sodium, chlorine, fluoride and a temperature higher than 30°C. These characteristics prevent the use of the water from the GSGAS as drinking water, as the concentration of some parameters exceed the maximum permitted value established by Brazilian legislation. The GSGAS has a great potential to be used as drinking water because of its great volume of water. One option to reduce the concentration of the critical parameters is to dilute the water with surface water. To foresee the viability of the use of water from the GSGAS using a dilution with surface water from the Bela Vista Reservoir, a simulation of the necessary dilution was carried out using the computer program PHREEQC. The program was developed by the U.S. Geological Survey and can be used for chemical specification, batch-reaction, one-dimensional transport, and inverse geochemical calculations. In this case the program was used to calculate the water composition after being mixed through a simulated dilution, based on the composition of the water used (groundwater and surface water) and on the chemical equilibrium constant of the involved reactions. The chemical parameters that exceeded the maximum permitted values in the analyzed water mixture were: total dissolved solids (TDS), sodium (Na+), chloride (Cl-), sulfate (SO42-) and fluoride (F-). For the calculation of the necessary dilution, it was first necessary to calculate the concentration factors of the water that is to be used in relation to the maximum permitted values of each parameter. The highest dilution was correspondent to the concentration of fluoride, which presented the highest concentration factor. According to the simulation, the water from the dilution could be used for drinking water purposes only if the studied parameters would define the standards of drinking water use, once all analyzed parameters were below the maximum permitted value established by the Brazilian legislation.

Keywords: *Guarany Aquifer, Dilution, Surface Water, Drinking Water*

1 Introduction

The Guarany Aquifer System covers an area of about 1.2 million km² distributed among: Brazil (69.8%), Argentina (19.2%), Paraguay (6.1%) and Uruguay (5.0%) (Boscardin Borghetti et al., 2011). The population that inhabits the regions where the Aquifer occurs corresponds to nearly 34 million people (Boscardin Borghetti et al, 2011).

The main goal of this paper is to show a viability study focusing on the use of the water of the Guarany Aquifer System (GAS), as drinking water with an emphasis on the Guarany Serra Geral Aquifer System (GSGAS), through dilution with surface water.

The study area (Figure 1) is located in the Paraná III River Basin, in the extreme west of the state of Paraná, in southern Brazil. This area is located in close proximity with Itaipú Hydroelectric Power Plant Reservoir. The region was formed by volcanic rocks.

The relief of the river basin of the Paraná III is between undulate and slightly undulate, with altitudes between 300 and 700 meters. The drainage basin is formed by the rivers São Francisco Falso, Taturi, Ocoí, Chocoró, Arroio Fundo and São Vicente, and all of them flow into the Itaipu Lake. The river basin total area is 8,389 km², with a population of 997,500 inhabitants, distributed among 27 municipalities.

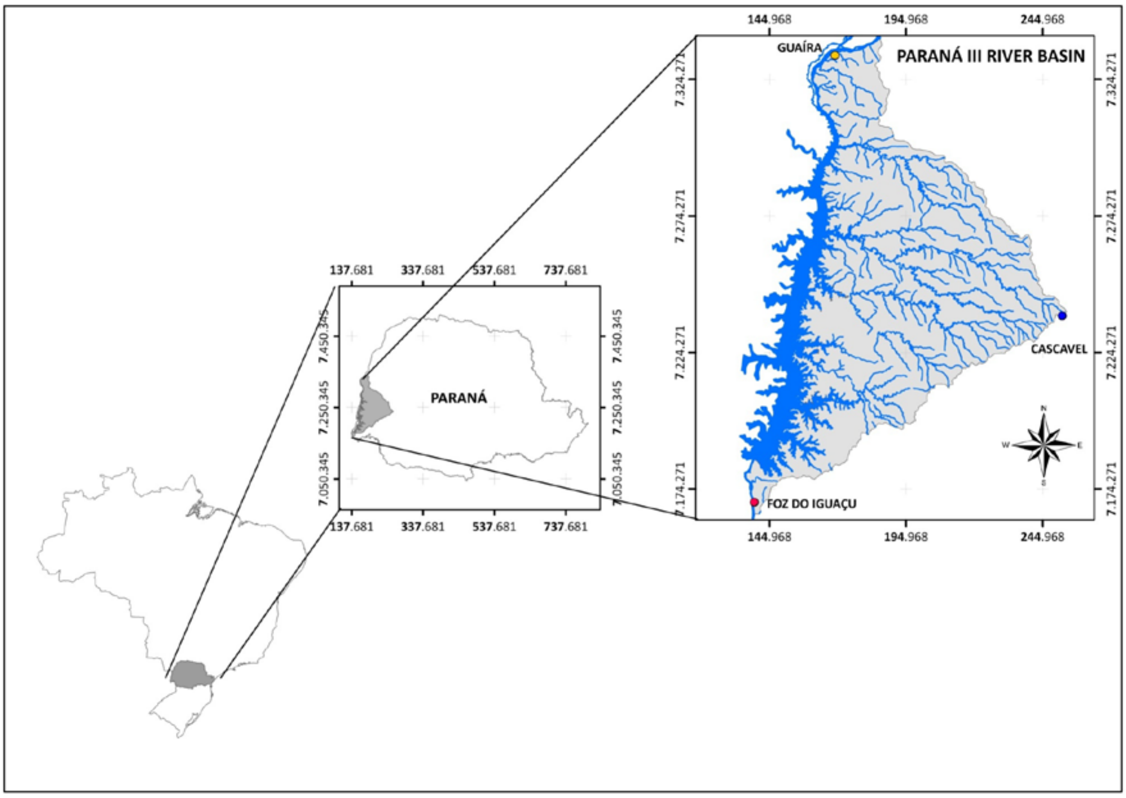

Figure 1: Study Area – Location of Paraná III River Basin.

The great number of geological faults, predominantly in the direction SE-NW, cause discharge zones from the GAS into the GSGAS. The GAS is formed by many hydrologic compartments caused by these geological faults and by the intrusions of diabase dykes, and each one has its own dimension. Figure 2 shows the geological section of the geological faults in the Guarany Aquifer System (GAS) and the Guarany Serra Geral Aquifer System.

Because of the complexity of the aquifer systems in terms of its spatial distribution, and of the high potentiometric height of each hydrogeological compartment, the recharge process of the GAS in this region is still not well known. The thickness of the basaltic cover at the Paraná III River Basin is fissural with free to locally confined aquifer. Fracturing zones parallel to the contacts and vesicular zones occur at the contact between the suffusion spillages. In these zones large amounts of water are stored, due to the primary and secondary porosity. The thickness of the basaltic layer in the region of the Paraná III varies between 632 to 920 m.

The GAS was formed by the formations Pirambóia and Botucatu during the Triassic-Jurassic Age. As an aquifer with intergranular porosity and hydraulic characteristics of a free aquifer in some areas where it emerges in the surface is going to be confined as it flows far from the emerging area. The GAS is connected to the GSGAS because of geological faults and diabase dykes of structural compartments (Figure 2) so that in some regions of the aquifer a sample of water of the GSGAS can present very similar characteristics to the GAS.

The geological section of the GSGAS and the GAS is presented in Figure 2, where the geological faults that cut both aquifers are shown.

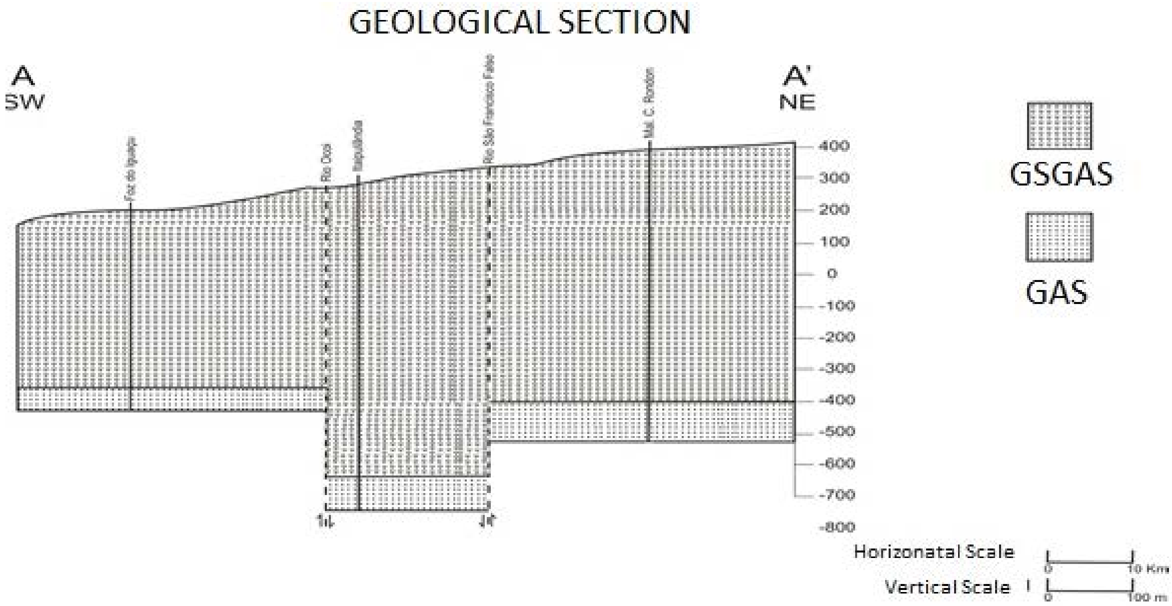

Figure 2: Geological section of the Guarany Aquifer System (GAS) and the Guarany Serra Gral Aquifer System (GSGAS) (Adapted from Bittencourt et al., 2003).

Although the GAS has a high potential for use as drinking water for its large volume of water, this is limited by its characteristics, like high temperature and salinity. This situation is worsened because of the excess of fluoride, sulfates, sodium and total dissolved solids (up to 1,000 mg/L), with predominance of the ion sodium.

The objective of this work was to calculate the necessary dilution of the water of the GSGAS with surface water from the Bela Vista Reservoir, also located in the study area using a simulation with the computer program PHREEQC.

The standards of water quality as drinking water are ruled by the “Portaria 2914/11” of the Brazilian Health Ministry.

2 Methodology

To evaluate the resultant water composition, it was considered the following parameters: pH, Temperature, Total solids, Conductivity, Sodium (Na^{+}), Potassium (K^{+}), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Carbonate (CO_3^{2-}), Bicarbonate (HCO_3^{-}), Nitrate (NO_3^{2-}), Silica (SiO_2), Chloride (Cl^{-}), Sulfate (SO_4^{2-}) and Fluoride (F^{-}).

After knowing the concentration of each parameter, the next step is to find the theoretical necessary dilution. For this calculation, it is first necessary to calculate the concentration factors of the water that are to be used in relation to the maximum permitted values of each parameter.

The quotient of concentration of the parameter in water to be harnessed and the maximum permitted values is considered as a factor of concentration. Equation 1 is used to calculate the concentration factor.

$$Concentration\ Factor = \frac{Parameter\ Concentration}{Maximum\ Permitted\ Value} \qquad (1)$$

Once this is done, the highest concentration factor is considered as a reference for the calculation of the necessary dilution with water containing a low concentration in dissolved matter, available in the region.

The basic equation for the dilution calculation is the following:

$$Concentration_{final} = C_{initial}\ x\ Q_{initial} + C_{dilution}\ x\ Q_{dilution} \qquad (2)$$

Where: C_{final} = final concentration desired or the maximum permitted value; $C_{initial}$ = concentration of the critic variable in the to be diluted water; $Q_{initial}$ = dilution volume of the to be diluted water; $C_{dilution}$ = concentration of the to be diluted water; $Q_{dilution}$ = necessary volume of the dilution water.

After knowing the necessary dilution, the program PHREEQC version 2 (Parkhurst, 2007) was used to generate a simulated composition of the water after the mixture. The program was developed by the U.S. Geological Survey and can be used for chemical speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations.

This simulation is done to calculate the expected concentration of each parameter, considering that more interactions can happen and all parameters can be altered due to these interactions. The program calculates the water composition after being mixed through a simulated dilution, based on the composition of the water used (groundwater and surface water) and on the chemical equilibrium constant of the involved reactions.

Figure 3 shows the Interface of the computer program PHREEQC exhibiting the composition of the fractions mixed and the concentration of each element.

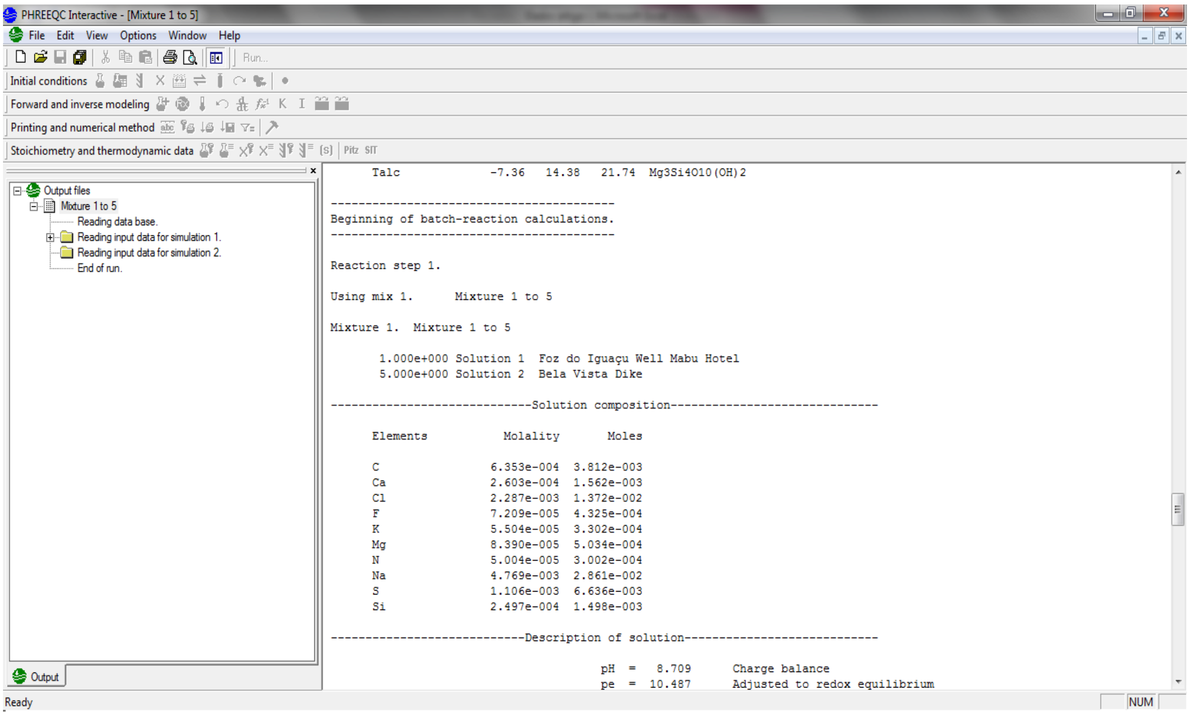

Figure 3: Interface of the computer program PHREEQC exhibiting the composition of the fractions mixed and the concentration of each element.

3 Results and Discussion

Table 1 shows the results of the water analysis in the water of the GSGAS and in the Bela Vista Reservoir.

Table 1: Results of the physical-chemical analysis in the Guarany Serra Geral Aquifer System in Foz do Iguaçu and from the surface water of the Bela Vista Reservoir (Bittencourt, 1978; Bittencourt et al., 2003). The results that are above the maximum permitted value were highlighted in bold.

*MPV: Maximum Permitted Value according to the “Portaria 2914/11” of the Brazilian Health Agency.

Parameter	GASSG	Bela Vista Dike	MPV
pH (-)	8.65	7.1	6.0 to 9.5
Temperature (°C)	33	22	-
Conductivity (mg L^{-1})	5004	-	-
Na^{+} (mg L^{-1})	646	2.1	200
K^{+} (mg L^{-1})	6.4	1.3	-
Ca^{2+} (mg L^{-1})	31.52	6.2	-
Mg^{+} (mg L^{-1})	8.87	0.67	
Cl^{-} (mg L^{-1})	482	0.3	250
HCO_3^{-} (mg L^{-1})	247.3	26.2	-
CO_3^{2-} (mg L^{-1})	5.45	-	-
SO_4^{2-} (mg L^{-1})	636.2	0	250
F^{-} (mg L^{-1})	8.2	0	1.5
NO_3 (mg L^{-1})	2.65	0.31	10
SiO_2 (mg L^{-1})	15	20	-

The chemical parameters that exceeded the maximum permitted values in the analyzed waters were: sodium (Na^+), chloride (Cl^-), sulfate (SO_4^{2-}), nitrate (NO_3^-) and fluoride (F^-). Table 2 shows the results of the calculation of the concentration factor for the parameters sodium, chlorine, sulfate and fluoride.

Table 2: Results of the calculation of the concentration factor for the parameters sodium, chlorine, sulfate and fluoride.

Parameter	Concentration factor
Na+	1.98
Cl^-	3.23
SO_4^{2-}	2.54
F^-	5.47

As shown in Table 2, the highest concentration factor was that of fluoride (5.47). So the concentration of fluoride was considered as reference, for being the most critical. The maximum permitted value and the initial concentration of fluoride was considered to apply the dilution equation (Equation 2):

$$1.5 = 8.2\ x\ Q_{initial} + 0.0\ x\ Q_{dilution} \quad (3)$$

$$Q_{initial} = 0.1829 \quad (4)$$

$$Q_{initial} = 18.29\ [\%] \quad (5)$$

This means that each cubic meter of water of the Bela Vista reservoir can receive the maximum of 18.29% of the water from the GSGAS.

If considered the proportion of 81.70% water from the Reservoir and 18.29% water from the GSGAS it results that for each cubic meter of water of the GSGAS must be diluted with 4.46 cubic meters of the surface water (81.70/18.29). To simplify the simulation, it was used the proportion 1:5. The resulting concentration of each parameter after of the mixture is presented on Table 3.

Table 3: Results of mixture from the water of the Guarany Serra Geral Aquifer System (GSGAS) in Foz do Iguaçu and from the surface water of the Bela Vista Reservoir. *MPV: Maximum Permitted Value according to the “Portaria 2914/11” of the Brazilian Health Agency.

Parameter	GASSG	Bela Vista Dike	MPV
pH (-)	8.65	7.1	6.0 to 9.5
Temperature (°C)	33	22	-
Conductivity (mg L^{-1})	5004	-	-
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HCO_3^{-} (mg L^{-1})	247.3	26.2	-
CO_3^{2-} (mg L^{-1})	5.45	-	-
SO_4^{2-} (mg L^{-1})	636.2	0	250
F^{-} (mg L^{-1})	8.2	0	1.5
NO_3 (mg L^{-1})	2.65	0.31	10
SiO_2 (mg L^{-1})	15	20	-

According to the simulation, all analyzed parameters are below the maximum permitted value. After the simulation of the dilution, the pH was altered, what was not expected, but the result is still below the maximum permitted value.

4 Conclusion

The highest dilution was correspondent to the concentration of fluoride, which presented the highest concentration factor. According to the simulation, the water from the dilution could be used for drinking water purposes if only the studied parameters would define the standards of drinking water use, once all analyzed parameters were below the maximum permitted value established by the Brazilian legislation. Yet, more data from both waters, e.g. biological contamination, are necessary to conclude if the mixture is adequate for the purpose.

More studies about the use of the Guarany Serra Geral Aquifer System for drinking water purposes using dilution with surface water should be conducted, especially with more data from the waters. Also, it would be very important to determine the economic viability of the whole process of transporting the water and its dilution.

5 Acknowledgements

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Initial Environmental Assessment (IEA) of Dam Construction Project for Water Supply to Thermal Power Plant

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Abstract

Maharashtra State of India had planned to install 1 x 250 MW unit of thermal power station (TPP). The estimated water requirement of the unit was 12 Mm³/Annum that would be met from the river by constructing a dam. IEA was essentially required by the statutory authority for site clearance for the construction. IEA was done to study the environmental feasibility of the dam construction project by carrying out preliminary site survey. Details of the catchments area and estimation of yield have also been studied so as to confirm the availability of water to the TPP and to maintain the designed minimum water flow in the river perennially. The findings of hydro-geological studies and seismic survey conducted at the site confirmed the safety of the dam and the surrounding area and population. The baseline status of all the environmental components was studied: air, noise, water, land, biological and socio-economic parameters. Based on primary and secondary data and its legitimate assessment, environmental feasibility of the site for dam construction was confirmed. Recommendations on compensatory afforestation and socio-economic compliance were given to the TPP.

Keywords: *IEA, dam construction, water supply, environmental feasibility*

1 Introduction

To cope up with the escalating demands of power utilities by rural, urban and industrial sectors and to achieve a self-sufficiency in power generation, Maharashtra state has set up a new 250 MW electricity project. The water requirement for the proposed TPP project was 32873 m^3/d (12 million cubic meter per annum, Mm^3/Annum). To make up this water demand, construction of a dam across Mun river of Tapi basin has been proposed to ensure constant and secured water supply to Thermal Power Plant (TPP).

1.1 Need of IEA

Overall environmental impact assessment offers a systematic process of examination, analysis and assessment of planned activities with a view to ensure environmentally sound and sustainable development (Panigrahi and Amirapu, 2012). Assessment of baseline environmental quality in the vicinity of the project site is an essential part of IEA for the construction of dams (MoEF, 1999). IEA study is a preliminary survey fulfilling the requirement of site clearance from the statutory authority (Lohani, 1997). IEA study has been carried out to identify adverse environmental impacts associated with the project which need to be given due consideration in the planning, design, construction, operation and monitoring of the project to minimize adverse environmental impacts. This is carried out by the site survey and studies based on collection and collation of primary and secondary data. Legitimate assessment of the data reflects on its feasibility such that it may not hamper the existing environment in future. For this purpose, baseline status of all environmental components is required to be studied: air, noise, water, land, biological and socio-economic parameters.

Expected benefits of the project are:

- *Water impoundment would assure adequate and constant water supply to TPP for uninterrupted power generation, domestic purposes, and irrigation;*
- *Construction of dam would maintain necessary water storage and regulation of storage level will rule out the possibility of flood which was otherwise evidenced in some regions in the downstream.*

1.2 Objective and Scope of IEA

IEA was envisaged to identifying adverse environmental impacts associated with the project which need to be given due consideration in the planning, design, construction, operation and monitoring of the project to minimize adverse environmental impacts. The IEA facilitated site clearance from regulatory agency.

- *Collection of information about site, salient features of the project, submergence area, catchment area, length of barrage and site attributes like geology, hydrogeology, topography, soil characteristics, land use pattern, surface and ground water resources and climate;*
- *Brief assessment of the present status of water, land including forests, biological, climatic and socio-economic components of environment including parameters of human interest based on secondary data.*

2 Material and methods

It is imperative to understand the inter-linkages and dynamics between various activities and direct, indirect and cumulative impacts on ecology and social sphere to evaluate the impacts and to suggest mitigation measures. The process of EIA varies with laws and local practices in individual countries (Panigrahi and Amirapu, 2012). The various steps involved in the IEA study were screening, scoping, baseline data collection, identification impacts and suggestion of management plan.

The IEA study was based on the actual site visit and field data collected for various environmental components: air, and noise, water, and land, biological and socio-economic parameters. Information related to the various aspects was also collected viz., site, salient features of the project, submergence area, catchment area, length of dam and site attributes such as geology, hydrogeology, topography, soil characteristics, land use pattern, surface and ground water resources and climate. To ascertain the depth of foundation, boreholes have been taken along the dam line, upstream and downstream of dam line and also along the flanks. Suitable quarries for sand and gravel were available 5 km on downstream of dam site.

The rainfall data for last 55 years has been used for developing the weighted rainfall (Thiessens polygon method), for the calculation of confirmed water supply. Empirical formula approach was used flood for discharge estimation. The Inglis formula was used to estimate the flood discharge.

$$Q = 125M/\sqrt{M+10} \quad (1)$$

Where Q = Maximum flood discharge [cumecs] and M = Area of catchment [km²]. Water balance of a drainage basin is given by equation:

$$R = P - E \pm \Delta S \quad (2)$$

Where Q = Runoff, P = Precipitation, E = Evaporation and Δ = Change in storage.

It is stated that the site of the proposed barrage fell under seismic zone III, thereby indicating no danger of earthquakes to the dam. Moreover, the structural design and the construction of the dam are undertaken by considering the appropriate safety factors for such type of seismic zone.

The area under submergence was extended upto 10 km on the upstream of the dam. Hence, the scope of IEA study includes characterization of existing status of environment in an area of 10 km distance all along upstream of Mun river adjoining its either banks from the point of the dam construction site for study of various environmental components such as air, noise, water, land, biological and socio-economic component for environmental viability of the site.

A study area of 10 km radius was considered for the environmental assessment. Sampling was carried out in winter season at 15 villages in the periphery of 10 km around the dam construction site. Minimum of 5 samples each for air, water, soil and noise were collected from each village. The individual environmental components were studied as follows:

- *Air Environment: Different air pollution parameters like SPM, RSPM, SO_2, and NO_x were sampled in and around the study area for representing baseline status of ambient air quality.*
- *Noise Environment: Noise pollution survey was required to be carried out in and around the project site to assess the existing noise pollution before the construction of barrage.*
- *Water Environment: Information on physico-chemical characteristics of surface water resources in the study area were collated which serves as a baseline status.*
- *Land Environment: Soil samples from study site were analyzed for physico-chemical properties that could depict the soil characteristics. Information on geology, land use / land cover, cropping pattern in the study were collected to strengthen baseline status.*
- *Biological Environment: Type of vegetation cover and floral species were analyzed by personal field visit to site and submergence area.*
- *Socio-economic Environment: To assess the socio-economic benefits and views of the project affected persons (PAP), the social survey was performed.*

3 Results and discussion

The scope of IEA study includes characterization of existing status of environment in the area of 10 km radius and all along upstream of the river adjoining its either banks from the point of the dam construction site for study of various environmental components. By using empirical equations, delta storage was decided by maintaining minimum flow in the river and estimating evaporation losses. The evaporation loss was estimated to be 2.34 Mm^3/year. The net available yield of water from river was 35.8 Mm^3/year as against the requirement of 14.34 Mm^3/year including evaporation losses. The type and location of gated spillway is shown in Figure 1.

3.1 Technical details of proposed dam

Technical details opf the proposed dam are:

- *Length of dam:* *570 m*
- *Total length of spillway:* *259 m*
- *Height of dam:* *15 m*
- *Size of gates:* *15 m (h) x 11 m (v)*
- *No. of gates:* *11 nos.*
- *Type of gates:* *Radial gates*

The storage details are:

- *Gross storage:* *10.0365 Mm^3*
- *Live storage:* *10.0365 Mm^3*
- *Dead storage:* *Zero*
- *The storage level @ R.L.* *260.30*

3.2 Water availability

The catchment area available for the proposed dam was 656.25 km^2 and the available net yield per annum was 35.8 Mm^3. The rainfall data for 55 years (from 1948-2002) was used for developing the weighted rainfall by Thiessens polygon method. For the calculation of confirmed water supply, 30 years carryover study is worked out which was found to be most successful in 27 years i.e. 90% dependability. The 90% dependable weighted rainfall was 20.63 inches (52.98 cm). It was seen that 15 Mm^3/yr. of water could be supplied at 90% dependability which indicated that the water demand of the proposed TPP was fulfilled by using the river water.

Figure 1: Gated spillway for controlled water discharge.

3.3 Land availability

Water storage level peaking to 260.30 m furnishing a catchment area of 656.25 sq.km. supported the water requirement of 12 Mm^3/yr. The river has 152.22 ha land under river bed hence additional land under submergence was 125.97 ha along its stretch on either banks upto maximum of 7 km distance in upstream. Total land under submergence was 278.19 ha. Land use pattern showed that major crops cultivated were Bajra (Pennisetum typhoides), Cotton (Gossipium herbaceum) and Jawar (Sorghum vulgare) (1991, Census of India).

Out of 278.19 ha of land estimated to go under submergence, 14% of land is owned by government while 3 % and 28 % of land belongs to forest dept. and private land owners respectively. The land under the river bed accounts to 55 %. The forest land would be compensated by purchasing the land at other location and hand over it to the forest department for its further afforestation.

3.4 Site selection

The parameters which influenced selection of site were availability of water to meet the requirements of expansion project, to save town from recurring floods, and close proximity to the TPP. It was stated that the site was under seismic zone III, thereby indicating no danger of earthquakes to the dam. Geologically, the proposed site has been categorized under Deccan traps formation consisting of Basalt, Dolerite and some varieties of Qabbro. The texture of soils varied from clay loam to sandy clay loam, which was very favorable for supporting heavy structures. The soil strata were considered suitable for construction of heavy structures. Location map of proposed dam is shown in Figure 2.

Figure 2: The site selected for the construction of the dam project.

3.5 Environmental assessment

The air and noise pollution were envisaged only during construction phase due to movement of vehicles on the construction site. Hence, the dam construction activity has been only source of pollution in the region, for which sufficient environmental dilution was available. The vehicular emissions from trucks and other vehicles during construction phase have been the sources of air pollution. The 24 hourly mean concentrations of SPM, RPM, SO_2 & NO_x varied between 97-406, 27-146, 5-20 and 5-28 mg/m³ at different locations which were well below the limits as per the Environment Impact Assessment Notification, 1994. As far as noise pollution was concerned during construction phase, movement of vehicles such as trucks, dumpers and road rollers at the site has implanted noise levels. Noise is defined as unwanted sound that deteriorates quality of human life. It was observed that within study area of 10 km periphery there were no other ongoing industrial activities. Baseline noise levels, observed were in the range of 40-50 dBA in the residential areas, 54-57 dBA in industrial area, and 50-60 dBA in commercial area. At sensitive locations such as schools, colleges and hospitals, the noise levels were found to be in the range of 40-46 dBA. All the values were found to be within the prescribed limits.

Physico-chemical characteristics of surface water for summer season were determined. Total dissolved and suspended solids were in the range of 476-594 mg/l and 19-28 mg/l respectively. The alkalinity was 182-239 mg/l, whereas total hardness was 202-238 mg/l. The chloride and sulphate content were 166 mg/l and 35 mg/l respectively. Nitrate and Phosphate contents were found to vary as 2 mg/l and 1.0 mg/l respectively. Bacteriological counts of Total Coliform and Faecal Coliform in surface and ground water were observed to be in the range of 200-1100, 8-32 CFU/100ml and 120-140, CFU/100ml. Construction of barrage does not impose any change in water quality. However, the water usage by the thermal power plant shall lead to heated water discharge with some contamination can certainly change the water quality over a period.

The project required a total land of 278.19 ha undergoing submergence all along its stretch of upstream upto 7 km. The land use/land cover status of the study region indicated 28% agriculture land, 16% land under water body, 42% of land covered with wild, unused with sparse vegetation cover and 14% of built up area. Majority of the submergence area was covered with wild, sparse vegetation cover in the form of herbs, shrubs and trees as shown in Figure 1. The forest land comprised general vegetation cover of common species like acacia cassia, caesalpinia, butea, pongamia, bauhiia and others.

The texture of soil in this region varied from sandy clay loam to clay loam. Regular cultivation practices increased the bulk density of soil thus indicating compaction. This results in reduction of water percolation rate and penetration of root through soil. The bulk density of the soils in the study area was observed to be varying from 1.17 – 1.35 gm/cm^3. Soil porosity is the measure of air filled pore spaces and provides information about movement of gases, inherent moisture, and development of root system and strength of the soil. The porosity and water holding capacity of soil were in the range of 50-59% and 30-46% respectively. The soils in the study area have poor to moderate water holding capacity.

Land use refers to human activities on land, utilitarian in nature whereas land cover denotes the vegetation and artificial constructions. The major crops grown were Bajara (Pennisetumtyphoides), Cotton (Gossipiumherbaceum) and Jowar (Sorghum vulgare). The cultivation was mostly rainfed. In the entire submergence area economically useful (timber) trees have not been noticed. The vegetation pattern did not have even-aged pure stands while, it has un-even-aged mixed stands with predominance of middle and lower canopy vegetation. The vegetation loss as forest cover was 3% under submergence/construction activity of dam which did not significantly affect the biodiversity of the region in general. It was observed that out of 77 plant species, there was no species recorded in Red Data Book (1990), as endangered, vulnerable, endemic or threatened.

3.6 Compensation package to PAP

The agricultural land under submergence was 79.18 hectares which accounted to be 28% of the total land under submergence. The monetary compensation was provided by TPP to the affected project affected people (PAP). They were given the appropriate compensation of their lands dedicated to the project. Disbursement of compensation amount of private land owners in lieu of agricultural land gone under submergence has been proposed to be done in consultation with District Collectorate office for its legitimate disbursement. Based on field survey, it was observed that the forest land undergoing submergence was very less 8.73 ha i.e. 3% of total submerged land. It was found during this survey that the project affected people (PAP) were given compensation packages by the TPP as prescribed by the government. The appropriateness of the site selection has been demonstrated by avoidance of relocation/rehabilitation/resettlement of population.

4 Conclusion

The site feasibility was checked from the point of view of stability and the life of the dam by studying the foundation stratum, earthquake possibility and spillway design. The decision on the site selection for the dam construction was taken with the consideration of minimum submergence of land under forest and agriculture. It was found during this survey that the project affected people (PAP) were given compensation packages by the TPP as prescribed by government. The appropriateness of the site selection has been demonstrated by avoidance of relocation/rehabilitation/resettlement of population. No endangered, threatened, vulnerable, rare, exotic and endemic species were observed in the submerged area. The initial environmental assessment thus proved that the proposed site was appropriate for the construction of the dam and it would not impose any adverse impacts on the ambient environment. However, the actual impact after the project completion is easily to deviate.

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Drinking water protection areas (in Germany): Significance of multi-barrier systems

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Abstract

Guaranteeing the drinking water supply in densely populated countries such as Germany requires the target-ortiented protection of water resources. In Germany, European law (EC Drinking Water Directive, EC Water Framework Directive), national law (Federal water act) and the laws of the federal states provide the basis for a sustainable protection of the water resources. Central instrument of water resources protection is the implementation of drinking water protection areas, safeguarding the catchments of those water bodies drinking water is abstracted from: Mainly groundwater and dams. Water protection areas are essential parts of the multi-barrier-system ensuring an optimal drinking water quality. This paper introduces the general concepts and the legal basis of drinking water protection areas and summarises the guidance of the DVGW (Deutscher Verein des Gas- und Wasserfachs) how to use the catchments of water abstraction works, suggesting a zonal approach of restriction or even prohibition of certain actions within the catchment area.

Keywords: *drinking water protection, multi-barrier system, protection zones, groundwater, dams and reservoirs*

1 Introduction

According to the German DIN 2000, drinking water is the most important food and cannot be replaced by any alternative. In Germany, 99% of the population is connected to the public drinking water supply network which is in contrast to severe deficiencies in many developing contries allover the world (UNESCO, 2012), as described in connection with the achievements towards the Millenium Development goals. The DIN 2000 as well as the German drinking water ordinance (TrinkwV, 2001) and the EC Drinking Water Directive (EC, 1998) make great demands on the water quality to be suitable for drinking water supply in Germany and Europe.

While the World Health Organisation (WHO) recommends at least 2 liters drinking water to be available per person and day, in Germany in average around 120 liters are consumed per person and day. Although from those 120 liters only 5 liters are used for drinking and preparing food, all 120 liters are delivered in high quality according to the standards set by the German drinking water ordinance (TrinkwV, 2001). This poses a big challenge to the water supply infrastructure, to guarantee such a big drinking water supply in a sufficient quality.

The protection of the natural water resources (e.g., groundwater, spring water, surface water) can assist in keeping the water resources in good quality and reducing the effort for water treatment. In Germany, around 70% of the drinking water is abstracted from groundwater, and the remaining 30% are taken from surface water bodies and bank filtration (Federal Statistical Office, 2009). Therefore, groundwater and surface water bodies from which water is abstracted for drinking water supply need to be protected.

The EC Drinking Water Directive (EC, 1998) and the EC Water Framework Directive (EC-WFD; EC, 2000) have set a framework to improve the ecological status of all water bodies in Europe and to contribute to a sustainable use of water resources. General aims and the implementation of the EC Water Framework Directive have already been described in detail by Althoff (2012). One central instrument for water resources management mentioned in the EC Water Framework Directive is the installation resp. continuation of drinking water protection areas.

This paper introduces the general concepts and the legal basis of drinking water protection areas and summarises the guidance of the DVGW how to use the catchments of water abstraction works, suggesting a zonal approach of restriction or even prohibition of certain actions within the catchment area (DVGW 1995, 2002).

2 Multi-barrier systems

According to Castell-Exner (2001), a multi-barrier-system related to drinking water supply can be interpreted as a combination of measures guaranteeing a safe drinking water quality in terms of protection of the resource, optimizing water abstraction, treatment and distribution and considering the domestic installation (Figure 1).

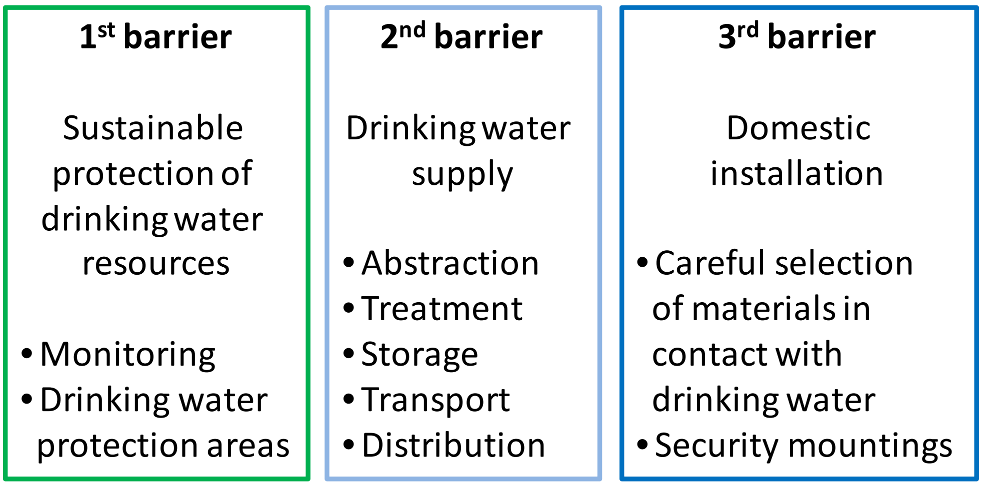

Figure 1: Multi-barrier-system related to drinking water supply systems. Changed after Castell-Exner (2001).

The 1st barrier consists of a consequent protection of the water resources in the catchment of groundwater wells, springs, dams or lakes. The 1st barrier aims at an area-wide preventive protection of the water resources in order to enable such a raw water quality which requires only a treatment based on natural techniques (such as filtration) to achieve a drinking water quality according to the EC Drinking Water Directive (EC, 1998). In addition to the general water protection provisions fixed in the European directives and the German water law (Federal Water Act; WHG, 2009), drinking water protection areas are an important instrument contributing to the multi-barrier system.

The 2nd barrier consists of the abstraction, treatment, storage, transport and distribution of drinking water according to the generally accepted codes of practice. This includes published regulations with respect to procedure, instrumentation and operation, which are generally accepted, and which have been proven to be suitable for the specific purpose (e.g., to meet the quality targets of the German TrinkwV (2001)). Necessary requirements for the acceptance of (private) organizations developing such regulations are their political indepence, benefit to the public (non-profit-making) and a well-regulated and transparent process to formulate the rules. In Germany, the DVGW (Deutscher Verein des Gas- und Wasserfaches e.V.; www.dvgw.de) and the DWA (Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e.V.; www.dwa.de) are responsible for the formulation of such codes of practice. However, one must be aware that codes of practice are not legally binding but a standard for technically correct action. Technical rules are developed by committees consisting of experts from water supply, industry, administration and research.

The 3rd barrier is the domestic installation. While the reponisibility of the water supplier ends at the water meter, the house owner is responsible that water still has a sufficient quality at the consumer's tap. Important aspects are the choice of an adequate material of the domestic drinking water installation (steel, copper, selected synthetic materials), an adequate operating temperature of the hot-water apparatus (in order to avoid the development of Legionellae) and the installation of backflow preventers.

3 Drinking water protection areas

3.1 General aims

Drinking water protection areas are – as mentioned above – essential parts of the multi-barrier-system guaranteeing a good drinking water quality. In general, the main goals of drinking water protection areas are:

- *To provide clean drinking water,*
- *To assist health, supply, and esthetics related aspects of drinking water,*
- *To contribute to an area wide protection of the (untreated) raw water in the entire catchments of the drinking water abstraction works,*
- *To minimize the transport of compounds and organisms affecting the water quality,*
- *To defend water against any new risk and hazard potential,*
- *To prevent water from negative temperature changes, and*
- *To monitor the water resources used for public water supply in a well focused manner.*

In oder to achieve those goals but, at the same time, allow for certain action in drinking water protection areas, in Germany drinking water protection areas are structured into three zones characterized by different restrictions and inhibitions depending on the respective risk potential of the related action. Such zoning approach takes care of the fact that – in addition to drinking water abstraction – generally there is also interest in activities such as habitation, agriculture, traiding, or others.

3.2 Legal basis for the implementation of drinking water protection areas in Germany: Federal Water Act and the water laws of the Federal States

The legal basis for the implementation of drinking water protection areas in Germany is defined in the German Federal Water Act (“Wasserhaushaltsgesetz”; WHG, 2009). §6 describes the general principles of the sustainable management of water bodies, aiming at:

1) *The conservation of functional capability of natural systems and habitats,*
2) *The prevention of deterioration of wetlands and terrestrial ecosystems depending on water bodies,*
3) *The use of water as public good, consistent with individual interest and*
4) *The conservation and creation of water bodies’ usability for public water supply.*

The implementation of water protection areas is regulated by §51. If required for human welfare, (1) water protection areas can be implemented by the governments of the federal states by ordinance in order to

1) *Protect water bodies,*
2) *Artificially recharge groundwater, and*
3) *Prevent the runoff of contaminated precipitation water as well as transport of sediments and pollutants into water bodies.*

Furthermore, (2) drinking water shall be structured into zones featuring different protection provisions considering the generally accepted codes of practice.

§52 defines the specific requirements of water protection areas. According to the ordinance of the federal states (§51) or by governmental decisions, activities in water protection areas can be regulated as follows:

1) *Interdiction or limitation of particular activities,*
2) *Committing the land owners to (a) conduct specific actions on their land, (b) to take notes of the land use, to preserve such information and to hand it to administration if required, (c) to tolerate measures with respect to the oberservation of water bodies and soils, the surveillance of the protection proviosions, as well as fencing, labeling, planting and reforestation,*
3) *Assignees can be committed to realize the measures mentioned under (2).*

Preliminary directives can be made for areas which are planned to get implemented as future water oprotection areas, including the above mentioned interdiction or limitation of particular activities, if otherwise the implementation of a water protection area would be at risk.

According to the water legislation of the federal state Northrhine Westfalia (Landeswassergesetz; LWG, 1995), the municipalities have the task to ensure the public water supply (§47). However, the municipality can confer this task to third parties if the proper water supply is guaranteed.

Installations for water treatment have to be in accordance with the generally accepted codes of practice (§48; if required to obtain the quality targets according to the TrinkwV). Public drinking water supply companies are obliged to monitor the water quality at their own cost (§50). Per ordinance, the water administration can regulate the frequency, parameters, location and extent of the sampling as well as the treatment and investigation.

For each drinking water protection area, a protection area specific ordinance has to be determined, specifying limited and forbidden actions. Such ordinance must be based on the water law of the respective federal state. In Northrhine Westfalia, the district councils are responsible for the determination and implementation of water protection areas (§150; LWG 1995). Public participation is safeguarded by public display. Persons concerned have the possibility to claim the personal interest.

4 Guidance for drinking water protection areas according to the DVGW

The protection of drinking water catchment areas has to be based on pro-active instruments aiming at a prevention of any transport of harmful substances into the water resources. Such prevention significantly reduces the necessary effort for water treatment. Since different water storages (e.g., groundwater, dams) are protected by different natural influcencing factors, prohibition and limitation of different actions has to be specific with respect to the type of the storage and the catchment characteristics. Therefore, protection area specific ordinances are determined considering such specific characteristics, and the DVGW as responsible organization on a professional basis has set-up two different worksheets towards the protection of the water resources in case of groundwater protection areas (DVGW worksheet W101; DVGW, 1995) and drinking water dam protection areas (DVGW worksheet W102; DVGW, 2002).

Figure 2 summarises the general structure of the drinking water protection areas for both cases, groundwater and dam based drinking water abstraction systems. In both cases, the whole catchment area is divided into three zones, from which zone III encompasses the whole catchment area, and zone I is located directly around the well (in case of groundwater) respectively the reservoir (in case of a dam). Determination, aims and regulations how to use the area (partly) differ.

4.1 Groundwater protection areas

In case of groundwater protection, the water protection area covers the whole catchment area (both, surface and subsurface catchment area). The potential sources of danger according to the type, location, duration and the characteristics of the subsurface are considered for structuring a water protection area into water protection zones for which different reasonable usage restrictions are defined. While the zones II and III are marked by appropriate signs, zone I is protected against unauthorized entry, e.g., by fencing.

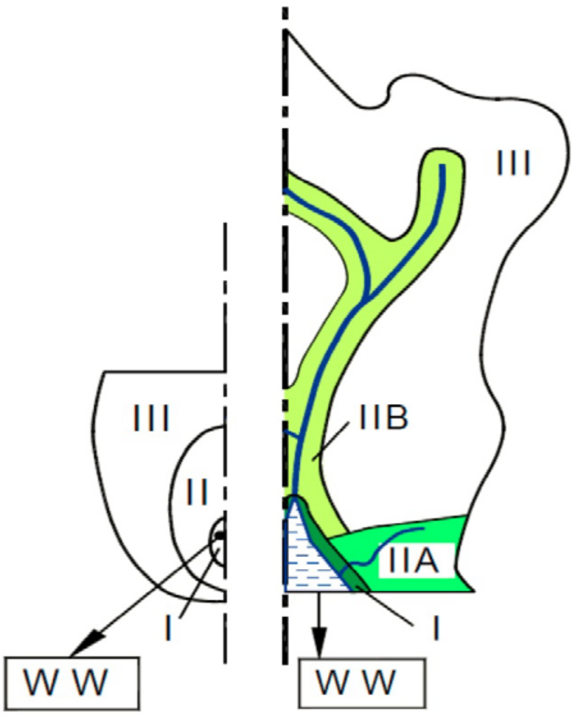

Figure 2: Zoning approach within the drinking water protection areas: comparison of groundwater protection areas (left) against drinking water reservoirs (dam; right). I, II, III: Protection zones; WW: Water works. Source: Aggerverband (Gummersbach).

Zone I is the direct protection area around the groundwater wells. It covers a radius of at least 10 meters around the wells (up to 50 m). It aims at the protection of the drinking water production facility and its immediate surrounding against any pollution and adverse effects. Exemplary hazardous activities forbidden according to DVGW (1995) are:

- *Any trespassing,*
- *Application of fertilizers and pesticides,*
- *Agricultural and forestry utilization or horticultural utilization,*
- *All activities, facilities and processes mentioned for zone III and II.*

Zone II is the closer protection zone. It aims at the protection against pollution caused by pathogenic micro-organisms as well as against other adverse effects. It is therefore defined by a minimum travel time in the saturated zone of 50 days ('50 days line') ensuring that pathogenic microorganisms are restrained during the flow time in the saturated zone. Exemplary hazardous activities forbidden according to DVGW (1995) are:

- *Application of organic fertilizers and grazing,*
- *Construction and extension manure containers as well as of manure repositories or silage silos,*
- *Construction of roads, railway lines and other traffic installations (except for farm tracks and forest paths),*
- *Construction and expanding structural facilities for commercial and agricultural operations – including their change of use,*

- *Camping sites, sportsgrounds, cemeteries,*
- *Swimming in surface water bodies, discharging wastewater into surface water bodies,*
- *Mining, gravel-pits, blasting operations,*
- *Transport of substances hazardous to water, or radioactive substances,*
- *Storage of fuel oil and gas oil,*
- *All activities, facilities and processes mentioned for zone III.*

Zone III is the further protection zone, aiming at the protection against far-reaching impacts, e.g., against chemical or radioactive impurities which are persistent or not degradable. Zone III covers the entire catchment area. Exemplary hazardous activities forbidden according to DVGW (1995) are:

- *Application or use of pesticides,*
- *Industrial livestock farming,*
- *Application of sewage sludge, faecal sludge and waste compost,*
- *Application of synthetic and organic fertilizers (exception: time and meeting the demands),*
- *Sewer systems including rainwater overflow and purification reservoirs as well as central waste water treatment plants,*
- *Wastewater discharge in the subsurface including the infiltration of wastewater,*
- *Waste treatment plants and waste treatment dumps,*
- *Pipelines for the transportation of substances hazardous to waste,*
- *Areas for industry and producing trade,*
- *Airports,*
- *Nuclear reactors.*

4.2 Surface water (dams, barrages, reservoirs) protection areas

In contrast to groundwater resources, water resources stored in a drinking water reservoir are not protected by the unsaturated soil zone. There is a direct connection to the atmosphere and to surface runoff processes. Additionally, the water of the tributaries flows directly into the reservoir. The latter can be inhibited through the installation of pre-dams. Pre-dams retain sediment, reduce suspended load, eliminate nutrients and diminish the impact of microbes. However, the functions of the pre-dam do not replace the measures in the catchment area but provide additional, protective effects.

Due to the different elements, the zoning approach has to be adapted in comparison to the concept for groundwater protection zones. Comparable to the approach for groundwater protection, three zones cover the entire catchment area of the reservoir in order to provide a preventive protection of the water resources.

Zone I aims at the protection of the stored water against any negative impact especially in its immediate environment. Zone I covers the reservoir itself, pre-dams if present and the nearshore environment represented by 100m buffer zone in a horizontal projection. In this zone, only following actions are permitted according to DVGW (2002):

- *Operation and maintenance of the dam and its technical facilities, considering the necessary protection of water at the same time,*
- *Measures which serve the maintenance of the land cover within the buffer zone (mainly forest) as far as they subserve the water protection targets.*

Operation buildings have to be contructed out of zone I which has to be secured against unauthorized entry in an appropriate way.

Zone II aims at the protection of the storage lake and their tributaries against negative impacts which may cause from human activities and facilities. Depending on whether pre-dams are present or not, zone II can be divided into the subzones IIa and IIb. Zone IIa covers a further 100m buffer zone along zone I and a 100m buffer zone along all tributaries to the reservoir (main dam; both in horizontal projection). Zone IIb covers a buffer zone along all tributaries to the pre-dams (if present; in horizontal projection). Exemplary hazardous activities forbidden according to DVGW (2002) are:

- *Water sports,*
- *Traffic installations, building areas and structural facilities,*
- *Handling of substances hazardous to water,*
- *Campgrounds, sportsgrounds, allotments and cemeteries,*
- *Application of chemical and organic fertilizers,*
- *Access by farmed animals to water bodies,*
- *Earth movements and earth fills,*
- *Discharge of wastewater, and*
- *All actions which are prohibited in zone III.*

Zone III aims at the protection of the storage lake and their tributaries against far-reaching negative impacts from the entire catchment area. It therefore covers the remaining catchment area not covered by the zones I and II. Exemplary hazardous activities forbidden according to DVGW (2002) are:

- *Industrial and commercial areas,*
- *Airports and military sites,*
- *Handling of substances hazardous to water, petrol stations,*
- *Sewer system including rainwater retention purification basins, central wastewater treatment plants,*
- *Infiltration of wastewater discharge, disposal sites,*
- *Waste treatment plants and landfills,*

- *Building areas,*
- *Application of sewage sludge, faecal sludge and waste compost on agricultural area,*
- *Application of pesticides,*
- *Forest conversion as well as building operations which are appropriate to promote erosion and surface runoff,*
- *Quarrying for stones and sediments,*
- *Soil dewatering, and ploughing permanent grassland.*

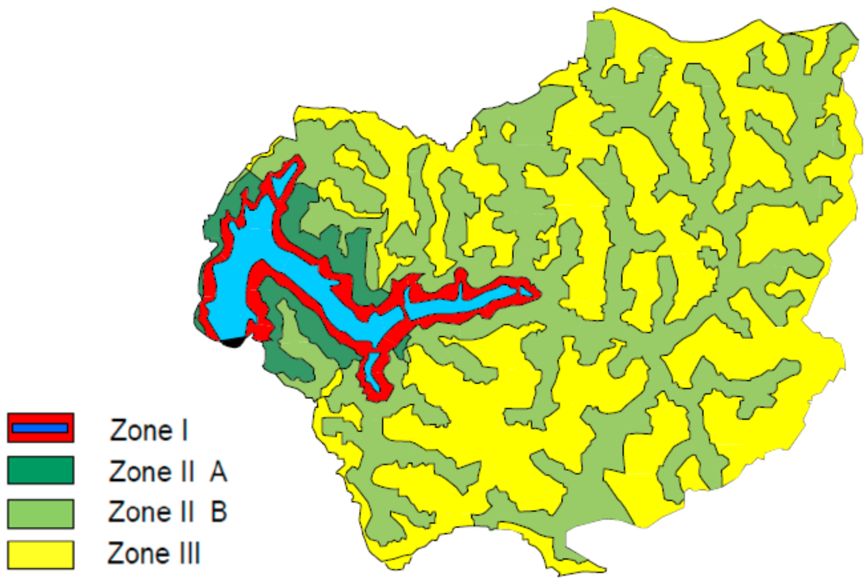

Figure 3: Zoning approach for the catchments of drinking water reservoirs (dam). Protection zones: I (red), II (green), III (yellow). Source: Aggerverband (Gummersbach).

Obviously, the riparian strips (buffer zones) play an important role in the zoning concept. They (dis-)connect the water body with the adjacent area, and they are an essential part of the multiple barrier system. Hence, many water suppliers aim at buying this area in order to be able to control the land use and any action in that area.

5 Additional tools

There are additional, optional measures to improve the efficiency of the multi-barrier system. Floating oil barriers, mostly in the pre-dams, can prevent the reservoir itself in case of damage against harmful substances.

Voluntary cooperation between water supply companies and agriculture can significantly reduce the amount of applied fertilizers and therefore the nutrient flow towards water bodies by percolation (leaching) and particulate transport (erosion, sediment transport). Permanent plant coverage of the soil (e.g., intertillage) reduces both, leaching and erosion by nutrient uptake and soil consolidation. Profit cuts should be compensated by the water supply companies in order to increase the attractiveness of such preserving land practices.

Within pilot studies, several German water suppliers undertake pilot projects in coorperation with farmers to install organic farming systems in groundwater protection areas. Inter alia, organic farming is characterized by closed nutrient cycles, abdication of pecticides and restricted use of mineral fertilizers. Such measures reduce the amount of fertilizers, optimize the efficiency of nutrient uptake by crops and thereby reduce the nutrient discharge in terms of leaching.

Setting up new water protection areas in at least partly developed catchments is a big challenge since on the one hand the guidance should be followed as far as possible with regard to restrictions of usage. But, on the other hand, not all activities in the respective catchment can be given up, which would induce economic and social consequences. For such case reasonable compromise is needed, combining an economically and ecologically promising use of the land surface and a sustainable use of the water resources.

Last but not least, a consequent monitoring system in the protection areas is a basic prerequisite for fast and consequent action. The European Water Framework Directive (EC, 2000) requires a systematic monitoring of dams (which can be interpreted as heavily modified sections of flowing water bodies) with respect to biological and physic-chemical quality components. In addition to the EC-WFD, monitoring of the raw and drinking water in Germany is carried out on the basis of the national law on the prevention and control of infectious diseases as well as on the Drinking Water Ordinace (TrinkwV, 2001) and the water law of the federal states (§ 50 in case of Northrhine-Westfalia). The results of the monitoring of raw and drinking water are submitted to the responsible authority on an annual basis and published in the annual report on drinking water (“Trinkwasserbericht”).

6 Conclusions

In the framework of the multi-barrier system, drinking water protection areas are essential and pro-active instruments for ensuring (or even improving) a good water quality. Prevention instead of reaction reduces the effort for water treatment and stabilizes the water price. Of course, implementing and operating drinking water protection areas involves restrictions concerning agricultuture, urban and economic development. However, such restrictions also offer economic possibilities, for example in terms of organic farming. The market for ecologically produced food has increased significantly in the last decade, going along with an increasing awareness of the population with respect to value of healthy food and sustainable production systems. In every case, an intense dialogue with stakeholders is meaningful for setting up drinking water protection areas as well as for improving the management of drinking water protection areas.

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Tools for water quality management at the catchment scale: Geostatistics and erosion modelling

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Abstract

This paper gives an introduction into useful tools for water quality management at the catchment scale: geostatistical analysis and interpolation as well as erosion modeling. Geostatistical methods are basic tools for analyzing spatial dependence of catchment properties, state variables or fluxes. They can be used for spatial data analysis, estimation of values at unknown locations and interpolation, based on the knowledge on the spatio-statistical properties of the interpolated quantities. Considering information on spatial characteristics, geostatistical methods generally achieves a more realistic representation of spatial patterns within catchments. Mathematical models try to approximate processes at different scales based on available spatial data and time series. Erosion models models are essential tools in the field of water quality management in agriculturally used areas. Since many different models are available, the selection and application of a suitable model requires the knowledge on the processes represented by a model, the equations behind and the data requirements. This paper attempts to introduce the basic ideas behind geostatistical methods and to structure state-of-the-art erosion models in terms of their characteristics, process representation and data requirements.

Keywords: *geostatstics, spatial interpolation, erosion modeling, model types, spatiotemporal scales*

1 Introduction

Extension and intensification of agriculturally used areas as well as recent water quality problems in many regions of the world require a reliable prediction of hydrological and erosion processes at the catchment scale. For example, model based impact analyses are needed to quantify the impacts of climate and land use change impacts as fundamental basis for watershed management. While hydrological models primarily deliver essential information for water quantity management, erosion models may provide important knowledge in terms of soil loss and the impact on surface water quality, affecting both soil productivity (on-site effects) and ecological conditions of aquatic ecosystems (off-site effects). Since many different models for watershed hydrology and sediment processes are available, the question arises which model is suitable for what modeling purpose and in a specific environment?

Another challenge is the optimum exploitation of available information, which is sparse in many regions, in developing and newly industrialising countries in particular. Data are essential for both, the identification and the analysis of spatial patterns as well as providing data input for hydrological and erosion modeling. Geostatistical methods try to make use of the spatial characteristics of available data sets. They are based on the analysis of spatial statistics of the data base instead of non-statistical interpolation such as Thiessen polygons, inverse distance, triangulation or spline functions which suffer the disadvantage of non-statistical interpolation algorithms. *Such algotithms do not know anything about the target variable*.

This paper attempts to introduce the basic ideas behind geostatistical methods and to structure state-of-the-art erosion models in terms of their characteristics, process representation and data requirements.

2 Geostatistics

Geostatistics is a specific field of statistics focusing on spatial (or spatiotemporal) datasets. Developed originally to predict probability distributions of ore grades for mining operations (see history of geostatistics), it is currently applied in many different disciplines, in particular in geosciences.

Geostatistics is intimately related to interpolation methods, but extends far beyond simple interpolation problems. The main fields of application of geostastical techniques are

- *Spatial data analysis, description of spatial structures, e.g., in terms of optimization of observational networks,*
- *Estimation of variables at locations without observations by interpolation (e.g., by Kriging), regionalization and mapping of variables,*
- *Data preparation for model application, e.g., spatially distributed model parameters.*

Geostatistics is based on the theory of regionalized variables. The main challenge is to determine the spatial correlation of a random variable Z and the value of the variable for unobserved locations. Geostatistics aims at the estimation of values of a spatially dependent variable at any location – where no observations are available – based on neighbored observations.

2.1 History of geostatistics

The Gold mining in Natal (South Africa) end of 19th century was the origin of Geostatics. The main question was how to gather the spatial distribution of an investigated substance based on spatially distributed observations? And, secondly, are ore deposits exploitable?

From a geostatstical point of view, the question could also be formulated as follows: How to estimate the value of a position dependent variable $Z^*(u)$ at a place u (where no observations are available) based on neighbored observations $z(u_i)$ and the corresponding weights λ_i?

Daniel Gerhardus Krige, a South African Mining Engineer, pioneered the field of geostatistics (Krige, 1951). The technique of kriging is named after him. Krige's empirical work to evaluate mineral resources was formalised in the 1960s by the French engineer Georges Matheron (Matheron, 1962).

2.2 Main principles of geostatistics

The main steps of geostatistical analyses are (1) observation, (2) statistical data analysis, (3) analysis of variance, (4) interpolation and (5) evaluation/error analysis.

The challenge of main field investigations is that maximum one observation per location is available, which means that there are no repetitions for statistical analysis available. Hence, there is only one value available to estimate random variables, and one realization to estimate random functions. A possible solution to this problem might be to substitute missing observations at one location by observation from other locations. This requires assumptions on the probability structure of a spatially distributed random variable. The main geoststistical hypotheses are:

- *Strict stationarity: The random function is independent on the location;*
- *Weak stationarity: The expected value is constant over space while the covariance depends on the distance vector but not on the location;*
- *Intrinsic hypothesis: The expected value is constant over the whole space; the (semi)variance of the increment between two locations only depends on the distance vector but not in the location itself; the knowledge of (semi)variogram is sufficient for describing the correlation.*

2.3 Variogram analysis

The (semi)variogram is the statistical description of the spatial correlation of a random function:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} (z(u_i) - z(u_{i+h}))^2 \qquad (1)$$

Where γ(h): semi-variance, N(h): Number of pairs with distance h, h: distance interval and $z(u_i)$: observation at location u_i. The variogram therefore describes the dependence of the variability within a spatially distributed sample on the distance between sample locations. It is assumed that the variance increases with distance between two locations while the covariance decreases. The variogram is the key function in geostatistics as it is used to fit a model of the temporal/spatial correlation of the observed phenomenon. The experimental (empirical) variogram is based on a sample separated by discrete distances. In case of a regular grid, the experimental variogram can be generated using variance of exact distances between pairs. In case of irregular sampling schemes distance classes are defined consisting pairs with similar distances (and directions in case of anisotropic behavior). As a rule of thumb, distance classes should consist of at lease 30 pairs. Variograms generally show a monotonically increasing variance with increasing distance between pairs. The general behavior is described by the following properties (Figure 1):

- *Sill: A threshold value of the distance dependent variance within a sample.*
- *Range: The maximum distance of auto-correlation within a sample.*
- *Nugget effect: Variance unequal to zero for a distance of zero.*

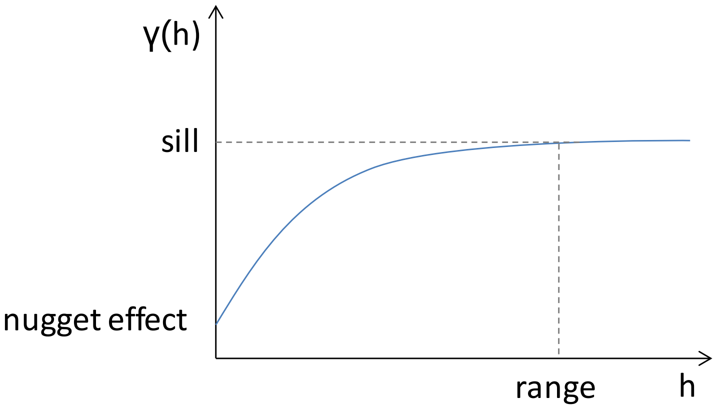

Figure 1: Variogram properties: Monotonically increasing variance, sill, range and nugget effect.

The theoretical variogram is an approximation of an experimental (empirical) variogram. Different theoretical variogram functions resp. models are available. They can be classified into two groups of models which fulfill (or not) second order stationarity. This can be interpreted in a way that the models include a sill value or not. Some of those models are: linear, spherical, exponential and Gaussian variograms whose equations are shown below (equations 2 to 5).

Linear variogram:

$$\begin{aligned} \gamma(h) &= C_0 + \left(\frac{C - C_0}{a}\right) \cdot h \qquad \text{for} \quad h \le a \\ \gamma(h) &= C + C_0 \qquad \text{for} \quad h > a \end{aligned} \qquad (2)$$

Spherical variogram:

$$\begin{aligned} \gamma(h) &= C_0 + (C - C_0) \cdot \left(1.5\frac{h}{a} - 0.5\frac{h^3}{a^3}\right) \qquad \text{for} \quad h \le a \\ \gamma(h) &= C + C_0 \qquad \text{for} \quad h > a \end{aligned} \qquad (3)$$

Exponential variogram:

$$\begin{aligned} \gamma(h) &= C_0 + (C - C_0) \cdot \left(1 - e^{\frac{-h}{a}}\right) \qquad \text{theoretical range} \\ \gamma(h) &= C_0 + (C - C_0) \cdot \left(1 - e^{\frac{-h}{a}}\right) \qquad \text{effective range} \end{aligned} \qquad (4)$$

Gaussian variogram:

$$\begin{aligned} \gamma(h) &= C_0 + (C - C_0) \cdot \left(1 - e^{-\frac{h^2}{a^2}}\right) \qquad \text{theoretical range} \\ \gamma(h) &= C_0 + (C - C_0) \cdot \left(1 - e^{-3\left(\frac{h}{a}\right)^2}\right) \qquad \text{effective range} \end{aligned} \qquad (5)$$

Where $\gamma(h)$ = (semi)variance, C_0 = nugget, $(C + C_0)$ = sill, a = range, h = distance. Further properties of empirical variograms can be:

- *Anisotropy: Properties (range, sill) are direction dependent. This can induce zonal and/or geometrical differences which require the calculation of different variograms for different directions.*
- *Drift: In case of drift the sill value is not reached based on the available sample. One explanation can be that the expected value is not constant over the area of interest.*
- *Hole effect: In case of a hole effect the variogram shows regular structures of increasing and subsequent decreasing variance. Such effects can for example be caused by regular subsurface layering in case of vertical substrate variograms.*

2.4 Kriging

Kriging provides an answer to the question how to estimate the value of the spatially dependent variable Z(u) at location u (no observations available) based on neighbored observations. The main idea behind Kriging is to build the weighted average of the neighbored locations. The remaing question is how to determine the weights?

The task of Kriging is to achieve an unbiased estimation and an optimization procedure (minimization of estimation errors) based on the available information, namely observational data and the variogram model derived from the data. The challenge consists of determining the weights in order to minimize the error variance (equation 6) while the sum of the weights remains 1. This can be achieved by solving equation 6 by calculating the partial derivatives with respect to the weights. The problem of the over-determined system of equations can be overcome by introducing the Lagrange multiplyer, resulting in a system of linear equations.

$$s^2(u) = Var[Z(u) - Z^*(u)] = -\sum_{j=1}^{n}\sum_{i=1}^{n}\lambda_i\lambda_j\gamma(u_i - u_j) + 2\sum_{i=1}^{n}\lambda_i\gamma(u_i - u) \qquad (6)$$

Important characteristics of interpolation by Kriging are the following:

- *Kriging is an exact interpolator: The estimated value equals the observed values at the observation locations;*
- *The weights are determined based on the variogram, the locations of the observations and locations to be estimated;*
- *Negative weights are feasible;*
- *Weights are independent of the observational values;*
- *Distant locations obtain smaller weights (if less distant observations are available);*
- *Clustered observations obtain smaller weights, as well.*

A virtual optimization of a network is feasible without any observations. Applying the intrinsic hypothesis, the estimated variance can be calculated based on the variogram. Selecting the weights in such a way resulting in an estimated variance of zero, the equation reduces to the Krige variance which does no longer contain any information on the observations.

Interpolation quality can be tested by cross-validation. Iterative removal of observational locations followed by an interpolation of that location enables the evaluation of interpolation quality. Jack-knifing splits of all observational values (locations) into two groups A and B. Using one subgroup for the interpolation of the remaining subgroup again enables the assessment of interpolation quality.

Alternative Kriging methods are:

- *Ordinary Kriging: The search radius is not known but constant;*
- *Simple Kriging: The search radius can vary but must be known;*

2.5 Nonstationary Kriging

External drift Kriging is a transient Kriging method which tries to explain a spatial trend in the sample by an auxiliary variable (not allowed according to the intrinsic hypothesis). Generally, a linear relation between the target variable and the auxiliary variable is assumed. Such external information must be available for each observational location as well as for each location to be estimated.

Examples for the application of external drift Kriging are the interpolation of temperature and precipitation in mountainous terrain. It is well known that both temperature and precipitation are well correlated with topography. External drift Krigin can consider such dependence as part of interpolating those variables. Another example is the use of information on elevation for the estimation of the groundwater surface (groundwater levels).

2.6 Indicator Kriging

A method for the interpolation of categorical variables (e.g., geological layers, soil horizons) is the indicator Kriging. The approach assigns numbers to categories (classes) which can then be used for Ordinary Kriging. The estimation of error variance is also comparable to Ordinary Kriging. One problem is that generally smoothed surfaces are obtained. This might be unrealistic for selected applications. One possible solution is the approach to perform geostatistic simulations, comparable to Monte-Carlo studies. The aim is to obtain different (equally possible) realizations of the subsurface. Based on those different realizations, statistics can be calculated on the simulations as well as uncertainty measures. Doing so, useful information for groundwater flow modeling can be obtained.

3 Erosion modelling

According to ASCE (American Society of Civil Engineers), erosion is a process of detachment and transportation of soil materials by erosive agents, caused by wind (wind erosion), rainfall (rainfall erosion) or runoff (runoff erosion). In this paper the focus is set on rainfall-runoff induced erosion processes. This includes processes such as raindrop erosion (soil detachment due to shear stresses), the impact of unconcentrated flow (sheet erosion), concentrated flow processes in rills (rill erosion) and gullies (gully erosion) as well as channel processes (channel/in-stream erosion). Depending on which processes are active on a hillslope or in a catchment of interest, an appropriate erosion model should be able to represent those processes. In addition to erosion processes, different movement modes of sediment can be distinguished according to Aksoy and Kavvas (2005), depending on the flow velocity and the related shear forces: Erosion, transport and deposition.

3.1 Model types

Different (mathematical) model types are available for the description of water transport and erosion processes. Those types distinguish between presence or absence of random influencing factors, the degree of causality, the spatial distribution of properties and processes as well as spatial and temporal scale.

Deterministic models are characterized by the fact that a given model set-up (combination of forcing, process description and parameterization) induces a well defined simulation result (fluxes, state variables). A repetition will exactly calculate the same result as the initial simulation. In contrast, stochastic models include random functions in the process description resulting in varying results (fluxes, state variables) which however reproduce a well defined distribution function determined by the nature of the random components. Most available erosion models are of a deterministic nature while some of them include random functions for example to describe the small-scale spatial variability in soil properties which cannot described in a deterministic way due to missing information.

With respect to the degree of causality, according to Merritt et al. (2003), following three major model types can be distinguished: Empirical, conceptual and physically based models. While empirical models – which are based on the analysis of observations – include the most simple process descriptions, model complexity increases with conceptual and physically based models. However, there is no sharp but only a subjective distinction between these model types. A general description on model typ characteristics is provided by Table 1.

However, it can be assumed that each model serves a purpose in practice, as argued by different authors:

- *Thorsen et al. (2001) argue that physics based models show stronger predictive capabilities;*
- *According to Perrin et al. (2001), over-parameterisation may prevent models from reaching their potential performance level; they infer that simple models mostly show a more robust behaviour;*
- *In general, it can be assumed that complex models are characterized by a high degree of uncertainty associated with model inputs which are transferred to model outputs. Such behavior compensates the advantage of more realistic process descriptions;*
- *Steefel and van Cappellan (1998) argue that model's simplicity against its explanatory power is the ultimate factor determining a model's value. Therefore, model selection should be made carefully.*

- *Grayson and Blöschl (2000) pronounce that an appropriate balance between model complexity and data availability is required. While complex models may run into identifiability problems in case of poor data availability, simple models are often unable to exploit large data availability.*

Table 1: General characteristics of different model types differing in the degree of causality.

Model type	Characteristics	Criticism
Empirical	Simplest of all available model types Characterizing the response based on available data Small computational and data requirements Small number of causal variables Parameter calibration / transfer from experimental sites	Unrealistic (physical) assumptions Ignoring heterogeneity, non-linearities Tendency not to be event-responsive Ignoring rainfall-runoff process
Conceptual	Storage based process representation General description of catchment processes Indication of change effects feasible	Lumping of representative processes Calibration of parameters (risk of overfitting) Limited physical interpretability
Physically based	Based on fundamental physical equations: conservation of mass and momentum for flow, conservation of mass for sediments Measurable model parameters (at least in theory, depending on scale)	Necessary calibration of many parameters against data Discrepancy between scale of model development (small scale) and model application (catchment scale) Questionable lumping of small scale physics

Concerning the degree representation of spatial variability represented by a model, spatially lumped and spatially distributed models can be distinguished. While spatially lumped models represent the entire simulation space as one computational unit, spatially distributed models subdivide the simulation space into several conputational units. Sediment transport modelling is only meaningful by applying distributed models, e.g., discretizing the landscape into grid cells, representative hillslopes or subcatchments in order to be able to distinguish between source areas, transport dominated areas and sedimentation areas.

Finally, sediment transport models can be differentiated in terms of spatial and temporal scale. With respect to spatial scale, erosion models focus on (small) catchments, hillslopes, fields and plots. With respect to time scale, models can be run in a time continuous mode or in an event-based mode, representing just one rainfall-runoff resp. erosion event.

The choice of an adequate model generally depends on the processes which the modeler intends to get represented by the model. For example, river erosion processes are generally not considered by hillslope scale models, and geological processes cannot be represented by event based model simulations.

3.2 Model intercomparison (types, processes)

A comparison of available state-of-the-art sediment transport models has been published by Merrit et al. (2003). Table 2 summarises their results in terms of degree of causality, spatial scale and represented processes.

Table 2: Comparison of standard erosion models based on Merrit et al. (2003); G = sediment generation, T = sediment transport, D = deposition of sediment.

Erosion model	Model type	Scale	Rainfall runoff	Land surface	Gully erosion	In stream erosion	Reference
AGNPS	conceptual	catchment	yes	G	yes	G, T, D	Young et al., 1987
ANSWERS	physical	catchment	yes	G, T, D	no	no	Beasley et al., 1980
CREAMS	physical	field	yes	G, T, D	yes	no	Knisel, 1980
EMSS	conceptual	catchment	yes	no	no	G, T, D	Vertessey et al., 2001
GUEST	physical	plot	yes	G, T, D	no	no	Yu et al., 1997
HSPF	conceptual	catchment	yes	G, T, D	yes	G, T, D	Johanson et al., 1980
IHACRES-WQ	empirical/ conceptual	catchment	yes	no	no	G, T, D	Jakeman et al., 1990
IQQM	conceptual	catchment	yes	no	no	no	DLWC, 1995
LASCAM	conceptual	catchment	yes	G	no	G, T, D	Viney and Sivapalan, 1999
LISEM	physical	catchment	yes	G	no	G, T, D	Takken et al., 1999
MIKE-11	physical	catchment	yes	G, T, D	no	G, T, D	Hanley et al., 1998
PERFECT	physical	field	yes	G	no	no	Littleboy et al, 1992
SEDNET	empirical/ conceptual	catchment	yes	G	yes	G, T, D	Prosser et al., 2001
SWRRB	conceptual	catchment	yes	no	no	G, T, D	USEPA, 1994
TOPOG	physical	hillslope	yes	G, T, D	no	no	Gutteridge Haskins and Davey, 1991
USLE	empirical	hillslope	no	G	no	no	Wischmeier and Smith, 1978
WEPP	physical	hillslope/ catchment	yes	G, T, D	no	G, T, D	Laflen et al., 1991

The overview shows that that a broad spectrum of combinations of model type, scale and processes is available. As to be expected, data requirements differ substantially among all those models. In general, data must describe the influencing factors of the erosion, transport and deposition processes: climate, topography, soil, vegetation, anthropogenic activities. In general, the more complex the model, the more data required (Aksoy and Kavvas, 2005).

Finally, the question arises which model, where and when to be applied:

- *The answer to this question can only be determined in relation to a precisely asked model's user's research question (study aim).*
- *The choice of the model strongly depends on the processes that require explicit representation for a given catchment or hillslope.*
- *The choice depends on the adequate spatio-temporal resolution related to the aim of the modeling task.*
- *General requirements for an appropriate model selection are (1) the suitability of the model to local the catchment conditions, (2) the data requirements in relation to the data availability, model complexity and the required accuracy of the simulation results, (3) the validity of the model for a given case (adequate model assumptions), (4) the representation of the spatial and temporal variation of properties and processes and finally (5) the congruency of model components and objectives of the model user(s).*

4 Conclusions

Two useful tools have been introduced in this paper, geostatistical methods for data interpolation and erosion modeling as helpful tool for land use and water quality management.

Geostatistical methods are helpful tools for data analysis, interpolation and optimization. Interpolation is carried out based on spatial correlation (instead of non-statistical methods), making use of the spatial statistical characteristics of the target variable. Geostatistics provides possibilities for quality estimation and alternative methods based on data characteristics (transient behavior, categoric variables). However, applying such a sophisticated technique cannot improve the data set itself or even replace data gathering. Better data in terms of resolution and accuracy could enable a more realistic interpolation even based on simpler interpolation algorithms.

Erosion modeling is a useful tool for assessing erosion risk areas as well as quantifying sediment yields. However, there is a lack of data in many parts of the world which make it difficult to drive and calibrate erosion models in a reasonable manner. Depending on the local properties, processes and available data, the user has to select an appropriate model. Thus, the success of model application strongly depends on the user's experience. There is a need to invest in both, improved data gathering and further model development in combination with an ongoing accuracy and sensitivity assessment.

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The role of the soil in water protection in rural areas

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Abstract

Currently, water scarcity is already a reality in many parts of the world. The situation may worsen in future mainly because of population pressures resulting in increased demand for water resources, and the future seems bleak to meet water demand in an environmentally friendly and sustainable manner. Therefore, the challenges to mitigate water scarcity require global effort and joint action to ensure that ecosystems continue to perform their ecological functions of water supply at acceptable quantity and quality. In this scenario, the soil becomes an important tool for the protection of both surface and groundwater and in the removal or retention of potential contaminants. To achieve these, it is necessary to adopt the appropriate soil use and management techniques that stipulate more sustainable agriculture such as reduction in the use of agrochemicals, proper waste generation and disposal, and maintenance or restoration of riparian vegetation. Thus, the potential risk of surface and groundwater contaminations will dramatically reduce and socio-economic welfare will be maximized without compromising the sustainability of vital ecosystems necessary for future generations.

Keywords: *Blue water; green water; soil management; soil properties; water pollutants.*

1 Introduction

In the 1950s, water scarcity was a problem for many nations. However, during the 20th century the world's population has tripled, and water use by man has increased six folds as lack of fresh water became evident in several countries (Mc Cutcheon et al., 1993). Currently and since the early 21st century, some 30 countries with a population of over 400 million people suffer from water scarcity (Vörösmarty et al., 2000). Future predictions indicate that 66 countries, about two-thirds of the world population will face moderate to severe water shortages by 2050 due to the increase of world population (United Nations, 2003). Water consumption will increase sharply, unlike the supply, which is fixed (Oki and Kanae, 2006), thus necessitating the performance of specific policies to meet the demands of humanity and protection of the environment which, together with the energy issue, will be the major challenges of the 21st century (Vörösmarty et al., 2000).

Currently, some developed countries are undergoing improvements over the management of water resources, and each year there is an increase in the number of people with access to basic sanitation (United Nations, 2003). However, this is not the reality in many places, since most of the world population, one in five has no access to potable water, half have no access to sewage collection systems, and frighteningly, each year, approximately five million people die from waterborne diseases, equivalent to the current population of Finland (World Health Organization, 2011). The agricultural sector, in turn, faces complex challenge: producing more and better quality food, using less water per unit of production by applying clean technologies that ensure environmental sustainability and contribute to the local and national economy, seeking to mitigate concern of global food security in the near future (Rockström et al., 2009). Thus, water scarcity poses challenges to the expansion of agriculture and food production, ecosystem health, social and political stability, requiring new approaches to water use and management especially with the projected global population growth, indicating that water consumption and the pressures on freshwater reserves are increasing (Hering and Ingold, 2012).

In light of these trends, one glimpses a future that will be difficult to meet water demand in a sustainable and environmentally manner if strategies are not designed for resource management, which is currently in deficit and already produces physical evidence of unsustainable use of groundwater, because in some cases the extraction has exceeded the limits of aquifer recharge, resulting in overexploitation of groundwater to meet demands (Oki and Kanae, 2006). Therefore, it is evident that there is a second water crisis, not the quantity, but the use and management of water resources which characterize many developing countries, including Brazil, where the concern for the quality and potential contamination of the groundwater is a national issue. In this context, the understanding and comprehension of the role of soil in the removal and retention of potential contaminants becomes an important point for the protection of both surface and groundwater.

2 Blue and green water: water for all purposes?

The concept of green water was first introduced by Falkenmark (1995), referring to the total evaporation during the crop growing season. Green water is the soil moisture used by plants and returned to the atmosphere through evaporation and transpiration (evapotranspiration). It is the supplement of water for all non-irrigated vegetation, whose availability depends largely on how water is managed in the soil (Liu et al., 2009). Green water is said to be productive when it contributes to crop production (if transpired through grains, leaves, stems, trees or natural vegetation), or non-productive (when evaporated directly from the ground or an open water surface). Typically, there has been little consideration about green water flow in agriculture, however, recently green water has been generally used to refer to water that comes from the precipitation, stored in the soil and subsequently released to the atmosphere through evaporation of culture (Siebert and Döll, 2010).

On the other hand, blue water refers to water in rivers, lakes, reservoirs, lakes and aquifers that are not readily available for plant growth. However, for food production systems, both green and blue water are extremely important. Rained agriculture, for example, uses only the green water; however, irrigated agriculture uses both green and blue water. Irrigation employs blue water because it is the one used in the creeks, rivers and underground and except that it has to be extracted (Rost et al., 2008). Thus, blue water allows crop cultivation and food production in areas without water reserves sufficient to meet the green water needs of a particular culture, which in this case will be supplied by irrigation (Siebert and Döll, 2010).

The distinction between green and blue water helps to understand the relationship between precipitation, soil, soil productivity and water availability for human use (Rost et al., 2008). Thus, it follows that adequate soil management has a direct influence on both green and blue water, for examples: facilitated infiltration, reduced runoff and water retention in soil pores increases the fraction of productive green water and, moreover, part of the infiltrated water will percolate to subsurface reservoirs which in turn feed rivers and lakes, and in turn, part may be available to the plants through irrigation (Siebert and Doll, 2010). Thus, it is necessary that a set of integrated practices and management techniques of green and blue water are implemented such as: maintenance of soil cover, use of conservation tillage, increased infiltration of rain water by planting in contour among others, aimed at converting the non-productive green water flow into productive green water through activities that take into account adequate soil management and sustainable irrigation practices (Rost et al., 2008).

However, in arid climates and countries with little rainfall, the situation becomes more delicate, since rainfall is scarce and volume limited. Currently, in these countries, an increasing amount of food is imported to meet the domestic demand (Rockström et al., 2009) and food imports are approximately equivalent to importing water, otherwise known as virtual water, to mitigate the lack of physical resource for food production in the countries concerned. Thus, arose in the mid 1990s, the concept of virtual water, which specifically addresses the connection from the perspective of food trade as a means of redistribution of global water resources and as a possible policy option in the management of local water resources, especially in countries facing water scarcity (Rockström et al., 2009).

Currently, it is estimated that a huge volume of virtual water transcends all the boundaries across the globe. The amount of virtual water exported will be proportional to the volume of water resources used in the manufacturing process so that certain food product may be exported fresh or processed after undergoing industrial processes, resulting in this case an additional consumption of water. With the ever-increasing population growth and economic development, water resources are threatened and in increasing number of countries (Rost et al., 2008). Thus, from the understanding of the relationship between water consumption by agricultural sector in one country and the other, it will be possible to predict and sustain the populations in countries with limited water resources. This shows the comparative importance of virtual water trade and making clear the need for appropriate policies for proper water resources management, particularly in countries with large reserves of fresh water, which can be distributed virtually and remedy the shortages in other nations.

3 Soil characteristics, properties and processes important for water contamination

3.1 Depth

Soil depth from the surface to the groundwater table is an important parameter primarily because it gives the volume of soil through which a pollutant must travel before reaching the aquifer. Also, it determines the time that a contaminant or chemical constituent is in contact with the soil mass. Where the soil is fairly deep, processes such as filtration, sorption, biodegradation, and volatilization operate effectively, thereby protecting both the surface water and groundwater bodies. On the other hand, shallow soils can absorb only a limited amount of pollutants while others are leached. The degree pollution increases where the soils are relatively thin and the underlying bedrock is completely permeable or where the water table is very near the soil surface (Porter and Stimmann, 1988). That is, if the underlying bedrock is impermeable, the surface water receives the pollutants especially when the soil is saturated and water reaches the rivers or streams through interflow during heavy storms.

3.2 Soil texture

The relative proportions of sand, silt, and clay affect all processes that govern the movement of water through the soil (Gardner, 2012), and therefore, the translocation of soil nutrients and dissolved chemicals such as pesticides (Feza, 2011). According to Gardner (2012), soils, in general, may be coarse- or fine- textured. Coarse-textured soils contain more sand particles, large pores and are highly permeable. They have high infiltration capacities and water tends to percolate easily through the soil rather than overland flow or be adsorbed to soil particle surfaces. Therefore, coarse-textured soils generally have high potential for leaching of pesticides and other agro-toxics to groundwater but low potential for surface loss to streams and lakes. On the other hand, fine-textured soils such as clays and clay loams generally are characterized by low infiltration capacities because they are more microporous. As a result of low infiltration rates, runoff predominates rather than percolation during saturation conditions and heavy storms. Soils high in clay and organic matter contents also have higher specific surface area. This creates more sites for adsorption of pesticides and higher populations of microorganisms to breakdown pesticides. Therefore, fine-textured soils pose low pesticides leaching potential to groundwater but high potential for pesticide surface water bodies under saturation conditions. Soil permeability is a measure of how fast water can move downward through a particular soil profile or section and can typically be inferred from soil texture. Permeable soils are susceptible to leaching since water moves quickly through the macropores, As such, these soils may directly lose dissolved chemicals with the percolating water. Thus, fast-draining soils such as sands and sandy loams are highly susceptible to leaching and hence contamination of groundwater during recharge (Hairston, 1995; Mahler et al., 1997; Jiang and Wan, 2009; Köhne et al., 2009). Soils containing large proportions of clay have low permeability because of loss of transmission pores, thus slow-draining clays and silty clays have the greatest runoff potential.

3.3 pH

Soil pH generally refers to the degree of acidity or alkalinity of the soil. At very high acid or alkaline pH levels, organic matter mineralization is inhibited or stopped because of poor microbial activity linked to bacteria. Nitrification and nitrogen fixation are also slowed down by low pH. The mobility and degradation of herbicides and insecticides, and the solubility of heavy metals are all pH dependent. The effects of soil pH on cation availability influence the aggregate stability since multivalent cations, such as calcium ions, act as bridges between organic colloids and clays (Smith and Doran, 1996). Clay minerals, oxides of iron and aluminum and organic matter have surface charge that is pH dependent. Thus, modification of pH alters the balance of the positive and negative charges.

In tropical soils, oxides exercise a great influence on the bioavailability of trace elements. The adsorption of these metals to the oxides can occur by means of formation of covalent bonding with OH^- or O^{2-} on the surface of these colloids. When the pH is less than the zero point of charge (ZPC), there is the predominant of positive charges, and the adsorption of anions is favored. Conversely, if the pH is above the ZPC, there will be predominantly negative charges and adsorption of cations will be favored. Hence, modification of pH directly affects the characteristics of the minerals and organic components of the solid phase whose charges are pH dependent and which determine the reactivity of the functional groups. For instance, an increase in pH favors the adsorption of cadmium (Cd) by increase in negative charges in the solo, thus diminishing its bioavailability for pollution (Meurer, 2010).

The pH of the soil solution maintained at neutral to slightly alkaline condition showed low mobility of all heavy metals. To increase the mobility of heavy metals, the pH of the soil solution should be lowered. The solubility of Pb in soil solution increases as the pH is adjusted from 6 to 3. At near neutral pH, the activity of Pb^{2+} showed no clear relationship to pH and a small but significant increase resulting from changing organic matter content. In the near neutral pH range, higher soil organic matter (SOM) increases the dissolved organic matter (DOM), promoting the formation of organo-Pb complexes and increasing Pb solubility. In general, sorption increases with increasing pH. That is, the lower the pH value the more metal can be found in solution and thus more metal is mobilized. When pH falls to below 5, mobility is enhanced as a result of the increased proton concentration. At pH values above 7, some heavy metals tend to form hydroxyl-complexes which will increase the solubility of the metal in question (Meurer, 2010).

3.4 Organic matter

According to Gardner (2012), organic matter (OM) content is considered the single, most important soil property affecting pesticide breakdown by microorganisms. Organic matter in the soil provides more surface area for adsorption, increases the soil's water holding capacity and degrade pesticides, and nourishes microorganisms which reduce the leaching of pesticides and OM into groundwater. Soils high in organic matter pose low leaching potential because soil organic matter directly influences how much water a soil can hold and how well it will be able to adsorb fertilizer and pesticides and prevent their movement. In addition, high organic matter may reduce potential for surface loss by increasing the soils ability to absorb water and dissolved fertilizers and pesticides in the root zone where they will be available to plants. High organic matter also supports much of the microbial activity that decomposes pesticides (Feza, 2011). Although OM represent less than 5% of the components of the soil solid phase, it is responsible for around 30 – 65% of cation exchange capacity of the soil minerals. This occurs because the functional groups of OM can occur in the form of outer-sphere or inner-sphere complexes. However, the stability of the complex formed can determine its solubility in water, which can be soluble or insoluble. The formation of complexes with organic compound have effects on the mobility of metallic cations in the soil because most stable complexes are soluble, and with the combined effects of stability and solubility, can increase nutrient transport or toxic metals in the soil profile, favoring the contamination of both surface and groundwater (Meurer, 2010).

3.5 Cation exchange capacity (CEC)

The cation exchange capacity (CEC) is an important property of the soil. It is a measure of exchangeable bases and soil acidity at some specific soil pH. The exchangeable bases and acidity neutralize negative charges arising from charges due to isomorphic substitution in clays, or pH-dependent charges from hydroxyl groups on clay and oxides or carboxyl groups on soil organic matter (Sumner and Miller, 1996). The quantity and proportion of soil constituents determine the value of CEC. If the CEC value is low, not many molecules are able to bind (react) to the particle surface. If the number is high, a larger number of molecules can bind to the particle's surface. Sandy soils have low CEC values, however, the value increases as the soil contains more clay, silt and organic matter (Beuerlein, 2011). Soil developed under tropical and sub-tropical climates, are predominantly 1:1 clay minerals (Kaolinite) and high Fe and Al oxides contents, have low CEC (Meurer, 2010). When applying nutrients to low CEC soils, it is best to apply a little at a time otherwise one runs the risk of leaching them through the soil and into ground water, especially on seasonally high water table sites. When applying nutrients to clay soils, it is best to incorporate them due to their naturally sow infiltration rate otherwise, they are easily washed away in run-off water or leached to groundwater during high intensity rainfalls and contaminating water bodies (Beuerlein, 2011).

4 How the soil affects the toxicology of mainly groundwater pollutants?

4.1 Nitrogen

The implementation of agricultural practices that are incompatible with the land use potential and increased use of high doses of fertilizers and pesticides have made intensive agriculture, an activity with great potential contamination of water resources. Consequently, there is a reduction in water quality and a rapid decline in production capacity of the soil (Kaiser et al., 2010). Leaching of large amounts of nitrate and pesticides in agricultural areas constitutes a serious bottleneck and the presence of high concentrations of nitrate (Stigter, 2006), pesticide (Hildebrandt et al., 2008) or both (Silva et al., 2006) have been observed in groundwater from various regions of the world. However, the results of groundwater contamination by nitrates and pesticides are still incipient (Andrade and Stigter, 2009). Water with high levels of nitrate is unfit for use because of its potential toxicity and is therefore considered hazardous to human health. Levels above 10 mg L^{-1} of NO_3 in drinking water can bring serious health hazards and these levels are easily found in surface water and groundwater near areas with intensive agricultural production (Costa et al., 2002).

The high nitrate levels in both fresh and salt waters can result in serious problems to the environment, as they provide an accelerated growth of algae and eutrophication of waterways and reservoirs (Morgenstern and Daughney, 2012). High levels of nitrate contribute significantly to eutrophication in coastal and marine areas, where nitrogen is a limiting nutrient (Andrade and Stigter, 2009). In the soil solution, the high levels of mineral nitrogen are largely from the use of nitrogen fertilizers and organic fertilizers applied at the time of crops planting or coverage. When nitrate is leached into the soil profile below the root zone, the nutrient becomes a pollutant and provide negative impacts on water quality, in addition to becoming a diffuse source of groundwater contamination (Andrade and Stigter, 2009; Kaiser et al., 2010).

In agricultural systems, the concentration of nitrate in the soil solution may reduce with time, and this can be attributed to nitrogen absorption of the soil solution by growing cultures, microbial immobilization, denitrification and also losses by draining or leaching. The concentration of nitrogen in ammoniacal form is generally decreasing over time, for different management systems, due to absorption of part of the ammonia by growing plants and due to the nitrification process (Kaiser et al., 2010). Nitrification is a fast process and leads to a marked increase in concentration of nitrate in the soil (Paramasivam et al., 2000). Crops that produce low residue and accompanying soil disturbance and high porosity are limiting the denitrification and thus leaching may be the main target of nitrate not used by crops (Kaiser et al., 2010). Cultivation systems where fertilizers are incorporated at the level of tillage, they are placed at greater depth, which means that the nutrients remain out of reach the roots until the plant establishes its root system enough to explore the soil (Kaiser et al., 2010). Nutrients are solubilized in equilibrium between the soil solution and soil solid phase. As nutrients are removed from the solution by root uptake or loss of nutrients, new fraction is released from the solid phase to maintain a balance. However, nitrate is predominantly present in free form in the soil solution and its movement occurs by mass flow, following the flow of water in soil (Kaiser et al., 2010).

The contamination of groundwater by nitrate also may result from point sources, such as intensive animals husbandry (Morgenstern and Daughney, 2012), septic tanks, sewage discharge sites and oxidation of soil organic nitrogen (Andrade and Stigter, 2009), with consequent proliferation of toxic algal and eutrophication of reservoirs, which occur when groundwater discharges into rivers and lakes, and of nitrate concentrations higher than recommended for drinking water supply (Morgenstern and Daughney, 2012). The magnitude of nutrient leaching is conditioned by the relative availability in the surface horizon and excess rainfall relative to evapotranspiration (Paramasivam et al., 2000). During rainy periods, the soil remains highly humid, which favors the solubilization of fertilizers, water flow and leaching of nitrate to positions below the crop root system. These conditions lead to the need for additional applications of nitrogen to compensate for the losses of nitrate, enhance efficiency in the absorption of other nutrients and to provide the proper development of plants (Kaiser et al., 2010). In agricultural systems, the highest concentration of nitrogen in the soil solution occurs to establish cultures after application and/or incorporation of base fertilizer and the high ammonium levels verified at the beginning resulting from the base fertilizer, which has nitrogen as ammonium (Kaiser et al., 2010). Under these conditions, leaching of nitrate can also be favored because the plants are at the beginning of the season and the demand for nitrogen is increasing, but the root system is still undeveloped and, in the event of merger, there is an increase in contact area between the soil and the fertilizer, which facilitates solubilization (Kaiser et al., 2010). Furthermore, the displacement of nitrate is favored not only by its high solubility, but also the low energy adsorption of the anion, NO_3^- with soil particles which are predominantly negative charges (Kaiser et al. 2010) or by preferential flow (Lindahl and Bockstaller, 2012).

Pedogenetically young and shallow soil may allow the rapid saturation of soil during rain events, which increases surface runoff and enhances saturated flux in the soil. Furthermore, stony soils with a high proportion of macropores may facilitate preferential flow and increase the rate of water infiltration into the soil (Lindahl and Bockstaller, 2012), which favors the loss of water and nutrients by leaching. During high rainfall events, the soil remains saturated for a longer time. This promotes subsurface flow in the soil and allows considerable part of the water to drain below the root zone, hence becoming inaccessible to the plants (Randall and Mulla, 2000), and consequently, recharges the groundwater. These conditions of high rainfall and maintenance of soil moisture can provide nitrate concentrations to exceed those permitted for human consumption (Perez et al., 2003).

The high levels of nitrate found in the soil solution at the beginning of crops cycle and the concentrations remaining after the period of highest demand of culture represent a high risk of groundwater contamination (Kaiser et al., 2010). After reaching the groundwater, nitrate can be removed only when there is a reduction as a result of its high solubility and leaching potential (Andrade and Stigter, 2009). The presence of nitrate in groundwater and its associated impacts indicate an urgent need for changes in the land use, as only recently recharged groundwater exhibit high nitrate concentration (Morgenstern and Daughney, 2012).

Quantification of nitrate concentration in soil solution below the root zone is a good indicator to assess the potential for contamination of groundwater and thus may help to assess the potential for water contamination by soil management systems planning and land use (Kaiser et al., 2010). Thus, appropriate techniques for soil and water management and conservation should be prioritized to prevent the addition or retention of nitrogen levels above the soil carrying capacity and therefore reduce the contamination of water in order to maintain quality for human and animal consumption, while providing quality and balanced environment. In cropping systems without tillage, fertilization is shallow and located near the root zone and, under these conditions, the solubilization and leaching of nitrate fertilizer may be delayed and hence a potential reduction in nitrate load and contamination.

4.2 Pesticides

Groundwater resources are under threat from pollution. The level of susceptibility depends on the land use and intensity of interventions made for each use, especially in areas of recharge of surface water and groundwater. The intensive use of pesticides in agriculture has a major impact on natural resources and therefore propagates its effects on human health and living organisms that make up different ecosystems (Lindahl and Bockstaller, 2012). Concerns about these effects led the search for solutions through development of assessment tools and techniques that enable agricultural practices that minimize the impact caused by pesticides, such as new farming technologies, resistant cultivars, restructuring of plant protection and cultivation systems that can provide reduction in chemical dependency (Lindahl and Bockstaller, 2012). However, there is still the leaching of large amounts of pesticides in agricultural areas, resulting in high concentrations of these pesticides in groundwater, in different parts of the world (Silva et al., 2006; Andrade and Stigter, 2009; Morgenstern and Daughney , 2012).

The contamination of groundwater by pesticides may be influenced by land use and management, edaphoclimatic factors (Lindahl and Bockstaller, 2012), properties of the substances involved (Jarvis, 2007) and the vulnerability of aquifers (Andrade and Stigter, 2009). Incompatible soil use along with the soil capability associated with inappropriate methods of waste disposal and inadequate pesticide application and control favor leaching, especially in saturated soils after subsequent rainfall (Andrade and Stigter, 2009) if the soil promotes preferential flow, loss of pesticides along with the percolated water is more pronounced (Jarvis, 2007).

Knowledge of rainfall pattern and the prevailing soil water content is critical to determining the appropriate time of pesticides application, as well as to avoid the loss of input efficiency and subsequent deep-water contamination (Lindahl and Bockstaller, 2012). Thus, leaching of pesticides is governed by climatic conditions before and those observed at the time of application of pesticides. The interactions between the effects of rainfall intensity and duration on leaching of pesticides are still little understood and also depend on soil properties and characteristics of pesticides (Lindahl and Bockstaller, 2012). Leaching pesticide to groundwater is less likely in clay soils with fine texture compared to soils with coarse texture, regardless of weather conditions or time of application of pesticides (Lindahl and Bockstaller, 2012), as they may be strongly adsorbed. However, preferential flow in the soil profile may have great contribution and increase the transfer of pesticides that are strongly adsorbed, particularly under conditions of high humidity (Jarvis, 2007; Lindahl and Bockstaller, 2012).

If the rates of degradation of pesticides exceed their rates of infiltration in soil, groundwater contamination is less likely (Silva et al., 2006). However, pesticides having high stability, such as those used in areas of grape production, were found only in groundwater but not in surface water in the same area, and with the presence of preferential flow, the risk of contamination of pesticides is elevated (Lindahl and Bockstaller, 2012). Of all the classes of pesticides, herbicides are most often detected in groundwater, which is related to its use and its properties (Andrade and Stigter, 2009), and principally due to the adsorption capacity (Jarvis, 2007). The greatest risks of pesticides in groundwater occur when the pesticide is relatively stable, the aquifers are overlain by permeable soils and the distance between the surface and the water table is relatively short to minimize or avoid the potential dilution of pesticides (Andrade and Stigter, 2009).

The quality of groundwater and the impacts caused by the intensification of land use can be identified using natural tracers such as tritium, which can be used as a tool for dating groundwater (Morgenstern and Daughney, 2012). Thus, it is necessary to continuously monitor the evolution of land use on water quality and to detect trends in pollutant concentrations, identify natural patterns and higher concentrations of chemical elements and distinguish between natural and anthropogenic sources. However, the identification of land use impacts on groundwater quality can be hampered if the monitoring wells are within agricultural or industrial areas and either have been refilled before the intensification of land use, or the wells monitoring does not reflect the impacts of land use after the activities (Morgenstern and Daughney, 2012).

The use of pesticides hydro-chemical parameters and evaluation of the groundwater recharging time make it possible to establish the moment when high concentrations of pesticide begin to occur and thus make it possible to correlate concentrations of contaminants with soil use in areas of high groundwater recharge. This identification is possible considering the fact that pesticides from altered ecosystems as a result of human action typically have high concentrations in groundwater recently recharged, while the evolution of groundwater through the results of the interaction between water and rock in hydro-chemical concentrations indicates that the recharge of the groundwater was more earliest (Morgenstern and Daughney, 2012).

The impact of land use on water quality has been evaluated in studies that aimed at estimating the time of groundwater recharge (Griffioen et al., 2008) to detect trends in water quality. These studies have able to establish the rates of chemical change in the groundwater (Rademacher et al., 2001), as well as identify the tendency of relative pesticide concentrations transported superficially or in the soil profile and the manner in which it get into groundwater (Morgenstern and Daughney, 2012).

In groundwater recharged after agricultural intensification, the most representative indicators of intensified land use and its effects on water quality are nitrates, sulfates, chloro-fluoro-carbons (CFCs) and pesticides. Pesticides tend to show high levels in groundwater with recent recharge and indicate the impact of land use (Morgenstern and Daughney, 2012). Chloride, bromide, and chromium are hydro-chemical parameters that are part of the pesticide composition and exhibit high concentrations in groundwater especially when recently recharged after the beginning of intensive soil utilization. Chloride and bromide are elements that maintain their concentrations over time because they do not have sources which can contribute to increase in concentration, however elevated concentrations of these elements were observed in soils with high concentrations of nitrates and sulphates, which indicates agricultural providence.

Chloro-fluoro-carbons (CFCs) have been used in agriculture to cultivate tobacco and vegetable crops; however its commercialization has been prohibited because of toxicity. High concentrations of CFCs have been reported in the groundwater of agricultural areas cultivated to tobacco or vegetables. Though CFCs are relatively stable in groundwater, however, they can be degraded by anaerobic microbial reactions and only the groundwater that have experienced recent recharge are contaminated with CFCs (Morgenstern and Daughney, 2012).

Reviews of groundwater quality before changes in land use are prerequisite for understanding the subsequent reduction of pollution and contaminants. High concentrations of chemicals present in pesticides are often found in groundwater that are recently recharged compared to those observed recharged before land use intensification may show the evidence that the parameters that are directly affected by changes in soil use as well as the magnitude of the impacts (Morgenstern and Daughney, 2012).

5 How can sustainable land use improve water quality?

Improvement in water quality in different ecosystems can be achieved by reducing the intensity of agricultural activities. Management systems can alter soil physical properties that have direct influence on water behavior. Conservation systems of soil and water management systems are employed in order to provide favorable conditions for root growth and proper development of plants in order to obtain higher yields. Therefore, it is necessary to improve the quality of the soil and reduce the loss of soil, water and nutrients by erosion.

Traditional farming systems are more susceptible to environmental degradation because under the conditions of upturned and exposed soil with no organic material in the surface, raindrop impact can promote surface sealing, a thin layer of soil with low porosity that limits water infiltration (Reichert et al., 1992). Thus, the reduction of cultivation intensity is an efficient way to control soil erosion and reduce production costs (Alletto et al., 2010).

The use of management techniques that stipulate more sustainable agricultural activities such as reduced use of pesticides and agrochemicals, as well as proper management of waste generated in intensive farming of animals, should aim to reduce runoff, increase infiltration and soil water storage, (Alletto et al., 2010; Merten et al., 2011). Conservation tillage systems can control soil erosion by protecting the soil surface from the rain drops impact, thereby reducing the volume and velocity of runoff. However such systems provide changes in the soil physico-chemical properties and biological activity (Alletto et al., 2010) that improve the quality of surface water resources due to reduced sediment production and nutrient loading (Kaiser et al., 2010) that are transported and deposited through erosion to water courses.

The protection of the ground surface against the impact of raindrops in these systems occurs by the presence of vegetation or residues that are permanent on the surface. However, reducing surface runoff is not only conditioned by the high soil surface roughness provided by crop residues maintained on the soil surface, but also the pore distribution and continuity, which provide adequate water movement in the soil (Merten et al., 2011). Infiltration rates are partly determined by soil texture and the conditions of the soil surface roughness related to the porosity (Kaiser et al., 2010). Thus, systems such as minimum tillage or no tillage and sowing has contributed not only to reduce erosion, but also to improve the soil structural condition, infiltration and water availability in the soil (Kaiser et al., 2010).

Conventional tillage under inadequate soil moisture conditions can overcome the load bearing capacity and create soil compaction, with increased bulk density and reduced total porosity and macroporosity and increased water retention capacity of the soil (Reichert et al., 2009). These soil structural conditions are unfavorable to infiltration and as a result, water can seep onto the surface and cause erosion with entrainment of soil particles containing nutrients and pesticides, which will sooner or later reach water courses (Minella et al., 2007). Once formed, the runoff can be mitigated by reducing the energy of flow through the construction of physical barriers in transverse to the flow direction, using cultivation techniques such as contour, terraces, or vegetated strands. These techniques are considered effective alternatives to reduce the erosive processes as only plant residues covering the soil surface is not sufficient to contain the runoff, especially rainfall event of high intensity occurs. The rainfall intensity is greater than the rate of infiltration of the soil, which normally occurs initially, the accumulation of water on the soil surface and then the overland flow may cause the formation of rills (Merten et al., 2011).

Regarding agricultural production, it is necessary that the productive systems situate activities according to the load carrying capacity. Reducing the use of chemicals and proper management of animal waste are essential practices to reduce pollution of water resources. Furthermore, the maintenance or restoration of riparian vegetation serves as a filter for pollutants carried by runoff (Merten el al., 2011). Given the above, it should be noted that knowledge of the interactions that occur in different ecosystems can improve environmental quality through production techniques with low impact to water resources.

6 Conclusion

Addressing the challenges of water shortages in the coming decades will require a global effort. For this, we must ensure that ecosystems continue to perform their ecological functions of water supply in acceptable quantity and quality. In this sense, the use of techniques and soil use and management practices that reduce the risk of groundwater contamination are essential to the sustainability of agricultural systems responsible for the production of food consumed by the population. Addressing the shortage requires an integrated approach to water resources management in order to maximize the economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems, and enhancing the water use efficiency in order to get the same service or product with decreasing amounts of water extracted from rivers, streams, lakes and aquifers.

Also, to protect and restore ecosystems that naturally capture, filter, store and release water, such as rivers, swamps and forests, are crucial to increasing the availability of good quality water. However, it is clear that without the full participation of the population, it is impossible to foresee or implement sustainable solutions. Raising public awareness through changes in the education system are essential to building a world socially just and ecologically balanced, a world in which man must belong to the environment and not just its user, because when the tap dries, it may be too late to be worrying about this precious resource called water.

7 Brazilian programs and experiences to achieve a better water quality

In agriculture, water is a key input: about 70% of the water consumed on the planet is destined to agricultural activities. Therefore, it is necessary that its use and management occur in adequate manner to ensure the availability and sustainability of watersheds. In Brazil, we can cite some successful federal programs, such as the "Water Producer", which aims at reducing erosion and siltation of water sources in rural areas. This is a voluntary program that provides technical and financial support for the implementation of actions for soil and water conservation, for example, the construction of terraces and infiltration basins, upgrading of local roads, recovery and protection of springs, reforestation of areas of permanent protection and legal reserves, environmental sanitation, etc. It also provides incentives (or some sort of financial compensation) to the rural farmers who contribute to the protection and restoration of watersheds, generating benefits for the basin and the population.

The granting of financial incentives is through the Payment for Environmental Services (PSA) in form of financial transfers to beneficiaries of environmental services for those who, due to sustainable production practices, conserve nature. This system occurs when those who benefit from environmental services generated by a certain area perform payments to the owner or manager of the area in question. In other words, the beneficiary makes a contract aimed at continuous flow and improvement of service required. This model complements the hallowed principle of "user pays" by giving focus to deliver the service: it is the principle of "provider receives", where users pay and conservationists receive. This is a recent and innovative policy that is attracting a lot of attention in both developed and developing countries. Innovation involves a departure from the environmental policies of command and control, using market forces to achieve greater environmental outcomes and rewarding providers of environmental services, which do not come until receiving any compensation.

Another innovative program, still under development is the project, "More Water", of the state government of Rio Grande do Sul, Brazil. The project goal is to conduct studies, developed by state agencies and universities, on the agricultural production systems in order to increase water availability and improve its quality. The goal is to perform an assessment of appropriate soil management practices and piggery waste generation and disposal, weather and hydrological processes monitoring, as well as an integrated socio-economic analysis of the different farming systems of the state of Rio Grande do Sul. The results are expected to comprise a set of integrated information, able to identify the best practices of occupation, soil use and management that determine quality and quantity of water, both in the soil and rivers. The program is aimed to provide information that will allow to develop public policies to improve issues related to the quality and quantity of water in the state.

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Soil Protection in Europe and Germany
(The EU Soil Protection Strategy, the Federal Soil Protection Act as well as the Federal Soil Protection and Contaminated Sites Ordinance)

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Abstract

Soil fulfils numerous functions, as for instance the capacity to store, buffer, and filter and transform substances including water, nutrients and carbon. Countless influences and processes endanger the soil which can lead to soil degradation. In contrast, soil formation and regeneration is an extremely slow process, thus soil cannot be considered as a renewable resource (KOM-2006-231, Sept. 2006). Due to socio-economic and ecological importance, further degradation of soil quality or soil function needs to be avoided and the trend should be reversed, thus the development of a Thematic Strategy on Soil Protection has been incorporated into the Sixth Environmental Action Programme at EU level (Beschluss 1600/2002/EG). Since 1998, the European Commission is striving for a common Soil Protection Strategy in Europe. Currently the European Community legislation contributes to soil protection in many different areas. A particular example is the environmental and agricultural policy as well as the development of rural areas. Although these regulations have beneficial effects on soil protection, they primarily aim to protect other environmental media and therefore fulfil other objectives. Thus they represent not a homogeneous soil protection policy. Moreover, they do not include all kinds of soil impacts. In the Member States, different concepts of soil protection exist. Nine of the Member States have their own legislations for soil protection as for instance the Federal Soil Protection Act and the Federal Soil Protection and Contaminated Sites Ordinance in Germany. Both legislations aim to protect and rehabilitate sustainable soil functions. All parties concerned are obligated to prevent dangers, to avoid soil sealing and to take precautionary measures against harmful soil changes. The legislations, strategies and guidelines of each member state of the EU do not provide a uniform framework at European level (KOM-2002-179, April 2002; KOM-2006-231, Sept. 2006). Against this background, the European Commission presented the Thematic Strategy for Soil Protection in 2006. This should take into account soil functions, variability, complexity and the various processes that contribute to soil degradation. It should also fulfil socio-economic issues and close existing gaps in knowledge. Especially, it provides the identification of risk areas and polluted sites and the regeneration of damaged soils. The EU Member States agreed to the Thematic Strategy for Soil Protection in 2007, but until now, they did not agree on a Soil Framework Directive at EU level (Umweltbundesamt, Sept. 2010; Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, Dez. 2011).

Keywords: *Soil protection, Europe, Germany*

1 Introduction

In Europe, the degradation of soil quality is an issue of serious concern, even if the loads/burdens differentiate from one member state to another. Human activities have a significantly negative impact on soil quality such as inadequate agricultural and forestry practices, industry and tourism as well as improper urban and regional planning (urban sprawl). This leads to erosion, losses in organic substance, local and diffuse contamination, salinization, reduction in biodiversity of soils, sealing, compaction, floods and landslides. Consequently, these processes result, amongst others, in reduction of soil fertility, carbon content and biodiversity, to a lower water-retention capacity, to an obstruction of gas and nutrient cycles and a reduced decomposition of pollutants. Since soil is the interface between the earth (geosphere), the air (atmosphere) and water (hydrosphere), the deterioration of soil quality has direct impact on other environmental media like the quality of water and air and nature protection (biodiversity). Furthermore, this can have a negative impact on human health as well as on food and feed safety. Concerning the environmental media (water, air, nature protection), uniform regulations exist within the EU (KOM-2002-179, April 2002; KOM-2006-231, Sept. 2006; KOM-2006-232, Sept. 2006; Umweltbundesamt, Sept. 2010; Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, Dec. 2011).

The deterioration of soil quality does not only implicate ecological consequences but also economic ones. In addition to the notification “Thematic Strategy on Soil Protection“, an impact assessment has been carried out which had essentially been based on the reports of the Joint Research Centre (JRC), the set up working groups, the reports for the Commission evaluating the economic impact of soil degradation as well as the economic, ecological and social effects of planned soil improvement measures. From this generated data, the possible costs arising from the degradation of soil quality could be estimated at 38 billion Euros of annual losses, taking into account the factors of erosion, losses in organic substance, salinization, landslides and contamination. At the stage of the impact assessment, no investigation on costs concerning soil compaction, soil sealing and reduction of biodiversity was available. The efficiencies of the provisions of “Cross-Compliance”, accepted in January 2005, and the measures that lately have been prescribed by the Member States are also not included. Since the alteration of soils is only very slowly discernible, it is assumed that the estimated costs can provide a helpful indicative value. The cumulative costs for the society mainly arise in the following areas: damage of infrastructures caused by sediment discharge, medical expenses for the people affected by soil pollution, treatment of waters which have been polluted by soils, deposition of sediment, loss of value of properties near contaminated sites, and increased need for controls in food safety. Soil plays a significant role for the human activities and concerning the ecosystem. Soil fulfils various functions since soil is habitat and gene pool, a part of the landscape and can be cultural heritage. Soil also provides raw materials. Moreover, soil is of great importance in terms of water protection and exchange of gases with the atmosphere. Soil performs storage, filter, buffer and transformation functions and is considered as a non-renewable resource. In order to preserve the numerous functions of soil, a good soil condition needs to be ensured (KOM-2002-179, April 2002; SEK-2006-1165, KOM-2006-231, and KOM-2006-232, all Sept. 2006; Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, Dec. 2011).

2 Soil Protection in Europe: Thematic Strategy on Soil Protection

2.1 General remarks

Currently there is no legal basis for soil policy in Europe such as “EU Soil Framework Directive”. Therefore, no legislation or financial instruments are directly related to soil protection. However, in Europe, numerous regulations indirectly achieve soil protection. These concern for instance the provisions in the existing environmental legislation of the community. Since 2002, great care is taken to ensure that environmental policy in the areas of waste, water, air, climate change, chemicals, flood protection, biodiversity and environmental liability contribute to improving soil protection. Moreover, traffic policy and research programmes, such as the 7th EU Research Framework Programme, refer to soil protection explicitly (KOM-2006-231, Sept. 2006; KOM-2006-232, Sept. 2006).

- *Nitrates Directive,*
- *Water Framework Directive,*
- *Groundwater Directive,*
- *Air quality directive,*
- *Directive on national emission ceilings for certain atmospheric pollutants,*
- *Sewage Sludge Directive,*
- *Waste Framework Directive,*
- *Urban Waste Water Treatment Directive,*
- *Landfill Directive,*
- *Environmental Impact Assessment Directive,*
- *Strategic Environmental Assessment Directive,*
- *Directive on Industrial Emissions (integrated pollution prevention and control),*
- *Habitats Directive,*
- *Directive on environmental liability with regard to the prevention and remedying of environmental damage.*

The reformed Common Agricultural Policy (CAP) in the EU and the policy in the area of rural development provide an important contribution to soil protection. In this context the “Good Agricultural Practice” should be mentioned which is based on sustainable protection of soil fertility and capability of soil as natural resource. Good Agricultural Practice especially elaborates on methods for cultivation, methods against soil compaction, and crop rotation farming. Additionally, the ordinance 1257/99/EU and 1698/2005/EU about the funding for rural development (agri-environmental measures) contribute to soil protection as well as the ordinance for the determination of rules for direct payments within the framework of the common agricultural policy “Cross-Compliance” (KOM-2002-179, April 2002; KOM-2006-231, Sept. 2006; KOM-2006-232, Sept. 2006; Umweltbundesamt, Sept. 2010).

Nevertheless, the previous EU-legislations primarily aim to protect other environmental media. They have other applications and other objectives. This is why the existing directives provide only an incoherent and incomplete soil protection even in cases of correct and full implementation, since the directives do not fully cover the whole range of soils and all recognised dangers for soils. There is only a specific legislation for soil protection in nine Member States, while the other members rely on the legislation of other policies that take soil protection implicitly into account. Thus significant differences between the Member States regarding the processes of ensuring a sustainable land use are existent. Against this background, in September 2006, the European Commission presented the soil protection strategy (hereinafter referred to as "strategy") to the European Parliament, the Environmental Council, the Economic and Social Committee and the Committee of the Regions. This strategy consisted of a notification "Thematic Strategy on Soil Protection", an "impact assessment" and a proposal on a "Soil Framework Directive". The Member States agreed on the strategy in the year 2007 but they did not agree with regard to the proposed Soil Framework Directive (KOM-2006-232, Sept. 2006; Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, Dec. 2011).

2.2 Objectives of the EU Soil Protection Strategy

Basic objectives of the strategy are soil protection and sustainable soil use. In more detail, this means to preserve the soil functions, to avoid further degradation of the soil quality and to reduce its consequences, and also to achieve a regeneration of damaged soils as far as possible, whereby the cost implications of the remediation are to be considered. The EU-wide soil protection should close existing gaps with respect to knowledge and the legal provisions as well as to ensure a consistent and efficient environmental protection across media (KOM-2002-179, April 2002; KOM-2006-231, Sept. 2006; KOM-2006-232, Sept. 2006; Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, December 2011). These objectives are based on the following four pillars:

- *A legal framework aiming on soil protection and sustainable use of soils regarding erosion, loss of organic substances, salinization, compaction, landslides and soil pollution;*
- *Inclusion of soil protection into measures of the Member States and EC;*
- *Filling knowledge gaps concerning certain areas of soil protection by fostering research at national and EU level;*
- *Increasing public awareness for the necessity of soil protection (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, December 2011).*

The Member States will be required to identify risk areas with respect to erosion, loss of organic substances, salinization, compaction and landslides. They shall describe risk reduction targets for those areas and develop measure programmes for achieving them. In addition, contaminated sites shall be identified, since such sites represent a significant risk for humans and environment. The Member States have to establish a national remediation strategy with targets, priorities and a timetable and have to ensure that the contaminated sites will be remediated. Furthermore, a financing mechanism is to find in case the polluter cannot be identified or cannot hold liable. In case of a potentially contaminated property to be sold, a soil status report shall be drawn up. The report has to be submitted to the prospective buyer and the relevant authority (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, December 2011).

2.3 Proposal for an EU Soil Framework Directive

The Thematic Strategy on Soil Protection provides a statutory framework for the protection and sustainable use of soils at EU level. Since soil is an extremely variable medium (structurally, physically, chemically and biologically), a soil protection policy for the community cannot be developed on a universal concept, but rather requires a flexible system which considers specific local characteristics of soils and land use as well as climate and socio-economics. At the European level, it is important to create a regulation framework for soil protection and preserving the soil functions. This includes the determination of common objectives and principles. The determination of detailed measures should take place at an administrative and geographical level of the Member States (KOM-2006-232, Sept. 2006; Umweltbundesamt, Sept. 2010). The proposal for a directive comprises nine essential aspects:

- *Establishing a framework for soil protection, preserving soil functions, avoiding a deterioration, limiting the consequences and regeneration of damaged soils;*
- *Obligation to describe and evaluate the impact of measures in other policy areas in the context of soil protection;*
- *The requirement for land users to take precautionary measures when it is expected that the way of soil use affects the soil functions significantly;*
- *Ensuring an approach in terms of handling soil sealing to achieve a rational use of land and for the protection of soil functions;*
- *Identification of areas endangered by erosion, loss of organic substance, salinization, compaction and landslides as well as the establishment of national measure programmes. Furthermore, the identification of endangerment should be carried out on the basis of joint criteria in order to ensure coherent and comparable procedures;*
- *Measures to limit the infiltration of dangerous substances into the soil in order to avoid the accumulation of certain substances;*
- *Establishment of a catalogue of contaminated sites and sites with certain potentially environmentally hazardous activities (for instance landfills, airports, ports, military grounds) as well as the predefinition of a remediation strategy for contaminated sites (similar to the Directive 2002/91/EC), and the creation of a financing mechanism for the remediation in case of unknown property situation;*
- *The obligation of the property sellers to provide a soil status report, if soil-endangering activities have taken place or are still taking place on the property;*
- *Public participation (KOM-2006-232, Sept. 2006; SEK-2006-1165, Sept. 2006; Umweltbundesamt, Sept. 2010).*

The proposal for the directive is based on the principles of precaution and prevention. Environmental degradation is to prevent at the source, and the polluter pays principle has to be considered. Furthermore, the proposal addresses cross-border aspects. An important element is the reporting obligation of the Member States. The member states have to send such a report to the EU Commission within eight years upon the directive entry into force and subsequently every five years. The report aims to inform about the state of measure programmes, identification of risk areas and contaminated sites, remediation strategies, public participation. An exchange of data and information between the Member States and parties concerned is required; for this purpose a platform at EU level is provided (KOM-2006-232, Sept. 2006).

2.4 Current state of the EU policy to protect soil

Approximately five years after the adoption of the Soil Protection Strategy in September 2006, the EU Commission published in February 2012 the policy report „The implementation of the Soil Thematic Strategy and ongoing activities“(COM-2012-46, Feb. 2012). The report gives an overview of the activities with regard to the four pillars of the strategy. Furthermore, it highlights current trends in deterioration of soil quality in Europe and worldwide as well as future challenges. The report concludes that the deterioration of soil quality represents a fundamental and persistent problem that requires measures. The Soil Protection Strategy has definitely contributed to bring the topic of soil more into the focus, but nonetheless soil quality is still not being systematically monitored and protected even five years after the adoption of the strategy. The knowledge about soil quality is fragmented, and an effective and coherent soil protection is not ensured in all Member States (COM-2012-46, Feb. 2012). The policy report has been supplemented by the scientific report “The state of the soil in Europe” published by the European Commission´s Joint Research Centre, in collaboration with the European Environment Agency. The following provides a brief overview of ongoing measures at EU level.

Raising awareness and sensitisation of the population: The EU Commission held speeches at conferences, created pamphlets and brochures, published several soil atlases and established a working group for awareness raising and education within the framework of the European Soil Bureau Network (ESBN). Furthermore, it is worth mentioning the European Network on Soil Awareness (ENSA). The Commission will continue to conduct public campaigns and training for young researchers, and to participate in conferences (COM-2012-46, Feb. 2012).

Research: In the context of the Seventh Framework Programme for Research, around 25 research projects have been financed which especially deal with questions with respect to soil, as for instance RAMSOIL (Risk Assessment Methods), ENVASSO (minimum requirements for soil monitoring measures) and SOILSERVICE (scenarios for long-term changes in land use). Interesting results are expected from the monitoring project LUCAS (Land Use and Cover Area frame Survey), which deals with a survey of ground cover, land use and agri-environmental indicators. The European Commission will continue to fund projects, especially in the fields of landslides, soil sealing, soil functions and their correlation with biodiversity, carbon and nitrogen cycle of soil, soil fertility and nutrient recycling in agriculture (COM-2012-46, Feb. 2012).

Integration into other political measures: The common agricultural policy (CAP) has been promoted, where aspects of soil protection form an integral component of good agricultural and ecological status. In the context of “Rural Development”, agri-environmental measures are designated which could especially serve to support soil protection measures. With regard to industrial facilities, a Directive on Industrial Emissions (Directive 2010/75/EU) has been adopted, which states that the operation of a facility may not lead to deterioration of soil quality (zero tolerance policy; polluter pays principle). However, the Directive does not consider numerous environmentally harmful activities. The European Pollutant Release and Transfer Register (E-PRTR) is an important tool for the collection of data on pollution (emission and the amount of waste) and tracing. It provides online information to the public, e.g. about pollutants that are released by the affected industry (e.g. power stations, chemical industry, factory farming of animals, big treatment plans). Despite a missing legal basis for soil protection in the EU, the EU cohesion policy provided funds for the remediation of industrial sites and contaminated areas. Currently, the EU Commission is working on a European Innovation Partnership “Agricultural Productivity and Sustainability” (COM-2012-46, Feb. 2012).

Regulation: In a meeting of the Environment Council in March 2010, a minority of the Member States inhibited the further progress regarding the directive due to concerns regarding subsidiarity and the worry that the implementation may cause high consequential costs and a disproportionally high bureaucracy effort. Therefore, the Council will have to continue to work on the proposal for a Directive (COM-2012-46, Feb. 2012).

Next step: The European Parliament, the Environment Council, the Economic and Social Committee and the Committee of the Regions are asked for the submission of a comment on the policy report COM-2012-46. The history of the European Soil Protection Strategy is presented in Table T1 in the Annex.

3 Soil Protection in Germany

3.1 The Federal Soil Protection Act - BBodSchG

The Federal Soil Protection Act is a framework law; it is complemented by the legislation of the 16 Federal States (e.g. 16 Soil Protection Laws). Each Federal State has its own law for soil protection where additional regulations can be adopted. Nevertheless, the laws of the Federal States must be based on the BBodSchG (1998). The Federal States regulate the implementation and enforcement of the BBodSchG. The BBodSchG serves the purpose to protect soil against harmful soil impacts and to ensure soil functions sustainably or to rehabilitate them. The principles and obligations of the BBodSchG ensure that the soil functions be secured in the future for humans, animals and plants. In order to achieve this, it is important to counteract to harmful soil changes and to remediate polluted soils and contaminated sites as well as water pollution caused by soil contamination. The BBodSchG considers not only the averting of a danger but also the idea of precaution (Bundes-Bodenschutzgesetz, March 1998, changed Feb. 2012). These are the principles and obligations:

- *Obligation to take precautions towards chemical or physical impacts in order to preserve the ecological capabilities of soils (the precautions for groundwater are governed by the provisions of water legislations, unless there are existing soil contaminations, in that case the BBodSchG is decisive);*
- *Remediation of soils representing dangers for humans and environment;*

- *Property owners and land users are obliged to avoid dangers for soil;*
- *Removing impervious surfaces that are not being used anymore.*

Furthermore, the BBodSchG includes standards for applying or introducing materials onto or into the soil, information on risk assessment and regulations for investigation. Additionally, "Good Agricultural Practice" fixes the requirements on the agricultural use of soil. A particular focus of the law is represented by the part "Supplementary Provisions for Contaminated Sites", which regulates that the Federal State Authorities have to record, investigate and to evaluate contaminated sites and sites suspected of being contaminated. In addition the BBodSchG includes statements about the investigation and planning of remediation. It regulates the supervision by authorities and self-monitoring (property owners and land users), especially with regard to investigation of soil and water plus the installation and operation of measuring stations. The responsible authority may impose measures for self-monitoring even after the implementation of measures for decontamination, protection and restriction. There are also regulations for penalty (charge) provisions. A person who counteracts a statutory provision whether intentionally or negligently commits an administrative offence, such an infringement is given as well when an enforceable order based on a statutory instrument is not carried out. The administrative offence is punishable by a fine up to fifty thousand Euros, if the provisions for unsealing, for applying or introducing materials onto or into the soil, the compliance of binding decisions of the European Community, or the obligations to hazard defence are not fulfilled. In the other cases (e.g. not fulfilling the provisions to investigation and planning for remediation or to supervision by authorities and self-monitoring) the offence is punishable by a fine up to ten thousand Euros (Bundes-Bodenschutzgesetz, March 1998, changed Feb. 2012). The BBodSchG will determine the adoption of an ordinance.

3.2 Federal Soil Protection and Contaminated Sites Ordinance (BBodSchV)

Whereas the BBodSchG assigns the principles and obligations relating to protection against harmful soil changes and the remediation of contaminated sites, the BBodSchV deals with the requirements for the implementation of those principles and obligations. The BBodSchG and the BBodSchV are related to each other. The Ordinance considers:

- *Requirements in respect of the investigation and evaluation of suspected sites and sites suspected of being contaminated (e.g. Investigation and evaluation);*
- *Requirements in respect of the remediation of harmful soil changes and contaminated sites (e.g. Remediation measures, safeguard and restrictive measures);*
- *Supplementary provisions for contaminated sites (e.g. Investigation and planning for remediation);*
- *Exceptions;*
- *Supplementary provisions for averting of a danger of harmful soil changes resulting from soil erosion by water;*
- *Precaution against the emergence of harmful soil changes (e.g. Concern over harmful soil changes, precaution requirements, admissible additional pollution load,*

requirements in respect of the application and introduction of materials onto or into the soil (Bundes-Bodenschutz- und Altlastenverordnung vom 12.July 1999, changed *Feb. 2012).*

Furthermore, the ordinance includes annexes: Annex 1 of the ordinance contains requirements in respect of sampling, analytical procedures and quality assurance during the investigation; Annex 2 of the ordinance contains action, trigger and precaution values; Annex 3 of the ordinance contains requirements in respect of investigations for remediation and the remediation plan; Annex 4 of the ordinance contains the requirements in respect of the investigation and evaluation of areas in case of which there is suspicion of a harmful soil change resulting from soil erosion by water (Bundes-Bodenschutz-und Altlastenverordnung vom 12. July 1999, changed Feb. 2012). The BBodSchG and the BBodSchV are supplemented by prior legal provisions of other fields like the Fertiliser and Crop Protection Act, the Federal Immission Control Act, and the Construction Planning and Building Regulations Law. In the following, the requirements of the BBodSchV will be explained in more detail referring to the preventive and aftercare soil protection. Figure 1 illustrates the interface between the preventive and aftercare soil protection.

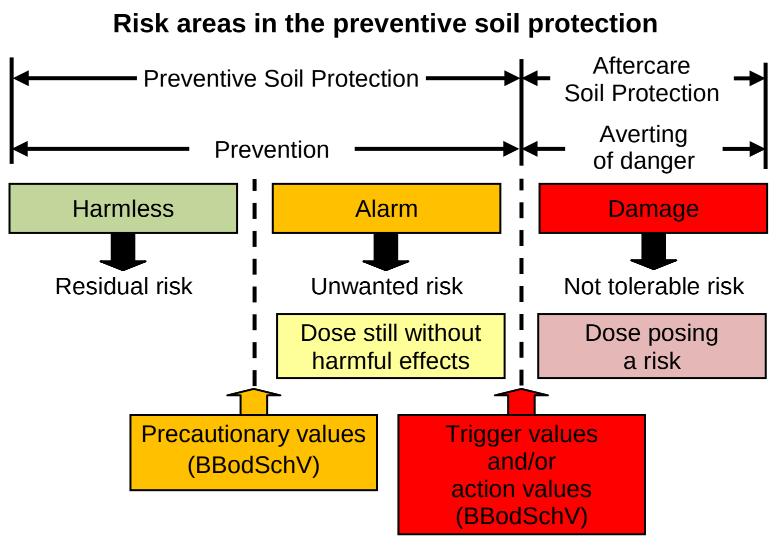

Figure 1: Point of intersection between preventive and aftercare soil protection. Source: Umweltbundesamt, Vorsorgender Bodenschutz, 2006.

Preventive Soil Protection

The idea of precaution aims to protect the natural resources and the livelihoods before hazards occur. Precaution does not only start with the probability of damage but the unease of harmful soil change is already sufficient. In terms of precaution, a difference is drawn between substantial loads and non-substantial loads. There are many causes, sources, transport paths and uses which give rise to substantial loads since traffic, private households, agriculture and industry produce emissions (see figure 2). These emissions in the long term have as immission a harmful effect on soil and thus on waters.

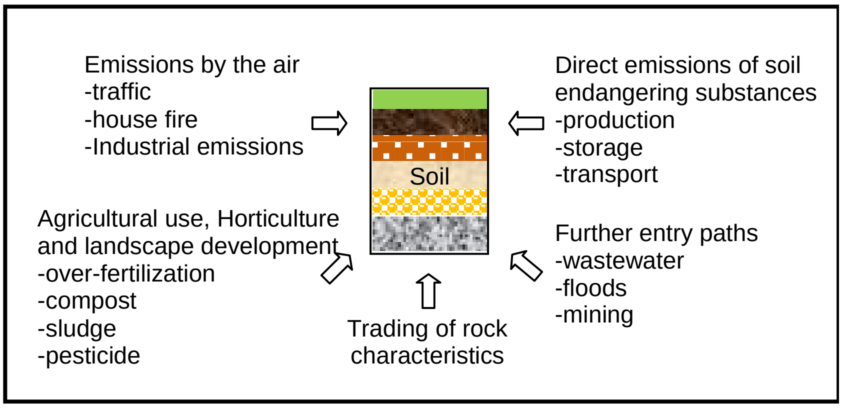

Figure 2: Soil impact by different emission.

The BBodSchV prescribes precautionary values that should not be exceeded. The precautionary values are determined based on eco-toxicological impact-thresholds and are soil-oriented values. They take the different soil characteristics and sensitivities into account. The precautionary values for different substances are determined depending on the soil type and the chemical status of the respective soil (BBodSchV, 12. July 1999, changed Feb. 2012, Umweltbundesamt-2, Sept 2010). The table T2 in the annex shows the precautionary values for heavy metals. The values for organic substances and the admissible additional annual pollutant loads through all pathways (soil - human being, soil - useful plant, soil - groundwater) are obvious in the BBodSchV as well. If the precautionary values are exceeded, it must be examined for the individual case, whether emission-reduction measures are possible carried out by the polluter. Regarding the avoidance of accumulation of pollutants in the soil from agriculture, requirements of the Sewage Sludge Ordinance, the Fertiliser Act and the Plant Protection Act have to be met. Moreover, an intensive guidance of the farmers takes place, as for instance advanced training seminars organized by the Chamber of Agriculture.

In Germany, the urgency and success of measures for the reduction of immission can be additionally assessed based on „Critical Loads“(CL). CL´s are area-related threshold values for the contamination with harmful substances taking land use into account. In compliance with the CL´s, no significant impact on the respective ecosystem is being expected, to the current state of knowledge (Umweltbundesamt-2, Sept 2010).

Whereas legislation and ordinances as well as precautionary values and trigger values for the substantial loads are available in order to minimize soil contamination, there are not any for the non-substantial loads, because there is no immediate impairment to human health. Nevertheless, the problematic issues concerning non-substantial loads should not be underestimated, namely soil sealing, compaction caused by agriculture as well as water and wind erosion. With reference to soil sealing in urban areas the precaution already begins with urban planning. The aim to obtain as much as possible green space and to limit soil sealing, is considered in the respective special laws, as for instance the Federal Building Code or the Regional Planning Law. The objectives can be incorporated into urban land-use planning as well as the land-use plan and local plan. Whereas the land-use plan reflects the permitted use, the local plan regulates the legally binding possible building use of an area. Furthermore, a contribution is also made by land recycling of former industrial sites and abandoned area that enables reconstruction without stressing undeveloped areas (greenfield sites). Another instrument is the “land value balance“. The evaluation system considers ecological criteria as well as social dimensions of land consumption. According to the land value balance, fertile loess soils for instance may not be built up. The precaution with regard to land use by agriculture, mainly at the usage of machinery and cultivation methods, reduces the risk of irreversible damages caused by compaction and the loss of soil substances. Regarding precaution against compaction, there are no specific legal regulations except the “good agricultural practice“, established by the BBodSchG. This also applies to the precaution against erosion caused by wind and water in a similar way. Moreover, directed expert consultations for the farmers referred to methods for preservative cultivation take place, including for instance a number of erosion-minimizing measures (Umweltbundesamt-2, Sept 2010; BBodSchV, 12. July 1999, changed Feb. 2012).

After-care soil protection

The after-care soil protection can basically be divided into two parts, contaminated sites (loads from previous uses, former industrial or waste disposal sites) on the one hand and the harmful soil changes on other hand. Thus, the after-care soil protection includes measures for remediation as well as safeguard and restrictive measures. In Germany, contaminated sites belong to the key issues of environmental policy. Prior to 1972 waste disposal had been disorganized, because a waste law at the federal and state level did not exist. Thus, the contaminated and suspected sites are being firstly ascertained and undergo a historical reconnaissance. If the suspicion is confirmed, an orientating investigation will be carried out. The contamination of soil will be evaluated by means of trigger values (see annex tables T3, T4, and T5). The pathways relevant for the individual cases (soil - human being, soil - useful plant, soil - groundwater) will be considered. The pathway soil - human being results from direct contact of humans with the soil, either by inhalation or putting soil in their mouth (for example playing children, gardening). The pathway soil - useful plant (crops) is considered as an indirect pathway since harmful substances can accumulate in agricultural crops and are being ingested from humans and animals by nourishment and feed. In the soil bound pollutants can find their way into the groundwater by percolating water, depending on the water solubility of the substances and binding strength in the soil. This is considered by the pathway soil - groundwater, whereby the trigger value at the place of the evaluation is relevant. The place of the evaluation is at the border between the unsaturated and saturated zone. Basically, the orientating investigation means substance evaluation, location evaluation and use assessment. The trigger values for pollutant transition soil-food plant on agricultural areas with regard to growth impairments of cultivated plants is obvious in the BBodSchV as well (Umweltbundesamt-2, Sept 2010; BBodSchV, 12. July 1999, changed Feb. 2012).

If the content or the concentration of a pollutant does not exceed the respective trigger value, the suspicion of a contaminated site or harmful soil pollution is nullified. If the trigger values are exceeded, a contaminated site or harmful soil pollution is usually present and as a result a detailed investigation will be carried out. The detailed investigation is a deepening further investigation in order to assess the danger. The amount and spatial dispersal of pollutants are examined as well as their mobile and mobilizable parts, their possibility to spread in the soil, waters and air and the possibility that humans, animals and useful plants may absorb these pollutants. The evaluation takes place by means of action values (see annex table T4) and by means of recommendations of the State Environment Agencies. If these action values are exceeded, the responsible local environmental authority decides on the type and extent of remediation measures. The action values for the direct intake of dioxins/furans at playgrounds, in residential areas, parks and recreational facilities, and industrial and commercial real properties as well as the action values for the pollutant transition soil-food plant on grassland areas with regard to the plant quality are obvious in the BBodSchV, too (Umweltbundesamt-2, Sept 2010; BBodSchV, 12. July 1999, changed Feb. 2012).

For the remediation of such sites decontamination-measures protective measures can come into consideration, depending on the existing contamination. Safeguard and restrictive measures can be prescribed in order to reduce danger or significant annoyances. In the case of decontamination measures, the pollutants are removed from the soil. Decontamination measures are suitable for remediation as far as they are based on technically and economically practicable methods and the removal or reduction of the contaminants qualifies as ensured. The methods need to be environmentally acceptable, and the consequences of the interference for the soils and waters must be considered. After the remediation has been completed the responsible authority must be informed about the achievement of the remediation objective (BBodSchV, 12. July 1999, changed Feb. 2012). For the decontamination of the soils microbiological methods, thermic methods, washing methods or pneumatic methods can come into consideration, depending on the local terms. The remediation of groundwater can be necessary. For this purpose, active methods (inducing measures) and passive methods are available. Active methods are pump and treat, in-situ-stripping, electro-kinetic methods, and microbiological in-situ remediation. Passive methods are for instance reactive systems like reactive wall, funnel and gate, and funnel and reactor. Protective measures should be prevent or reduce the dispersal of pollutants in the long term. They can be applied if it is ensured that permanently no danger, significant disadvantage or annoyances for the individual or for the community occur due to the remaining contaminants in soil. The effectiveness of the measure must be demonstrated to the responsible authority and monitored ongoing. If the effectiveness of the measure decreases, a subsequent renewal of the protective effect must be possible (BBodSchV, 12. July 1999, changed Feb. 2012). Protective measures are for instance surface sealing with appropriate foils, surface covering with a soil layer, seal walls and immobilisation. Safeguard and restrictive measures can be taken into consideration for agricultural and silvicultural land. Examples of these measures are a ring fence, greening in order to prevent drifts and to minimize direct contacts, management requirements (e.g. pH-value-regulation by liming, application of mulch materials, and selection of plant species) or restrictions on land utilisation (e.g. ban on cultivation for specific pollutant enriching plant species, exclusion of an use for the cultivation of food plants). In particular cases, a combination of different individual measures may be necessary for averting of a danger. The safeguard and restrictive measures must be documented and approved by the responsible agricultural authority (BBodSchV, 12. July 1999, changed Feb. 2012).

Regardless of whether decontamination, protective, safeguards or restrictive measures are intended, an investigation for remediation and a remediation planning need to be carried out according to the annex 3 of the BBodSchV (BBodSchV, 12. Juli 1999, changed Feb. 2012). No further action is required after the entire removal of contaminants in the soil or the groundwater. In all other cases, the corresponding areas will remain in the land register as “remediated contaminated sites” (Umweltbundesamt-2, Sept 2010). An action plan for the investigation of harmful soil changes and contaminated sites is shown in figure A1 in the annex.

3.3 Soil Continuous Observation and Soil Information System

In order to address the tasks of soil protection, information is required on substance-loads, soil characteristics and causes for soil impacts. Therefore, a soil continuous observation is important with the objective to gather data on the current status of soils, to monitor soil changes on a long-term and to depict development trends. Two decades before, the establishment and operation of soil continuous observation areas (BDF) were based on federal states specific programmes. These programmes had respectively separate requirements. In 1991, the Federal/State Soil Protection Working Group (LABO) prepared a concept for soil continuous observation in order to get a uniform evaluation of data at federal level. The data collection is in the responsibility of the federal states. The exchange, access and protection of data are regulated by an administrative agreement on data exchange in the environmental sector. Currently, there are 800 BDF distributed over whole Germany. These are the essential functions of soil continuous observation:

- *Early warning system for harmful soil changes,*
- *Control instrument for environmental policy measures,*
- *Preservation of evidence,*
- *Reference for the assessment of soil impacts,*
- *Basis for environmental research and development of methods.*

With reference to the extent of the investigations, two types of observation areas are distinguished, namely the Basis-BDF for the documentation of characteristics and the Intensive-BDF for the documentation of characteristics and processes. The data collection of the Basis-BDF takes place periodically without permanent installation of measuring instruments. By means of measuring instruments installed in the soil, additional material flows and processes are collected for the Intensive-BDF (Umweltbundesamt-3, Dec. 2011). Due to the stipulations of the BBodSchG, the Federal Government has the opportunity to operate a Soil Information System (BIS). It comprises data collected by the Federal States and serves for the collection, assessment and depiction of information on soils, soil functions, status of soils and soil impacts as well as entry and discharge of substances. The information system consists of a combination of different specific information systems (FIS) as the specific information system of soil science (FISBo-BGR), the specific information system of soil protection (bBIS-UBA) and the specific information system of contaminated sites (ALIS-UBA). The specific information system of soil science (FISBo-BGR) is being managed and updated by the Federal Institute for Geosciences and Natural Resources, Hannover, www.bgr.de. The findings of the pedological mapping provide the data basis for information on the status, the risks and utilisation capability of soils (Umweltbundesamt-4, April 2012). The FISBo-BGR consists of:

- *Area database: – entire geometry and factual data per unit areas that are designated in the soil maps;*
- *Laboratory and profile database: – includes the measurement results ascertained in the laboratory and all profile data of the terrain mapping;*
- *Methods database: – providing procedures to derive simple and complex pedological characteristic values (for example pedo-transfer functions, pedo-transfer rules);*
- *Thematic maps: – it is possible to request maps of background values for heavy metals (see figure 3).*

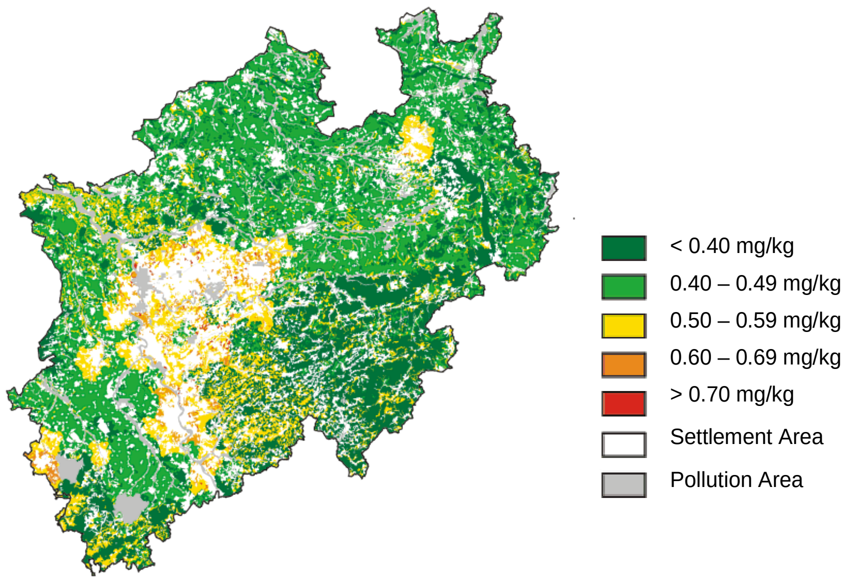

Figure 3: Background values for cadmium in NRW; Source: http://www.lanuv.nrw.de/boden/bodeninfo/fisstobo/regionalisierung/regionalisierung04.html.

The Federal Environmental Agency (UBA) administrates and updates the data about anthropogenous soil changes as well as soil impacts. There is a substance database (STARS) and an information system soil protection (bBIS-UBA) available, in which currently data on soil continuous observation and the transfer data on the pathway soil-useful plants (TRANSFER) are being recorded. The specific information system contaminated sites (ALIS-UBA) has been developed by the UBA. It provides tools for substance evaluation, general premises administration as well as for the derivation of sector-specific pollutant spectra and analysis plans (Umweltbundesamt-4, April 2012).

With three different applications, ALIS-UBA enables a uniform approach with respect to the processing of contaminated sites:

- *STARS: – substance database for substances with relevance for soil protection and environment, general information on substances;*
- *ALV: – database for the administration of contaminated sites and sites suspected of being contaminated. The database contains data masks on general information on the location, usage data, presumed spectrum of contamination, information on the*

remediation (measure, current planning stage) and information on sources, land register and coordinates;

- *XUMA-AMOR: – analysis planning at the investigation of contaminated sites. The programme enables the drawing up of analysis plans. Furthermore, a sector-specific spectrum of pollutants for civil sectors, military contaminated sites and armament-contaminated sites can be derived. The information is based on existing data on production methods, process operations, usage, applied substances, intermediate or waste products, time reference and media-related parameters (Umweltbundesamt-4, April 2012).*

More information about ALIS-UBA, bBIS-UBA, STARS, ALV, and XUMA-AMOR can be found under the website: http://www.umweltbundesamt.de/boden-und-altlasten. In order to operate the database, the environmental authorities of the federal government and the federal states work together. In addition to the databases of the federal government, there are also databases and specific information systems of the federal states, as for instance in North Rhine-Westphalia (NRW). In NRW the soil information system BIS-NRW, the specific information system on substance-based soil impacts FIS-StoBo, the substance database SSDB as well as the specific information system on contaminated sites and harmful soil changes FIS-AlBo is available. Moreover, there is the specific information system soil science FIS-Bo, the environmental data catalogue UDK and the information system for dangerous substances IGS. The IGS is edited in a comprehensible way and for different purposes, for action force (e.g. fire service, police), for authorities and for the public. The FIS-StoBO currently comprises approximately 75,000 sample data of about 60,000 locations with point related information and substance contents in the soils (LANUV NRW 2007; LANUV NRW, 2009 -1; LANUV NRW, 2009 -2; LANUV NRW, 2010).

4 Cross-Compliance

In agriculture, environmental-friendly measures and other obligations contribute to soil protection. Thus, for instance organic and integrated farming or the extensive cultivation in mountain areas are methods that have a positive impact on maintaining organic substance in the soil and that can prevent landslides (KOM-2006-231, Sept. 2006). In order to support the “good agricultural practice”, the ordinance laying down rules regarding direct payments within the framework of common agricultural policy “Cross-Compliance” is an important instrument. According to the Ordinance 73/2009/EC, the authorisation of direct payments is bound by strict rules. Thus, regulations with respect to the areas of environment, food and feed safety as well as animal health and protection must be complied. Infringements of the requirements lead to reductions in payments. Moreover, the Ordinance 73/2009/EC commits the member states to maintain permanent grassland. The central implementing rules of the cross-compliance obligations can be found in the Ordinance 1122/2009/EC. As in the Ordinance 1698/2005/EC, a comprehensive operational approach is presupposed, the agricultural enter-prises (farmers) have to comply with the obligations in all production areas (e.g. cultivation, livestock holding, greenhouses, speciality crops) and production facilities, even though they are located in several federal states. In order to enlighten the farmers and for awareness-raising, in Germany the Chambers of Agriculture of the federal states published a brochure “Information about the adherence to the other obligations (cross-compliance)” – Cross Compliance 2012. The brochure deals with the cultivation of arable land in order to avoid erosion. This is related to arable land for which an increased risk of erosion due to wind or water has been noticed. In terms of the avoidance of erosion several measures are expedient, for instance measures like leaving the entire straw of previous crops on the soil surface, intermediate crops, overwintering field grass, nurse crop remaining in winter or windbreak plantings. Figure 4 shows the influence of cultivation on soil erosion and P-export.

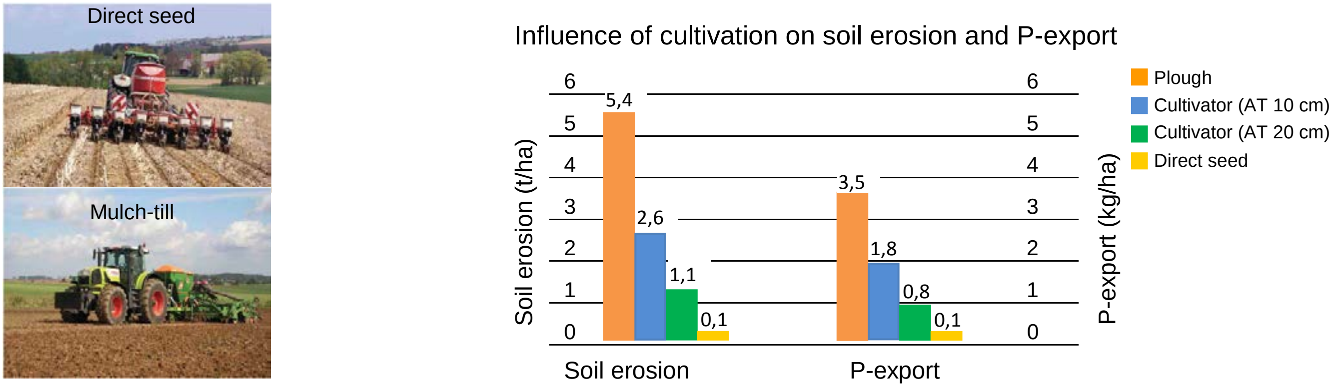

Figure 4: Influence of cultivation–Loess soil, winter wheat (3-leaf stage), 8% slope, 38 mm of rain in 20 minutes; Source: Landesamt für Umwelt, Landschaft und Geologie, Freistaat Sachsen.

Furthermore, framework conditions for ploughing arable land are provided, as for example contour ploughing or only in particular seasons. A humus balance for the whole agriculture enterprise and investigations on humus content in the soil must be carried out according to scientifically recognized methods and for each unit of cultivation. The compliance of a cultivation ratio of at least three different crops is required. In addition, it is not allowed to burn down stubble fields. Landscape elements such as hedges, rows of trees, copses and field borders are to preserve since they are important for the protection of environment and nature (habitats). The same applies to permanent grassland. In addition, basic requirements for the operational management of agricultural enterprises are also of importance. Concerning this requirements further EU directives have to be kept, such as the Birds Directive, the Directive on the conservation of natural habitats and of wild fauna and flora, the Groundwater Directive, the Sewage Sludge Directive, the Nitrates Directive, the Pesticide Directive, the Directive on the prohibition to use certain substances in the animal production, and the Regulation to the identification and registration of animals, the Regulation on food and feed safety, the Regulation on feeding prohibition (feed ban), the Regulation on animal epidemic as well as the Regulations on protection of animals (LESchV, 2010; Landwirtschaftskammer NRW, 2012).

According to the Sewage Sludge Directive, the application of sewage sludge is only permitted after the pH-value, the content of heavy metals, the phosphate available for the plants, potassium and magnesium in soil have been investigated. Among others, the application of sewage sludge on vegetable-growing and fruit-growing areas or on soils in zone I and II of water protection areas is prohibited. The same applies on soils in the range of riparian strips of waters up to a width of 10 metres. The Nitrates Directive regulates the application of fertilizers. The concentration of total nitrogen needs to be calculated before fertilizers (organic, organic-mineral), soil auxiliary materials, crop substrates or plant auxiliary materials (with predominantly organic constituents in each case) can be applied; a fertilizer assessment of demand has to be made. With respect to liquid manure, slurry, other liquid organic fertilizers or poultry faeces, in addition the content of ammoniacal nitrogen is to be ascertained. It is important to ensure a distance of at least 3 meters from the top edge of river banks and to avoid that fertilizer washed-out in surface waters. At a distance of 3 to 10 meters from the top edge of river banks, fertilizers have to be applied by using suitable techniques (e.g. injection of liquid manure). In the case of unplanted arable land at a distance of 10 to 20 meters from the top edge of river banks, fertilizers must be directly processed (see figure 5). Furthermore, according to the requirements of the Fertilizer Ordinance, balance sheets must be compiled (Landwirtschaftskammer NRW, 2012). For the storage and filling up of liquid manure, slurry, solid dung, and silage leachate, specific requirements are to be met (see figure 5).

Figure 5: Left side- Injection of liquid manure in the case of grassland; center- directly processed liquid manure in the case of unplanted arable land; Source: Bayrisches Landesamt für Landwirtschaft; Institut für Ökologischen Landbau, Bodenkultur und Ressourcenschutz; right side- storage and filling up of liquid manure; Source: Kreis-Olpe.de/2041_824_1_g.JPG.

The Pesticide Directive regulates application-provisions, application-prohibitions and restrictions as well as the obligations to produce records and also the protection of bees. Basically, devices for the application of fertilizers, soil auxiliary materials, crop substrates or pesticides must correspond to the generally recognized codes of practice. Within the scope of the cross-compliance obligations, there is a system of controls and penalties. The relevant specialised law authorities of the federal states are responsible for the control/monitoring of the farmers. There are systematic controls as well as additional controls (cross-checks). The assessment of infringement against the other obligations (cross-compliance) ensured in general by the criteria of frequency, extent, massiness and duration. According to these criteria the specialised authority has to classify the infringement as slight, medium or serious. Penalties for cases of non-compliance with the requirements happen in monetary terms. The extent of penalties is clearly defined according to the serious of the infringement (Landwirtschaftskammer NRW, 2012). With regard to Germany, it is important to point out that cross-compliance does not replace the German special laws. Hence, among the explained cross-compliance obligations the existing obligations which arise from the federal special laws need to be kept, even though they exceed the cross-compliance requirements.

5 Conclusions

In all states of the EU soils are degraded to different degrees. Against this background, the EU Commission presented a proposal for a framework directive on soil protection on 22. September 2006. Due to the obstructive attitude of Germany, France, Great Britain, Austria and the Netherlands, the law proposal has not been adopted until today. The assessment report (2010) for the Council of the European Union shows that the majority of the EU member states generally support a soil framework directive. In 1998, there has already been an initiative with the collaboration of Germany to improve the consideration of soil protection concerns at EU level. Germany or the Federal Government, respectively, welcomes a high standard in soil protection in all countries of the European Union and agree with the opinion of the EU that soil protection represents a general and border-independent task. Soil protection is highly relevant in society as a whole, not only with regard to health and food safety. Soil protection also needs to be adequately taken into consideration with respect to climate and flood protection in several policy areas. The justification for the critical attitude towards the framework directive is that the directive is not consistent with the subsidiarity principle, and that it requires a disproportional effort on bureaucracy and that the implementation entails high follow-up costs. Furthermore, there is doubt that an EU Soil Framework Directive can provide a surplus value compared to the existing legal provisions (environmental legislation of the EU).

Information about the financial burden (additional costs) that actually arises on the federal government and the federal states varies significantly, due to estimations often driven by interests. The Federal Ministry of Food, Agriculture and Consumer Protection (BMELV) commissioned a study in order to estimate the costs for the implementation of the directive. The study was completed in June 2010. It needs to be taken into account that the estimated costs do not understood as a binding real representation of actually arising costs but represent just a rough estimate. The study calculated for instance with a development of methods in the area of erosion endangerment. However, corresponding methods do already exist because of the cross-compliance regulations. The EU Commission tries to counter the fears of additional costs through bringing forward the argument that the benefits of the directive exceed the costs over longer observation periods.

Since the adoption of the Federal Soil Protection Act in the year 1998 and the corresponding ordinances, Germany can ensure high levels of soil protection and thus is in a good position. In this context, the national research funding should be mentioned as well. The similar applies to the countries France, Great Britain, Austria, Sweden and the Netherlands that also have adopted legal provisions on soil protection at national level. Especially the status of soils is already well documented in Germany. Hence, the additional expenses due to the framework directive are likely keep within a limit. For public information, the Federal Government publishes a soil protection report in every legislative period. The argument of subsidiarity represented by France, Austria, the Netherlands and Sweden, is weakened by the Federal Government itself by saying that the cross-border benefit of effective soil protection is high. Thus, subsidiarity is a controversial argument for rejecting a directive. Article 5, paragraph 3 EUV-Lisbon (Treaty establishing the European Union) implies: "Under the principle of subsidiarity, in areas which do not fall within its exclusive competence, the Union shall act only if and insofar as the objectives of the proposed action cannot be sufficiently achieved by the Member States, either at central level or at regional and local level, but can rather, by reason of the scale or effects of the proposed action, be better achieved at Union level".

Germany considers the further development or the deepening of a thematic soil protection strategy at EU level without a special legal provision as target-aimed instrument for the promotion of soil protection in Europe. On this basis, the soil protection should be implemented on a voluntary basis. The Federal Government considers the soil protection for a national task. Improvements have been achieved by means of the voluntary self-commitments within the European Union but the protection level of the soils in the Member States differ significantly until today (also see report "The State of Soil in Europe, 2012"). In counties without corresponding soil protection laws, the other EU environmental laws considering soil protection are obviously not sufficient. That implies that two thirds of the EU states have an accumulated need in soil protection. With an EU framework directive on soil protection, these states could benefit from countries experienced in the law, practice and implementation of the corresponding legal provisions, as Germany, the Netherlands or Great Britain.

In order to attain the objective of the 10th United Nations Biodiversity Conference in October 2010 in Nagoya to stabilize the ecosystems in its entirety until 2020, the EU and the member states need to close the regulatory gaps at the soil protection. The same applies for non-EU states. Since without healthy soils, neither effective environment protection nor long-term food security will be achievable. In addition a missing cross-border soil protection complicates also water protection. It is a fact that there will be the risk of high economic costs running into billions in the future, not only in Europe, if the degradation of soils is not stopped today. Currently, the soil degradation costs the EU states € 38 billion a year. It is indisputable that common objectives and comparable evaluation methods are required in the EU for a better coping with soil protection. The question arises whether an EU framework directive may help to achieve this aim or whether one should continue relying on voluntary self-commitment. These discussions have not yet been concluded.

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VERORDNUNG (EG) Nr. 1257/1999 DES RATES vom 17. Mai 1999 über die Förderung der Entwicklung des ländlichen Raums durch den Europäischen Ausrichtungs- und Garantie-fonds für die Landwirtschaft (EAGFL) und zur Änderung bzw. Aufhebung bestimmter Verordnungen.

VERORDNUNG (EG) Nr. 1698/2005 DES RATES vom 20. September 2005 über die Förderung der Entwicklung des ländlichen Raums durch den Europäischen Landwirtschafts-fonds für die Entwicklung des ländlichen Raums (ELER).

VERORDNUNG (EG) Nr. 73/2009 DES RATES vom 19. Januar 2009 mit gemeinsamen Regeln für Direktzahlungen im Rahmen der gemeinsamen Agrarpolitik und mit bestimmten Stützungsregelungen für Inhaber landwirtschaftlicher Betriebe und zur Änderung der Verordnungen (EG) Nr. 1290/2005, (EG) Nr. 247/2006, (EG) Nr. 378/2007 sowie zur Aufhebung der Verordnung (EG) Nr. 1782/2003.

VERORDNUNG (EG) Nr. 1122/2009 DER KOMMISSION vom 30. November 2009 mit Durchführungsbestimmungen zur Verordnung (EG) Nr. 73/2009 des Rates hinsichtlich der Einhaltung anderweitiger Verpflichtungen, der Modulation und des integrierten Verwaltungs- und Kontrollsystems im Rahmen der Stützungsregelungen für Inhaber landwirtschaftlicher Betriebe gemäß der genannten Verordnung und mit Durchführungsbestimmungen zur Verordnung (EG) Nr. 1234/2007 hinsichtlich der

Einhaltung anderweitiger Verpflichtungen im Rahmen der Stützungsregelung für den Weinsektor.

Verordnung zur Einteilung von landwirtschaftlichen Flächen nach dem Grad der Erosionsgefährdung durch Wasser und Wind (Landeserosionsschutzverordnung - LESchV), vom 30. April 2010; in Kraft getreten am 30. Juni 2010.

http://www.umweltbundesamt.de/boden-und-altlasten/boden/bodenschutz/europa.htm; (UBA) Bodenschutz in Europa, Stand: 07.09.2010 [1]; 10th July, 2012.

http://www.umweltbundesamt.de/boden-und-altlasten/boden/bodenschutz/europa.htm; (UBA) Vorsorgender Bodenschutz, Stand: 07.09.2010 [2]; 10th July, 2012.

http://www.umweltbundesamt.de/boden-und-altlasten/boden/bodenschutz/dauerbeobach-tung.htm; (UBA) Boden-Dauerbeobachtung, Stand 29.12.2011 [3]; 10th July, 2012.

http://www.umweltbundesamt.de/boden-und-altlasten/boden/daten/bodeninformations-system.htm; (UBA) Bodeninformationssystem, Stand 23.04.2012 [4]; 10th July, 2012.

http://www.eea.europa.eu/soer; Umweltzustandsbericht 2010 der Europäischen Umwelt-Agentur; 10th July, 2012.

http://www.lanuv.nrw.de/boden/ssdb.html; LANUV NRW 2007; 10th July, 2012.

http://www.lanuv.nrw.de/altlast/altnrw.htm#fisalbo; LANUV NRW 2009 [1]; 10th July, 2012.

http://www.lanuv.nrw.de/boden/boschu-lua/fisstobo.html; LANUV NRW 2010; 10th July, 2012.

http://www.lanuv.nrw.de/stoffdaten/stoffdaten_2.htm; LANUV NRW 2009 [2]; 10th July, 2012 .

7 Annex

Table T1. Chronology/History of the European Strategy for Soil Protection. Source: Umweltbundesamt, 2010; KOM-2006-232, Sept. 2006; Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, Dez. 2011; COM-2012-46, Feb. 2012; http://www.eea.europa.eu/soer.

Year	Event
1972	Soil Charter of the Council of Europe; the States were called to promote a soil conservation policy. Adopted EU-directives consider the soil indirectly.
1998	Together with the EU Commission, Germany took initiatives for a better consideration of soil protection interests/issues at EU level
2002	In the Sixth Environmental Action Programme, soil protection has been listed as one of seven Thematic Strategies. In the same year, the EU Commission published an official note “Towards a Thematic Strategy for Soil Protection“(COM-2002-179final) which describes the dangers for the soil and possible measures. The EU Council of Environmental Ministers took the basic decision that the EU Community needs to get active in the area of soil protection
2003/ 2004	An open consultation was held with the parties concerned. Moreover, five working groups and one advisory council with a steering role have been formed dealing with the topics of erosion, organic substance and biodiversity of soil, contamination and land management, monitoring and research. The working groups drawn up comprehensive reports which

	provide information on the status of the soil in Europe, the contamination/loads, the driving forces for soil degradation as well as recommendations for the development of soil policy
2005	The EU Commission accomplish a public internet-consultation with the result that a framework regulation at EU level and concrete measures at a national and local level are considered as significant for soil protection. The EU Commission presented the plans for the elaboration of the soil protection strategy (Strategy, Framework Directive, Impact Assessment) to the Member States
2006	In September, the EU Commission presented the Soil Protection Strategy consisting of the official note “Thematic Strategy for Soil Protection”, the proposal for a Soil Framework Directive and an Impact Assessment to the European Parliament, the Environmental Council, the Economic and Social Committee and the Committee of the Regions
2007	The Committee of the Regions agreed to the initiative of the EU Commission. The Economic and Social Committee as well as the European Parliament supported the Soil Protection Strategy and basically also a Framework Directive. In the Environmental Council (representing the EU Member States), the proposal for the Directive did not come to a vote, since Germany, the United Kingdom, France, the Netherlands and Austria had signalized that they would not agree to the directive in the present version due to concerns about the subsidiarity
2008	The consultations on the draft directive were resumed
2009/ 2010	Further development of the proposal of a directive took place. September 2010: The European Environmental Agency published the Environment Status Report of 2010 which shows evidence for the growing deterioration of soil quality
2011	There was no consultation for the planned Soil Framework Directive
2012	The ongoing activities see chapter 2.4 “Current state”

Precaution values for soils pursuant to § 8 paragraph 2 sentence 1 Federal Soil Protection Law (Analytic according to Annex 1 BBodSchV). Detailed information concerning the usage of the precaution values is given in the BBodSchV.

Table T2. Precaution values for metals (in mg/kg dry weight, fine soil, aqua regia-decomposition). Source: BBodSchV, 12. Juli 1999, zuletzt geändert Feb. 2012.

Soils	cadmium	lead	chromium	copper	mercury	nickel	zinc
soil type clay	1.5	100	100	60	1	70	200
soil type loam/silt	1	70	60	40	0.5	50	150
soil type sand	0.4	40	30	20	0.1	15	60
soils with naturally increased and large-area settlement-related in-creased background contents	Safe, as far as the release of pollutants or additional inputs pursuant to § 9 paragraphs 2 and 3 of the Ordinance do not give reason to expect any adverse impacts on the soil functions						

Pathway soil-human being (direct contact)

Delimitation of uses

a) Playgrounds: Places for children that are generally used for playing, without the playing sand in sandboxes. Officially identified playgrounds shall, if applicable, be evaluated on the basis of the standards applied in the field of public health.

b) Residential areas: Areas serving housing purposes, including back gardens or other gardens of similar use, also as far as they are not represented or specified under planning law within the meaning of the Building Use Ordinance, except for parks and recreational facilities, playgrounds, as well as paved traffic surfaces.

c) Parks and recreational facilities: Facilities serving social, health and sports purposes, in particular public and private green areas as well as unpaved areas that are regularly accessible and used in a comparable way.

d) Industrial and commercial real properties: Unpaved areas of work and manufacturing plants that are used only during work hours.

Table T3. Trigger values pursuant to § 8 paragraph 1 sentence 2 No. 1 Federal Soil Protection Law for the direct intake of pollutants at playgrounds, in residential areas, parks and recreational facilities, and industrial and commercial real properties (in mg/kg dry weight, fine soil, analytic according to Annex 1 BBodSchV). Source: BBodSchV, 12. Juli 1999, zuletzt geändert Feb. 2012.

[1)] in back gardens and small gardens where children stay and food plants are grown, trigger value 2.0 mg/kg TM shall be applied for cadmium.

[2)] as far as PCB-total contents are determined, measured values shall be divided by a factor of 5.

	Trigger values (mg/kg TM)			
substance	playgrounds	residential areas	parks and recreational facilities	industrial and commercial real properties
arsenic	25	50	125	140
lead	200	400	1000	2000
cadmium	10 [1)]	20 [1)]	50	60
cyanide	50	50	50	100
chromium	200	400	1000	1000
nickel	70	140	350	900
mercury	10	20	50	80
aldrin	2	4	10	--
benzo(a)pyrene	2	4	10	12
DDT	40	80	200	--
hexachlorobenzene	4	8	20	200

	Trigger values (mg/kg TM)			
substance	playgrounds	residential areas	parks and recreational facilities	industrial and commercial real properties
Hexachlorocyclo-hexane (HCH-mix or ß-HCH	5	10	25	400
pentachlorophenol	50	100	250	250
polychlorinated biphenyls (PCP_6)[2)]	0.4	0.8	2	40

Pathway soil - useful plant

Delimitation of uses

a) Agriculture: Areas for the cultivation of varying field crops, including vegetables and field food plants; this also includes areas for commercial gardening

b) Vegetable garden: Back garden, small garden and other garden areas used for growing food plants

c) Grassland: Permanent green areas

Table T4. rigger and action values pursuant to § 8 paragraph 1 sentence 2 No. 1 and 2 Federal Soil Protection Law for the pollutant transition soil-food plant on agricultural areas and in vegetable gardens with regard to the plant quality (in mg/kg dry weight, fine soil, analytic according to Annex1 BBodSchV). Source: BBodSchV, 12. Juli 1999, zuletzt geändert Feb. 2012

[11)] extraction process for arsenic and heavy metals: AN-ammonium nitrate, KW- aqua regia

[22)] in case of soils with occasionally decreasing conditions, a trigger value of 50 mg/kg dry weight shall be applied

33) On areas that are used for growing bread wheat or strongly cadmium-accumulating vegetables, an action value of 0.04 mg/kg dry weight shall be applied; otherwise, the action value is 0.1 mg/kg dry weight.

Agriculture, vegetable garden			
substance	method 11)	trigger value	action value
arsenic	KW	200 22)	--
cadmium	AN	--	0.04 / 0.1 33)
lead	AN	0.1	--
mercury	KW	5	
thallium	AN	0.1	--
benzo(a)pyrene	--	1	--

Pathway soil – groundwater

Table T5. Trigger values for the assessment of the pathway soil – groundwater pursuant to § 8 paragraph 1 sentence 2 No. 1 Federal Soil Protection Law (in mµg/l, analytic according to Annex 1 BBodSchV). Detailed information concerning the usage of the trigger values is given in the BBodSchV.

1)N-alkanes (C10 C39), isoalkanes, cycloalkanes and aromatic hydrocarbons

2)High-volatile aromatic hydrocarbons (benzene, toluol, xylols, ethylbenzene, styrene, cumene)

3)High-volatile halogenated hydrocarbons (sum of the halogenated C1- and C2- hydrocarbons)

4)PCB, total: sum of the polychlorinated biphenyls; as a rule, determination by way of the 6 congeners according to Ballschmiter pursuant to Used Oil Ordinance (DIN 51527) multiplied by a factor of 5; if applicable, for example in case of a known substance spectrum, simple formation of the sum of all relevant individual substances (DIN 38407–3-2 or 3-3)

5)PAH, total: sum of the polycyclic aromatic hydrocarbons without naphthalene and methylnaphthalene; as a rule, determination by way of the sum of 15 individual substances according to the list of the US Environmental Protection Agency (EPA) without naphthalene; if applicable, in consideration of other relevant PAH (e.g. quinolone) - Source: BBodSchV, 12. Juli 1999, zuletzt geändert Feb. 2012

Inorganic substances	Trigger values (mµg/l)
antimony	10
arsenic	10
lead	25
cadmium	5
chromium total	50
chromate	8
cobalt	50
copper	50
molybdenum	50
nickel	50
mercury	1
selenium	10
zinc	500
tin	40
cyanide total	50
cyanide easily set free	10
fluoride	750

Organic substances	Trigger values (mµg/l)
Mineral oil hydrocarbons 1)	200
BTEX 2)	20
benzene	1
High-volatile halogenated hydrocarbons3)	10
aldrin	0.1
DDT	0.1
phenols	20
PCB total 4)	0.05
PAH total 5)	0.20
naphthalene	2

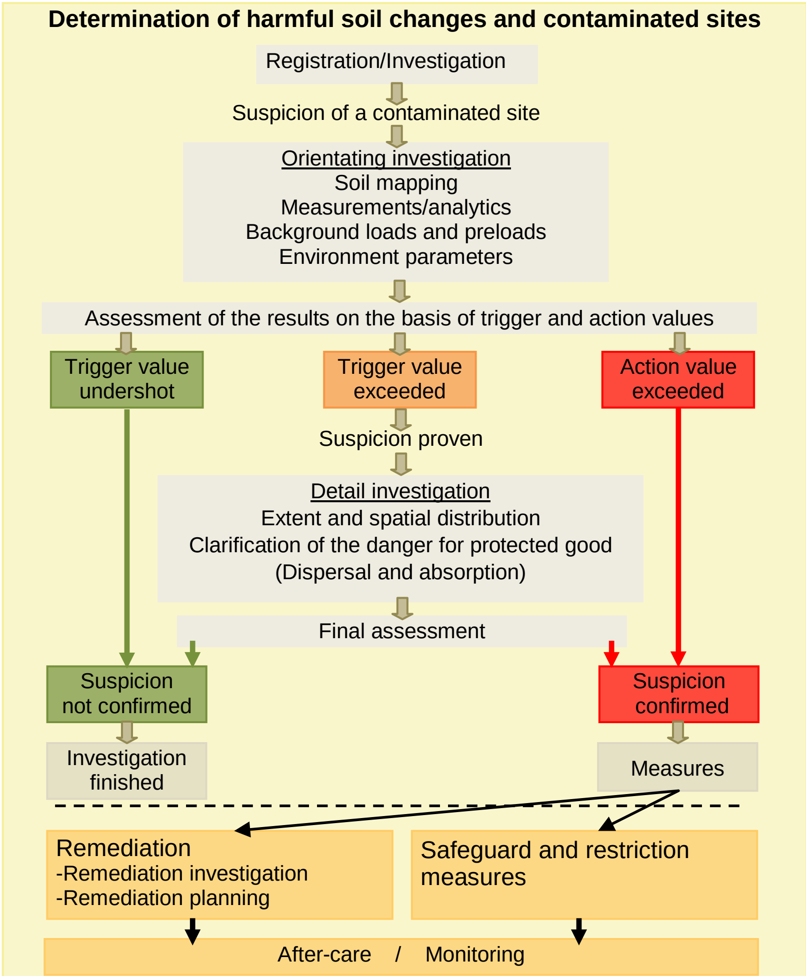

Figure A1: Action plan for the investigation of harmful soil changes and contaminated sites. Source: Umweltbundesamt, 2006 – Boden und Altlasten – Nachsorgender Bodenschutz

Advances in biological nitrogen removal: Operation, modeling and control

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Abstract

This paper summarizes some research results, which were mainly focused on optimization of integrated nitrogen removal processes and modeling & control of bioreactors for reaching stable operation on long-term basis. The nitrogen removal process consists in an uncompleted oxidation of ammonia to nitrite under aerobic respiration - partial nitrification -, and a subsequent reduction of nitrite to molecular nitrogen under anoxic respiration. Partial nitrification to nitrite has three practical advantages: lower oxygen consumption, lower need for organics and lower sludge production. In order to develop a stable partial nitrification a novel operational strategy was studied in a sequencing batch rotating disk reactor under oxygen concentrations lower than 1.0 mg/L throughout 270 days. The strategy was based on a supervisory pH control and an automatic interruption of aeration at the endpoint of ammonia oxidation. The supervisory control enabled the maintenance of a concentration of 3 to 4 mg NH_3-N/L for optimal growing of ammonia oxidizing bacteria. For this reason on-line monitoring of sodium carbonate consumption was implemented during nitrification. The results showed that it is possible to reach a stable partial nitrification with high nitrite accumulations of 84 to 88% during long term assays, and a relatively high ammonia conversion rate of 1.45-4.25 kg NH_4^+-N/m^2/d. A dynamic model of a Rotating Disk Biofilm Reactor was developed in order to determine optimal operation conditions for partial nitrification. The biofilm model considered the active biomass fraction as a state variable; it was calibrated at steady state and validated with long-term experiments. A good agreement between the measured and modeled results was obtained. Results demonstrated that nitrite accumulation (β) is strongly influenced by the nitrogen load rate (NLR) and the pH. The optimal operation zone for $\beta > 70\%$ is reached for NLRs between 8.5 and 11.5 g N m^{-2} d^{-1}, pH > 8 and dissolved oxygen concentration < 3 mg O_2 L^{-1}.

Keywords: *Partial nitrification, nitrite accumulation, biofilm, modelling*

1 Introduction

The biological removal of inorganic nitrogen by a combination of nitrification and denitrification is widely used in the treatment of municipal and industrial wastewaters. The first step of nitrification is the oxidation of ammonia to nitrite by the ammonia-oxidizing bacteria (AOB). The second step is the oxidation of the nitrite to nitrate by the nitrite-oxidizing bacteria (NOB). Both steps are performed by the chemolithoautotrophic bacteria under aerobic conditions. Afterwards, during the denitrification step, the nitrate, under anoxic conditions, is reduced to molecular nitrogen by chemoorganoheterotrophic bacteria via three intermediates: nitrite, nitrogenmonoxide, and dinitrogenoxide. Since the nitrite is consumed by the nitrification and formed again during the denitrification, the nitrite oxidation becomes an unnecessary step. Partial nitrification or exclusively oxidation of ammonium to nitrite has three practical advantages: lower oxygen consumption during nitrification (25%), lower need of organics for denitrification (40-60%), and lower sludge production (van Loosdrecht *et al*., 2000; Bernet *et al*., 2001; Wiesmann, 1994).

Accumulation of nitrite can be achieved by inhibition and/or limitation of the growth of NOB. Ammonia concentration (NH_3) is often regarded as the most important inhibiting agent (Cecen *et al*., 1998; Abeling *et al*.,1992; Bae *et al*., 2001). Inhibition is a strong function of the pH, since it determines the equilibrium between acid and basic forms. Inhibiting concentrations of 1 to 5 mg NH_3-N/L of nitrite oxidation have been reported (Abeling *et al*.,1992; Bae *et al.,*2001).They found significant inhibition for values higher than 4 mg NH_3-N/L. On the other hand, (Liu and Tay*,* 2001) reported an important inhibition of the NOB even at concentrations as low as around 0.1 mg NH_3-N/L. However, for continuous operation over long periods of time under inhibitory ammonia concentrations, an acclimation of nitrifying bacteria has been found (Turk and Mavinic*,* 1989; Villaverde *et al.,* 2000).

Partial nitrification is largely unstable on a long-term basis (Fux *et al.,* 2004*;* Ruiz *et al.,* 2003*;* Turk and Mavinic*,* 1989). Nevertheless, it has been reported that pH and oxygen control strategies favor high removal efficiencies and nitrite accumulation that can be maintained over a prolonged period (Ciudad *et al.,* 2007*)*. Thus, to establish environmental conditions favorable to ammonia-oxidizing bacteria (AOB) growth and unfavorable to NOB growth, a simple, efficient model is necessary to design supervisor control systems that generate dynamic pH and DO set points based on a dynamic model of the biological process. However, most partial nitrification models reported in the literature have been formulated in steady state conditions (Bernet *et al*., 2005; Picioreanu *et al.,*1997) and do not consider the pH effect on chemical equilibrium of NH_3/NH_4^+ and HNO_2/NO_2^- species, which has been validated in short operating periods (Perez *et al*., 2009; Fang *et al*., 2009).

Therefore, this study proposes a dynamic model of nitrification in order to determine optimal operating conditions and design control strategies for maintaining high ammonium removal efficiencies and nitrite accumulation for long-term operations (months). In addition, this study suggests a model that incorporates autotrophic population growth in time and space.

The objectives of this work were:

- *To implement a novel operational strategy based on a supervisory pH control and an indirect method for ammonia monitoring in order to develop a stable partial nitrification to nitrite in a sequencing batch rotating disk reactor (SBRDR).*
- *Dynamically model partial nitrification to nitrite in a rotating disk biofilm reactor RDBR.*
- *Predict by simulation the optimal operating zones for simultaneous high nitrite accumulation and ammonia degradation as a function of DO concentration, pH values and nitrogen load rate (NLR).*

2 Multiple Species Model

This study is based on the multiple species model presented by Wanner and Gujer (Wanner and Gujer, 1986). The mass balance equations of the RDBR are:

Liquid bulk

The equations in the liquid bulk are:

- *Nitrogen species in continuous operation (equation 1).*

$$\frac{\partial c_{i,bulk}}{\partial t} = \frac{1}{HRT} \cdot \left(c_{i,0} - c_{i,bulk} \right) - a_p \cdot D_i \cdot \left. \frac{\partial c_i}{\partial z} \right|_{z=L} \quad (1)$$

- *Nitrogen species in batch operation (equation 2).*

$$\frac{\partial c_{i,bulk}}{\partial t} = -a_p \cdot D_i \cdot \left. \frac{\partial c_i}{\partial z} \right|_{z=L} \quad (2)$$

for c_i: c_{TAN}, $c_{NO_2^-}$, $c_{NO_3^-}$.

- *Dissolved oxygen in continuous operation (equation 3).*

$$\frac{\partial c_{DO,bulk}}{\partial t} = \frac{1}{HRT} \cdot \left(c_{DO,0} - c_{DO,bulk} \right) - a_p \cdot D_{DO} \cdot \left. \frac{\partial c_{DO}}{\partial z} \right|_{z=L} - k_L a \cdot \left(c_{DO,bulk} - c_{DO}^{*} \right) \quad (3)$$

- *Dissolved oxygen in batch operation (equation 4).*

$$\frac{\partial c_{DO,bulk}}{\partial t} = -a_p \cdot D_{DO} \cdot \left. \frac{\partial c_{DO}}{\partial z} \right|_{z=L} - k_L a \cdot \left(c_{DO,bulk} - c_{DO}^{*} \right) \quad (4)$$

Biofilm

Equations 5, 6, 7 and 8 present the mass balances inside the biofilm, considering diffusion and reaction by nitrification. In these equations, the following assumptions were made: the consumption rate considers substrate consumption, mainly due to energy requirements for cell growth; mass transfer is one-dimensional along the z-axis; and advective transport is neglected.

- *Total ammonia nitrogen (equation 5).*

$$\frac{\partial c_{TAN}}{\partial t} = D_{TAN}^{b} \cdot \frac{\partial^2 c_{TAN}}{\partial z^2} - \left(\frac{\mu_{AOB}}{Y_{AOB/TAN}} \right) \cdot c_{AOB} \quad (5)$$

- *Total nitrite nitrogen (equation 6).*

$$\frac{\partial c_{NO_2^-}}{\partial t} = D_{NO_2^-}^{b} \cdot \frac{\partial^2 c_{NO_2^-}}{\partial z^2} + \left(\frac{\mu_{AOB}}{Y_{AOB/TAN}} \cdot Y_{NO_2^-/TAN} \right) \cdot c_{AOB} - \left(\frac{\mu_{NOB}}{Y_{NOB/NO_2^-}} \right) \cdot c_{NOB} \quad (6)$$

- *Total nitrate nitrogen (equation 7).*

$$\frac{\partial c_{NO_3^-}}{\partial t} = D_{NO_3^-}^{b} \cdot \frac{\partial c_{NO_3^-}}{\partial z^2} + \left[\frac{\mu_{NOB}}{Y_{NOB/NO_2^-}} \cdot Y_{NO_3^-/NO_2^-} \right] \cdot c_{NOB} \quad (7)$$

- *Dissolved oxygen (equation 8)*

$$\frac{\partial c_{DO}}{\partial t} = D_{DO}^{b} \cdot \frac{\partial^2 c_{DO}}{\partial z^2} - \left(\frac{\mu_{AOB}}{Y_{AOB/DO}} \right) \cdot c_{AOB} - \left(\frac{\mu_{NOB}}{Y_{NOB/DO}} \right) \cdot c_{NOB} \qquad (8)$$

The relation between D_i and D_i^b is D_i^b / D_i =0.8.

The initial and boundary conditions are given by Eqs. 9 to 11, which represent the mass transfer at the interfaces between biofilm-support material (z = 0) and biofilm–liquid (z = L). Equation (10) represents the stopping of the diffusion transport at the inert support–biofilm interface. Equation (11) represent the continuous mass flux from the liquid bulk to the biofilm–liquid interface through the stagnant liquid layer, and is based on the assumption of a pseudo-steady state for the substrate concentration in the effective sublayer (Wanner and Gujer, 1986).

$$c_i(z,0) = c_{i,0} \qquad \text{for t} = 0 \qquad (9)$$

$$\frac{\partial c_i(0,t)}{\partial z} = 0 \qquad \text{for z} = 0 \qquad (10)$$

$$D_i^b \left. \frac{\partial c_i}{\partial z} \right|_{z=L^-} = k_L \cdot \left(c_{i,bulk} - c_{i,z=L} \right) \qquad \text{for z} = L \qquad (11)$$

for c_i: c_{TAN}, $c_{NO_2^-}$, $c_{NO_3^-}$, and DO.

The specific growth rates of AOB and NOB can be expressed by Haldane Kinetcis (Antileo et al., 2007).

3 Material and Methods

3.1 Reactor and instrumentation

The reactor and its instrumentation and control system are schematized in Fig. 1. It consisted in a single rotating disk (diameter = 35.4 cm) with a specific projected area of 35 m^2/m^3, which was totally submerged in an 8 L reaction volume, to avoid oxygen uptake from the atmosphere during rotation. The disk was moved by an external motor at 2 to 3 r.p.m. Temperature was controlled at around 20 ºC through a thermostatic bath (Julabo, Model EC, Germany).

The monitoring and control system consisted of oxygen and pH/temperature electrodes (WTW Oxi 701, Germany, and HACH EC 310, USA, respectively).

The sodium carbonate solution of 0.5 M, used for H^+ neutralizing during nitrification, was dosed by a membrane pump (LANG, type ELADOS EMP II, 41 L/h, Germany), and the aeration was carried out by using pulses width modulation (PWM) for pneumatic valve opening (Festo, 457, MSG-24DC, Germany). The air was supplied by an aquarium aeration pump (COSMOS double type 1000, China).

Two PID (Proportional Integral Derivative) controllers were configured in the PLC (Programmable Logic Controller). The first uses the pH signal to follow a pH set-point by commanding the stroke frequency of the carbonate pump; the second one uses the oxygen signal to follow an oxygen set point by commanding the PWM (Pulse Width Modulation) signal applied to the pneumatic valve. In order to avoid a coupling effect between both controllers owing to the bacteria action, they were tuned to achieve a setting time lower than 4 min and a rise time lower than 30 seconds.

The average error obtained in both controls was lower than 0.1 for the pH and lower than 0.05 mg/L for the oxygen.

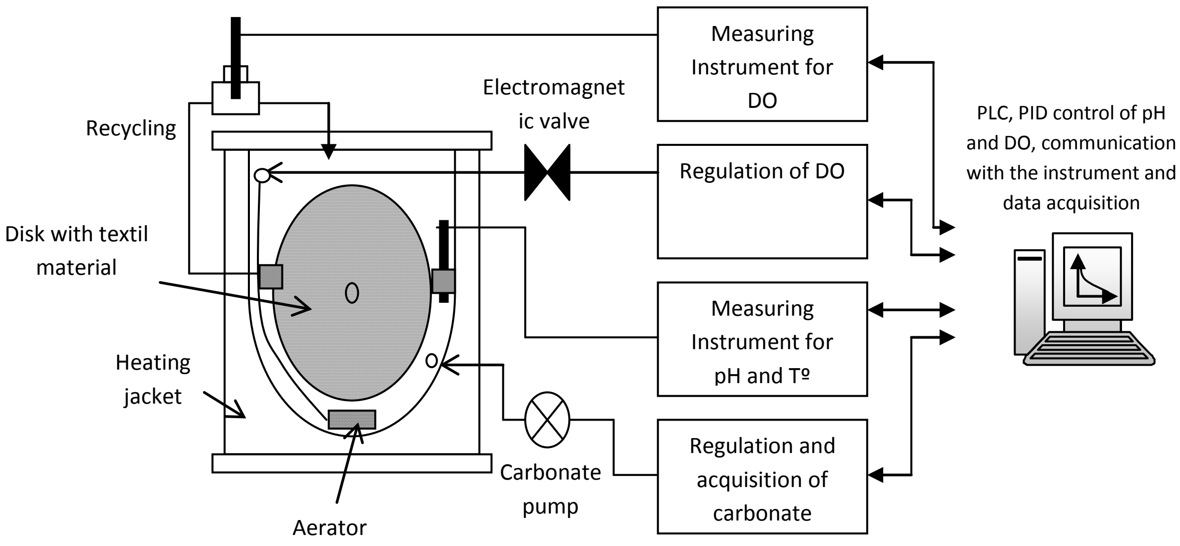


Figure 1: Experimental instrumentation and control system.

3.2 Supervisory pH Control

This work proposes a supervisory pH control to accomplish at any time the ammonia concentration during the whole sequencing batch operation. The supervisory control calculates the required value of pH, which is set in the reactor by a PID control. For calculation of the pH set point an indirect method for ammonia concentration was implemented by using on-line measurement of the stroke frequency of the carbonate pump.

The indirect method for calculating of TAN (total ammonia nitrogen), represented by Eq. 12, is a function of the numbers of strokes of the membrane pump (NS) -equivalent to a volume of carbonate (VS) pumped to the reactor during one stroke- and the initial concentration TAN_0 of each cycle.

$$TAN = \frac{TAN_0 \cdot V_R - \dfrac{N_S \cdot V_S \cdot c_C \cdot 14gN/mol}{Y^*_{CO_3^{2-}/NH_4^+}}}{V_R} \qquad (12)$$

3.3 Operation of the RDBR

After a start-up period of 120 d, a total of 59 batch cycles were carried out during a period of 270 d. In order to accumulate nitrite during nitrification, the operating pH and oxygen concentration were set for promoting the growth of AOB, and limiting-inhibiting the growth of NOB. A number of 31 batch cycles were conducted at limiting DO of 1.0 mg/L, 11 cycles at 0.8 mg/L, and 17 at 0.6 mg/L. The pH was set in the range of 7.5 to 8.6. Depending on the operational conditions (pH, DO and initial N concentration), each batch cycle lasted in the range of 50 to 120 h, using the following sequence: Filling up of the reactor with a known initial TAN concentration substrate solution, partial oxidation mainly to nitrite, interruption of aeration when the TAN was almost completely converted, emptying of the reactors contents, and beginning of a new cycle by renewing the total volume of liquid with fresh substrate within few minutes.

For each batch cycle the endpoint of ammonium oxidation was detected by on-line measurement of the carbonate solution consumption, and defined as the time at which the dosing pump did not make a stroke during 1 h. At this point the aeration was stopped until the beginning of the next cycle. Using this method, the two oxidation steps could be separated to avoid the oxidation of the accumulated nitrite to nitrate, and thus saving energy necessary for aeration.

All substrates were prepared with a constant ratio of N:P:Mg=340:10:1. The synthetic substrate composition, which is shown in Table 1, which was fed diluted to 150 g NH_4^+-N/L as initial TAN concentration. A solution of micronutrients, in a relation of 0.5 mL/g NH_4^+-N, was also added according to Ciudad et al. (2005).

3.4 Calibration and validation

The partial nitrification was modeled, running a nitrifying RDBR in continuous and sequencing batch modes for more than 700 days. In order to calibrate the model, experimental data were acquired at different pH and DO concentrations (stepwise increased). A validation at non-steady state (sequencing batch mode SBR) was carried out for different DO concentrations and pH values.

4 Results

4.1 Validation of the indirect method for the calculation of TAN

In Fig. 2 the experimental total ammonia concentrations are compared with the predicted values from Eq. 12, during three batch cycles at different concentrations of oxygen. The right axis of Fig. 2 shows the moles of carbonate pumped for the neutralizing of the protons released during nitrification, which was then converted by using Eq. 12 to TAN concentration. Fig. 2 shows a good prediction of the measured values of TAN; the differences are low and probably due to variation in the factor Y^*CO_3/TAN. This factor Y^*CO_3/TAN used in Eq.12 was not always stable during operation and varied between 1.0 and 2.5 mol CO_3^{2-}/mol NH_4. According to Fig. 2, the indirect method of calculation of TAN concentration by using on-line measurement of the consumption of carbonate can be considered reliable and valid, representing an easy and simple method for monitoring the ammonium oxidation in a SBRDR.

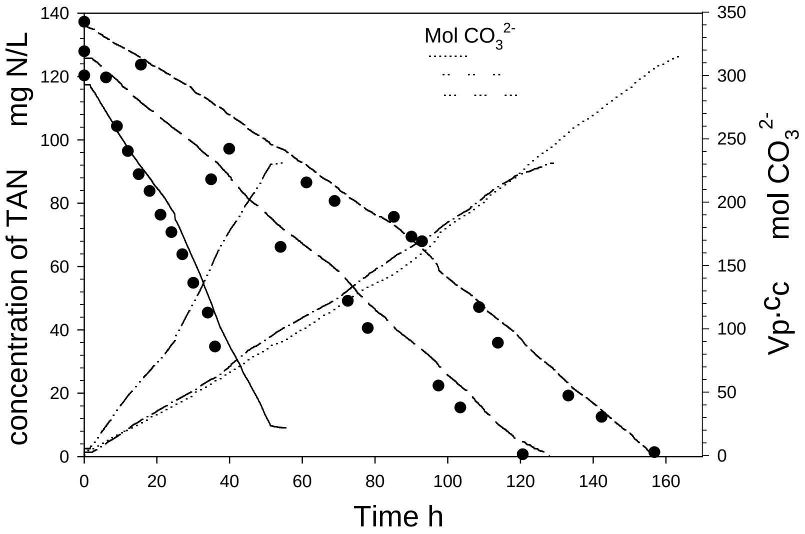


Figure 2: Experimental validation of the indirect method for measurement of TAN concentration.

4.2 Ammonium oxidation rate under partial nitrification in a RDBR

Table 1 summarizes operational information for 26 selected cycles with supervisory pH control. The greatest impact was observed by decreasing DO from 1.0 to 0.8 mg/L, causing a significant ammonium removal rate reduction from 0.10 to 0.04 kg/m³/d. Thus, the oxygen concentration clearly becomes the limiting rate during the nitrification at DO lower than 1.0 mg/L. In addition, an ammonia inhibition of NOB could possibly be due to an ammonia concentration permanently around 3 mg NH_3-N/L throughout the whole sequencing batch period (see Table 1), which is in agreement with findings reported by Bae et al. (2001). and Abeling and Seyfried (1992). Therefore, owing to simultaneous oxygen limitation and ammonia inhibition on NOB, a nitrite accumulation of 84% to 88% was possible (Table 1). The best condition for simultaneous high ammonia removal rate (0.10 kg/m³/d) and nitrite accumulation (84%) was obtained at 1.0 mg O_2/L.

Table 1. Operational information for BRDR cycles with supervisory pH control.

Nitrite accum. = NO_2^- /[NO_2^- + NO_3^-]·100

No. of Cycles	DO (mg /L)	c_{NH3} (mg N/L)	T (ºC)	r_{TAN} (kgN/m^3/d)	$r`_{TAN}$ (kgN/m^2/d)	Nitrite accum. (%)	N Loss (%)
10	1.03 ±0.03	2.77±1.57	19.1±1.2	0.10±0.07	4.25±3.12	84 ±5	4.9 ± 5
9	0.82 ±0.02	3.06±1.04	19.3±0.5	0.04±0.01	1.62±0.55	86 ±8	8.2± 6
7	0.62±0.01	2.89±0.85	22.1±0.7	0.03±0.01	1.45±0.44	88 ±7	13.2±9

The volumetric conversion rates obtained during the batch operation of the RDR were in the typical range of reactors reported by Çeçen et al.(1996) and Antileo et al. (2003). As shown in Table 2.

Specific area of RDR is relatively low (<50 m^2/m^3) compared to other biofilm reactors, which are normally higher than 100 m^2/m^3. However, if surface conversion rate is considered, results are in the same range of continuous nitrification without nitrite accumulation (Wiesmann, 1994; Thorn et al.,1996). This difference can be explained by the novel operational strategy proposed in this work for a SBRDR that leads to higher specific growth rates only limited by the oxygen concentration. In continuously operated reactors, an optimal free ammonia concentration is almost impossible if low effluent concentrations have to be reached. In addition, Table 2 shows that the nitrite accumulation lies amongst the higher levels reported in literature, but in this work the nitrite accumulation was achieved by a thin biofilm enriched with AOB, as is shown below.

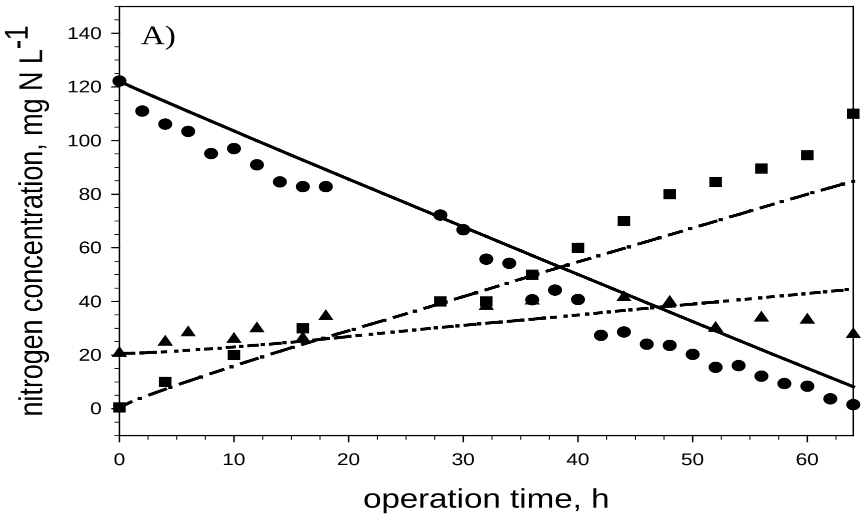
Table 2: Comparison of results obtained by different authors. UF: upflow submerged reactor; FB: fluidized bed; TF: trickling filter; Susp.: suspended culture; cont: continuous; bat: batch; OL: oxygen limitation.

Study	Reactor	pH	DO (mg /L)	Nitrite accum. (%)	r_{NH4} (kg N/m^3/d)	r'_{NH4} (kgN/m^2/d)
This study	SBRDR	7.5-8.6	0.6-1.0	>84	0.04-0.1	1.45-4.25
Cecen et al. 1996	Cont. RDR	7.5-9.0	1.3	73-90	0.1	---
Liu et al. 2001	Cont. UF	7.9-8.8	1.5-4.9	60	0.03	---
Thorn et al. 1996	Cont. UF	---	OL	97	1.2	---
Antileo et al. 2003	Bat. Susp.	8.1	2.5	>85	0.03	---

4.3 Model validation

Once the model had been calibrated in steady state (data not shown), the model was then validated in batch mode. Figures 3A and 3B show an adequate prediction of the model for two batch experiments. This result was systematically observed in all batch assays for the operation of 130 days. Therefore, the model is able to predict the operation of a nitrifying RDBR even under non-steady and batch conditions.

From Figures 3A and 3B, the decrease of TAN concentration over time is practically a straight line and depended strongly on the DO concentrations (0.8 and 0.6 mg L^{-1}). At these conditions, nitrification was strongly controlled by the oxygen transport and a possible inhibitory effect of ammonia was not detected.



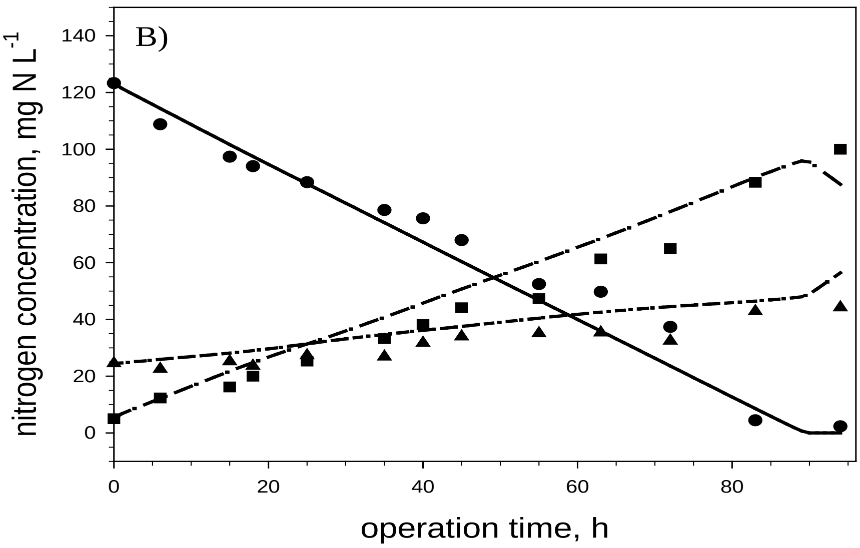


Figure 3: Model validation at non-steady state RDBR operation, pH = 8.5, = 30000 mg VSS L^{-1}, k_L = 0.44 m h^{-1}: (A) = 0.8 mg L^{-1} and (B) = 0.6 mg L^{-1}. (●).

4.4 Model Simulation: Effect of pH value and DO concentration on the partial nitrification efficiency

A continuous RDBR was simulated using the following operating conditions: HRT=12 h, ρ_b =100 g VSS L^{-1} and k_L =0.5 m h^{-1}.The combined effect of pH and dissolved oxygen concentration on nitrification in a RDBR was also evaluated in a range of 0.5 to 7 mg O_2 L^{-1} and pH values between 7 and 9. Figure 4 shows that the TAN oxidation rate is found to be strongly determined by the external transport of oxygen at NLR=12 mg N L^{-1} h^{-1} (8.5 g N m^{-2} d^{-1}). At c_{DO} < 1.5 mg O_2 L^{-1}, the TAN oxidation is always below 50% at all pH values. At c_{DO} > 2 mg O_2 L^{-1}, and as the pH increases, the availability of ammonia for AOB is higher and the TAN oxidation increases with pH. This confirms that the partial nitrification-to-nitrite process is strongly controlled by oxygen transport as well as a significant simultaneous influence of bacterial-kinetics (by pH/NH_3) is observed.

Nitrite can be feasibly accumulated at levels greater than 80% only at c_{DO} < 3 mg O_2 L^{-1} and values of pH higher than 7.5. This is due to oxygen transport limiting conditions and also because alkaline pHs favor free ammonia formation by the chemical equilibrium, and thus the competitive inhibition on NOB. The analysis of simulation established a zone of optimal operation at a NLR=12 mg N L^{-1} h^{-1}, where the nitrite accumulation β > 70% and TAN oxidation α > 80%: pH > 8 and c_{DO} < 3 mg O_2 L^{-1}.

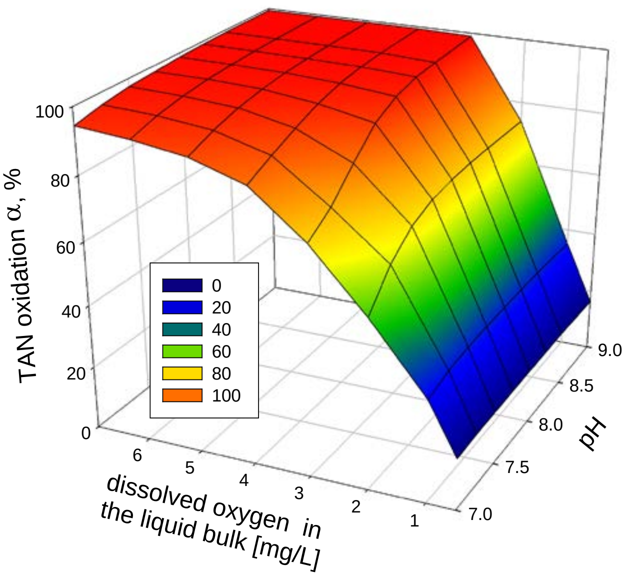


Figure 4: *Dissolved oxygen concentration and pH effect on the ammonia degradation, α. $c_{TAN,0}$ Simulation at = 150 mg N L^{-1}, HRT = 12 h, ρ_b = 100000 mg VSS L^{-1}, k_L = 0.5 m h^{-1}.*

5 Conclusions

In order to develop a stable partial nitrification to nitrite a novel operation strategy was implemented based on a supervisory pH control- for maintaining optimal ammonia concentration in the reactor- and an automatic interruption of aeration when the endpoint of ammonia oxidation was detected. The results showed that it is possible to reach a stable partial nitrification with high nitrite accumulations of 84-88% during long term assays, and a relative high ammonia conversion rate 1.45-4.25 kg NH_4-N $^+$/m^2/d with low total ammonia concentration in the effluent <1 mg N/L. A reliable indirect method for on-line monitoring of ammonia oxidation during nitrification has been implemented, by using on-line measurement of carbonate solution consumption.

The process of partial nitrification to nitrite in a RDBR operated on a long-term basis (>700 d) was represented using a dynamic model of 1-D multiple species biofilm. The dynamic model was calibrated by adjusting two parameters and adequately predicted the continuous and sequencing batch operations of a RDBR at different oxygen dissolved concentrations, pH values and NLRs. Simulating the effect of the pH and the dissolved oxygen concentration in the liquid bulk indicated that the total ammonia nitrogen oxidation was strongly controlled by external oxygen transport.

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7 Nomenclature

a_p	: Specific area of the RDBR, m^2 m^{-3}
c_{TAN}	: Total ammonia nitrogen concentration NH_3-N+NH_4^+-N, mg N L^{-1}
$c_{NO_2^-}$	: Total nitrite nitrogen concentration HNO_2-N+NO_2^--N, mg N L^{-1}
$c_{NO_3^-}$	: Total nitrate nitrogen concentration HNO_3-N+NO_3^--N, mg N L^{-1}
c_{NH_3}	: Concentration of NH_3-N, mg N L^{-1}
c_{HNO_2}	: Concentration of HNO_2-N, mg N L^{-1}
c_{DO}	: Concentration of dissolved oxygen, mg O_2 L^{-1}
c_{DO}^*	: Equilibrium concentration of oxygen at the liquid-gas phase, mg O_2 L^{-1}
c_{AOB}	: Concentration of ammonia-oxidizing bacteria , mg VSS L^{-1}
c_{NOB}	: Concentration of nitrite-oxidizing bacteria, mg VSS L^{-1}
D_i	: Diffusion coefficient of *i*: TAN, NO_2^-, NO_3^-, O_2 in water, m^2 h^{-1}
D_i^b	: Diffusion coefficient of *i*: TAN, NO_2^-, NO_3^-, O_2 in the biofilm, m^2 h^{-1}

f_i	: Volume fraction of microbial species *i*:*AOB*, *NOB*, inactive biomass
HRT	: Mean hydraulic residence time, h
$k_L a$	: Transport coefficient of oxygen concentration in the RDBR, h^{-1}

Subindex

k_L	: Mass transfer coefficient in the biofilm-liquid interphase, m h^{-1}
k_d	: Constant of death for nitrifying bacteria, h^{-1}
L	: Thickness of the biofilm, ☐m
$r_{HCO_3^-/DO}$	: Alkalinity-dissolved oxygen mole ratio, mol mol^{-1}
$Y_{AOB,i}$	: Yield coefficient of ammonia-oxidizing bacteria over to *i*: TAN, NO_2^-, NO_3^-, DO, mg VSS/mg *i*
$Y_{NOB,i}$	: Yield coefficient of nitrite-oxidizing bacteria over to *i*: TAN, NO_2^-, NO_3^-, DO, mg VSS/mg *i*
$Y_{NO_2^-/TAN}$	: stoichiometric coefficient of component NO_2^- over TAN, mg N /mg N
$Y_{NO_3^-/NO_2^-}$	: stoichiometric coefficient of component NO_3^- over NO_2^-, mg N/mg N
t	: time, h
V_L	: reactor volumen, L^{-1}
z	: Length axis in the biofilm, m
α	: Ammonium degradation coefficient, %
β	: Nitrite accumulation coefficient, %
ρ_b	: biomass density, mg VSS L^{-1}
$\mu_{\max,i}$	: maximum specific growth rate of i: AOB, NOB, h-1
bulk	: Liquid bulk
i	: Compound i = c_{N-3}, c_{N+3}, c_{N+5}
j	: inicial value
L	: Thickness of the biofilm
0	: Inlet concentration

Nutrient removal of waste water using Algae Culture and its applicability in Nepal

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Abstract

Excessive nitrogen and phosphorus loading from Municipal Wastewater Treatment Plant (MWTP) is an ongoing threat to water quality which may result in permanent eutrophication of a water system. Algae Culture is sustainable alternative technology for the removal of nutrient in wastewater. In this study, treatment efficiencies of removal of nitrogen and phosphorus in Pilot scale project, Suderburg (in 90 l basin inside the Greenhouse in MWTP) and in Lab scale research, Nepal by using Algae culture were investigated in detail. This study provides the better understanding on the mechanism and efficiency on removal of nitrogen and phosphorus in wastewater by using Algae Culture.The Total Nitrogen removal efficiency in Pilot Project, Suderburg was ranging from 75.3% to 87.9%. The removal efficiency of NH4-N in the lab scale research in Nepal was almost 100%, while the total nitrogen removal efficiency were different ranging from 69.7 % to 85.5 %. The average removal efficiency of Phosphate-P in Suderburg was 50.6% to 65.3% whereas in Nepal it was 83.8% to 94.4%. More nitrogen and phosphorus accumulate into algal biomass was identified as the main nitrogen and phosphorus removal mechanism. This shows that Algae culture can be used for the removal of nitrogen and phosphorus in wastewater and can integrate in conventional wastewater treatment or constructed wetland plant and has further possibility for application in Nepal.

Keywords: *Mass Algae Culture, Nutrient removal, Treatment efficiency, Nitrogen and Phosphorus accumulation.*

1 Introduction

Secondary effluents from wastewater constitute a medium rich in nitrogen and phosphorus nutrients. When abundant in secondary wastewater effluents, these organic nutrients are the major cause of degradation of receiving waters which may result in permanent eutrophication of a water system (Metcalf and Eddy, 1979). This problem can however be solved by tertiary treatment like Activated sludge, Biotic Nitrogen Removal, and Chemical Precipitation method. But these removal methods normally consume significant amounts of energy, chemicals and carbon source, and therefore are cost intensive. Furthermore, chemical based treatments often lead to the contamination of the sludge by-product (Tchobanoglous et al., 2003; Hoffmann, 1998). For those reasons, more research and further methods have been studied towards the development and application of economical nitrogen and phosphors removal process.

Algae Culture is a more sustainable environmental friendly technology for the removal of nitrogen and phosphorus from wastewater. It is an energy efficient system without using any kind of chemicals. In algae based wastewater treatment, algae provide an efficient way to consume nutrients and provide the aerobic bacteria with the needed oxygen through photosynthesis. So it doesn’t require extra high energy costs for aeration while aeration is an energy intensive process, accounting for 45 to 75% of a wastewater treatment plant’s total energy costs. Algae produce oxygen that can be used by aerobic bacteria to biodegrade pollutants whilst, in return, they consume the carbon dioxide released from bacterial respiration (Oswald, 1988), which provides a cheaper and safer alternative to mechanical aeration and contributes to CO_2 mitigation (Munoz and Guieysse et al., 2003; Munoz and Guieysse, 2006).

Microalgal cultures offer an elegant solution to tertiary treatments due to the ability of microalgae to use inorganic nitrogen and phosphorus for their growth (Oswald, 1988) and their capacity to remove heavy metals (Rai et al., 1981), as well as some toxic organic compounds (Redalje et al., 1989). Research was conducted to determine the treatment efficiencies on removal of nitrogen and phosphorus in Pilot Project, Suderburg, Germany and in Lab scale research, Nepal by using Algae culture and was investigated in detail.

Limitation of Algal Culture Technology:

1. *In Cold region, temperature and light become the limiting factors since microalgae generally require an optimal temperature of 20-30°C and a diurnal illumination of 45 µmol/ (m^2s) and 400-700 nm wavelengths sufficient for photosynthesis. So it will be difficult for the algal growth.*
2. *One of the main limitations of this technology is the requirement for cost-effective biomass harvesting techniques (Hoffmann, 1998). A technical separation unit consisting of filtration or centrifugation has to be applied (Mohn, 1988) which will raise the operation cost.*

2 Methodology

2.1 Experimental Set up and Operation

The experiment was set up in Suderburg Municipal WWTP and in ENPHO laboratory to conduct the research on removal of nutrient by using algae culture in pilot scale project, Suderburg and lab scale research, Nepal. The main algae species used in this study were Chlorella, Scenedesmus and natural algae from the eutrophied lake. For pilot project, 91 l basins were used and for lab scale research, 5 l basins were used (Figure 1). The secondary effluents from Municipal WWTP Suderburg and from 4 different constructed wetland plant of Nepal are used as the medium for the basins. In Pilot project, Basin 1 is filled with 5 l chlorella and 5 l scenedesmus and in Basin 3, 10 l algae from the natural eutrophic lake Hankensbuttel is used for the treatment of wastewater and the rest filled with secondary effluent from Suderburg WWTP. In lab scale research, the basin A, B, C and D (Figure 1) are correspondingly secondary effluent from ENPHO laboratory, Sunga community constructed wetland, Aamaghar Orphanage Home constructed wetland and Sushma Koirala Memorial Hospital Constructed Wetland respectively. These basins were continuously stirred for 24 hrs with 300 rev/min to avoid the sedimentation of algae. The online Digital solar meter was also installed to measures the light radiation (W/m^2) automatically for 24 hours daily. The experiment was run in natural light cycle. The basins were run in batch culture where there was no influent in the basins and was treated by the algae in certain volume of wastewater.

Figure 1: (A) Setting of Basin in Pilot Green House Project in Suderburg, Germany and (B) Experimental research set up in Environment and Public Health Organization (ENPHO), Laboratory, Nepal.

2.2 Analytical Procedure

The pH, Temperature, conductivity and O_2 (%) and O_2 (mg/l) were measured daily to determine their effects in the treatment process. The detail chemical analysis was done for NH_4-N, NO_3-N, NO_2-N and PO_4-P from each sample of the basin to determine the removal of nitrogen and phosphorus. The chemical test was done by standard method by using spectrophotometer. NH_4^+, total phosphorus and dissolved phosphorus (PO_4^{3-}) were determined according to DIN 38406-E5-1 and DINEN ISO6878-D11 (DEV., 2002) using a UV/Vis Spectrometer (Perkin Elmer, Lambda 40, USA). NO_3^- and NO_2were determined using an Ion Chromatograph (Dionex DX-100, USA) according to DINENISO10304-1 (DEV., 2002).

2.3 Measurement of Algal growth

The Micro algal growth can be measured by determining the Total Solid (TS 105°C) and Volatile Solid (VS 550°C).

2.4 Checking the settling properties of algae

The settling properties of algae from all basins were investigated. The samples from all 3 basins were put in the 1000 ml Imhoff cone and notice the settling properties of algae. The videos and photos were taken during the sedimentation of algae. An optical microscope (OLYMPUS CHT, Japan) was used for morphological characterization of microalgae.

3 Result and Discussion

3.1 Result of Pilot Algae Project in Municipal Wastewater Treatment Plant, Suderburg, Germany

3.1.1 Temperature, Dissolved oxygen and pH

Changes in temperature, pH and dissolved oxygen during operation were monitored to determine their effects on the treatment process. The initial pH value in basin 1 and 3 are 9.6 and 8.7 respectively. Then pH value decreases gradually with the treatment time (Figure 2). The pH value of each basin was totally alkaline at the beginning and later it turns into slightly acidic and reduced up to 5.5 - 6.5. Nitrogen uptake changes pH of the water medium. There are several factors which influence the culture pH such as micro algal growth, pH increase as a result of CO_2 uptake, pH decreases due to the release of H^+ ion in nitrification and excretion of acidic or basic metabolites from organic matter biodegradation (Gonzalez et al., 2008). The pH of the wastewater is affected by respiration, carried out by all microorganisms along the entire water column as long as oxygen is present, and this tends to lower the water pH as CO_2 is released into the water in the oxic zone, while the organic acids and CO_2 are discharged in the anoxic zone. On the other hand, the photosynthetic process tends to elevate water pH, due to the extraction of CO_2 (Abeliovich, 2004).

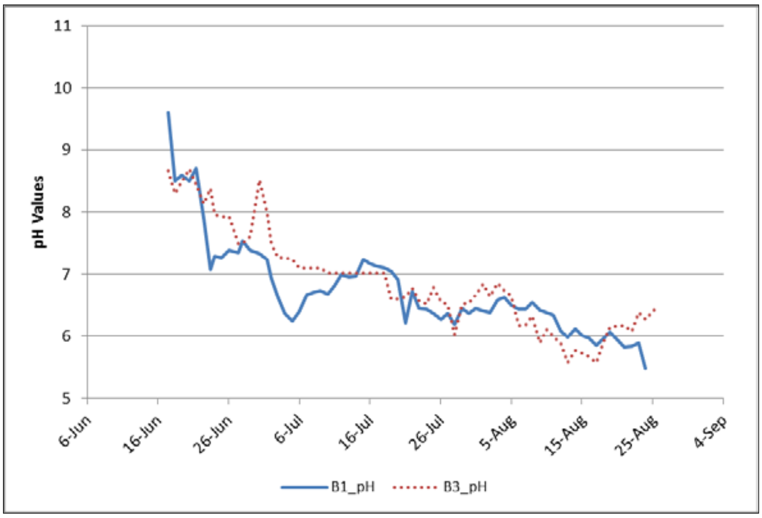

Figure 2: pH value in the basins.

The online average temperature in degree centigrade is shown in Figure 3. The temperatures in all basins were almost same. The temperature of the wastewater was between 15-33°C from 17.06.2011 to 25.08.2011.

The DO is recognized as a reliable and sensitive indicator of the state of the culture, in relation to growth and productivity. The Figure 4 shows that there is almost all similar oxygen concentration in Basin 1 and 3. Initially the algae release oxygen in the wastewater due to autotrophic process. Very high concentration of DO may build up in actively growing cultures of photoautotrophic microorganisms. When O_2 concentration decreases it indicates that O_2 released from the algal photosynthesis was consumed by processes such as by the own anabolism algae process and nitrification. Early detection of an inexplicable decrease in DO or an obvious decline in the normal rate of the daily increase under given environmental conditions, serves as a reliable warning signal that the culture is stressed and may quickly deteriorate if corrective measures are not taken (Richmond, 1986).

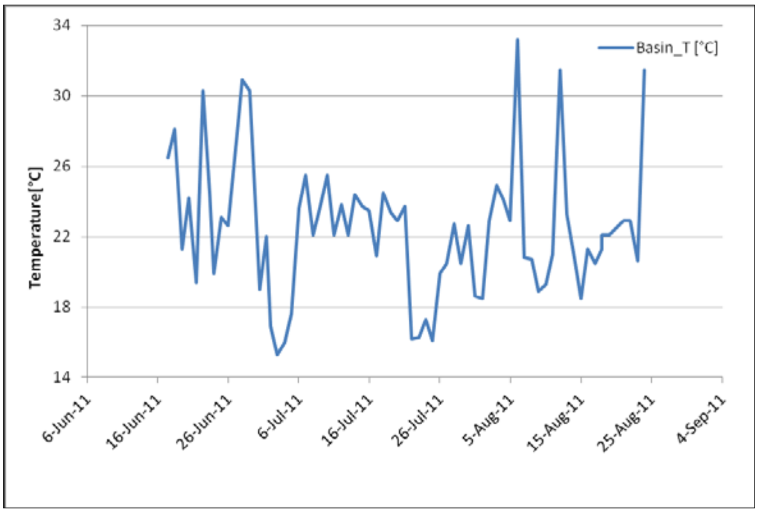

Figure 3: Temperature in the basins.

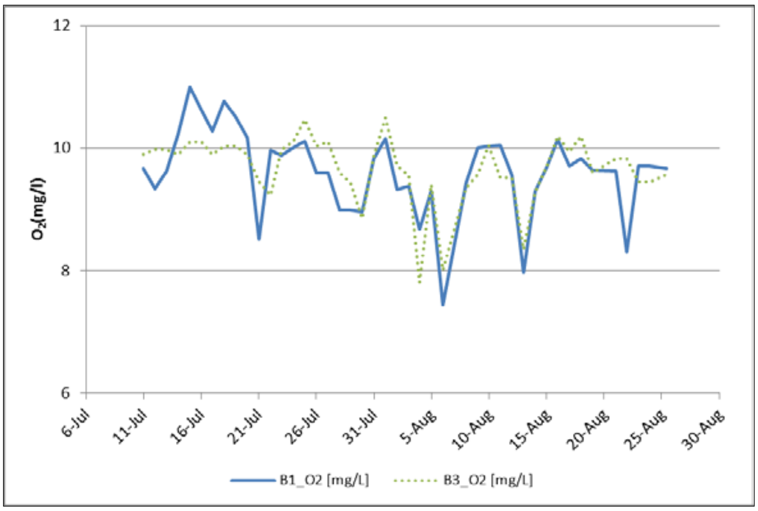

Figure 4: Oxygen concentration in the basins.

3.1.2 Removal of Phosphorus in Pilot Algae Project, Suderburg

The removal of Phosphate-P during the treatment is shown in Figure 5. The initial Phosphate-P concentration in basin 1 and 3 was 22.2 mg/l and 10.7 mg/l respectively. The Phosphate-P uptake efficiency can be calculated as:

$$P_{ei} = (P_0 - P_i) / P_0 \cdot 100 \, [\%] \quad (1)$$

Where: P_o = concentration of Phosphate-P at the beginning; P_i = concentration of Phosphate-P at the day i of the treatment.

The average Phosphate-P removal was about 50.6% and 65.3% in basin 1 and 3 respectively. There are various factors that contribute to the phosphorus removal in algae.

These include the initial nutrient concentration, nitrogen/phosphorus ratio and light/dark cycle or algae species.

Previous studies have shown that the optimal ratio for maximum nitrogen and phosphorus uptake by algal culture is N:P= 30:1 (Chavelier and de la Noue, 1985). However the ratio of NH_4-N:PO_4-P concentration in basin 1 and 3 are 4:1 and 8:1 respectively at the beginning of the batch test which is lower than optimal in this research.

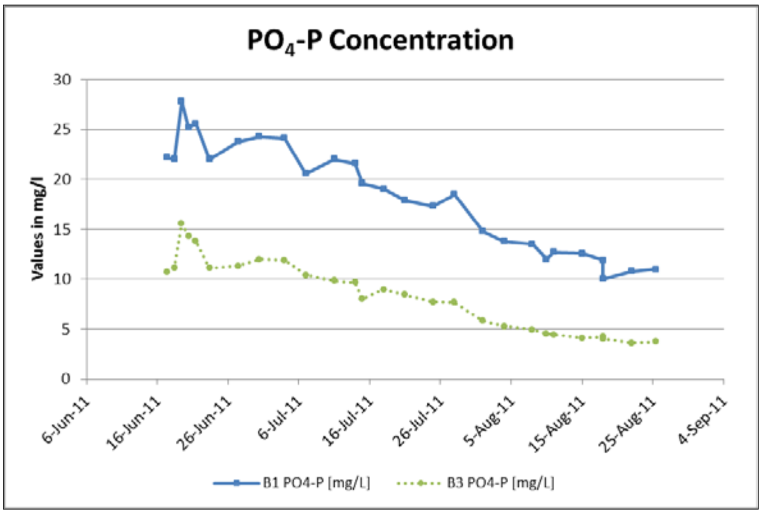

Figure 5: Phosphate-p concentration in the basins.

3.1.3 Removal of Nitrogen in Pilot Algae Project, Suderburg

The simultaneous Ammonium-N removal during the treatment in basin 1 and 3 are shown in Figure 6. The initial NH_4-N in basin 1 and 3 are 97.9 mg/l and 83.0 mg/l respectively. The average removal efficiency was about 87.8% and 84.8% in basin 1 and 3.

The Figure 7 shows the removal of Nitrate in batch culture during the treatment. The initial NO_3-N concentration in basin 1 and 3 were 15.8 mg/l and 4.9 mg/l respectively. The removal efficiency was about 82.9% and 65.1% in basin 1 and 3 respectively.

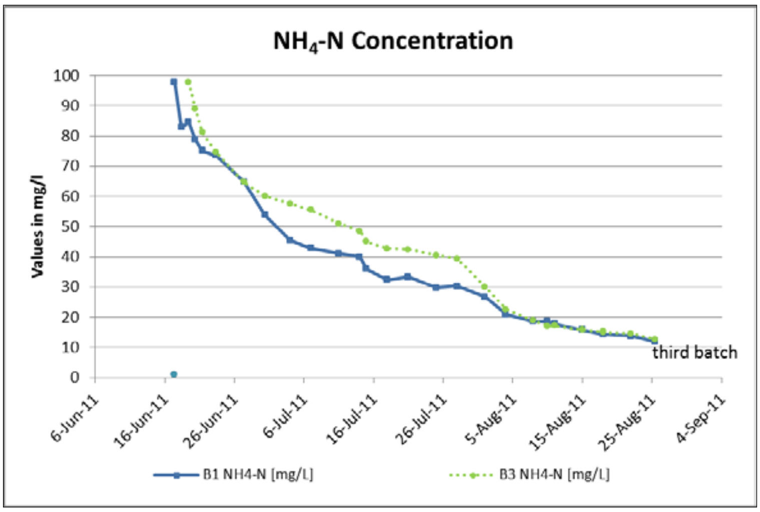

Figure 6: Ammonium-N Concentration in the basins.

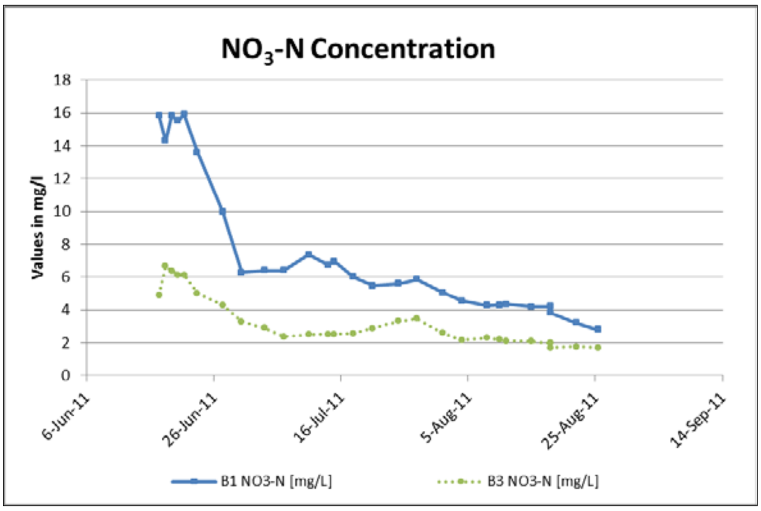

Figure 7: Nitrate-N Concentration in the basins.

The removal of NO_2-N during the treatment is shown in Figure 8. The removal efficiency of NO_2-N upto the end of the batch culture in all basins was almost 100 %. The average removal rates of Total Nitrogen in Basin 1 and 3 were 0.41 g/(m^2.d) and 0.33 g/(m^2.d) respectively. Comparing both the average removal rates for Total N and PO_4-P in all basins, it is possible to observe the following ratios:

Basin 1 = 410 mg N: 45 mg P ~ 10:1,

Basin 3 = 330 mg N: 31 mg P ~ 10:1

So in basin 1 and 3 we can see that when 1 mg P is removed, approximate 10 mg N will be removed.

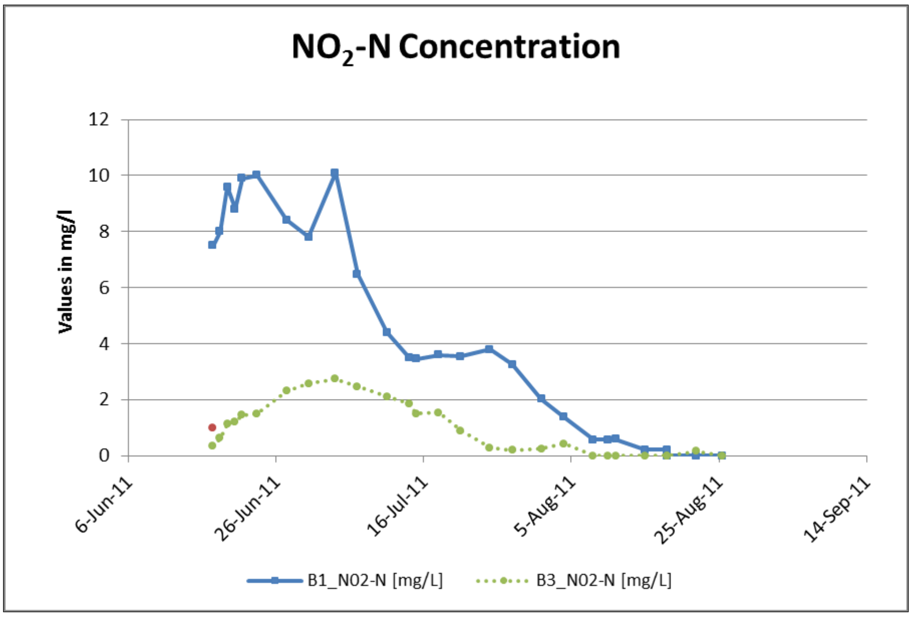

Figure 8: Nitrite-N Concentration in the basins.

The removal of NO_2-N during the treatment is shown in Figure 8. The removal efficiency of NO_2-N upto the end of the batch culture in all basins was almost 100 %.

3.1.4 Overall removal efficiency of Nitrogen and Phosphorus in Basins

The removal efficiency of Phosphorus and Nitrogen in basin 1, 2 and 3 are shown in Table 1.

Table 1: Removal Efficiency of Nitrogen and Phosphorus in Pilot Algae Project, Suderburg

Basin	PO_4-P (%)	NH_4-N (%)	NO_3-N (%)	NO_2-N (%)
Basin 1	50.58	87.80	82.28	100
Basin 3	65.33	84.75	65.10	100

3.1.5 Biomass Generation

The Figure 9 and 10 shows the Total Solids and Volatile Solids in g/l in basin 1 and 3 up to the end of batch mode. The Table 2 shows in detail the initial and Final TS and VS during the experiment period and the average increase rate of TS and VS in basin 1 and 3.

Table 2: TS and VS in the basins

Basin	Total Solid			Volatile Solid		
	Initial TS	Final TS	Average Increase rate	Initial VS	Final VS	Average Increase rate
	(g/l)	(g/l)	$g/(m^2.d)$	(g/l)	(g/l)	$g/(m^2.d)$
Basin 1	1.189	1.461	3.62	0.364	0.629	3.36
Basin 3	0.866	1.205	4.61	0.226	0.433	2.52

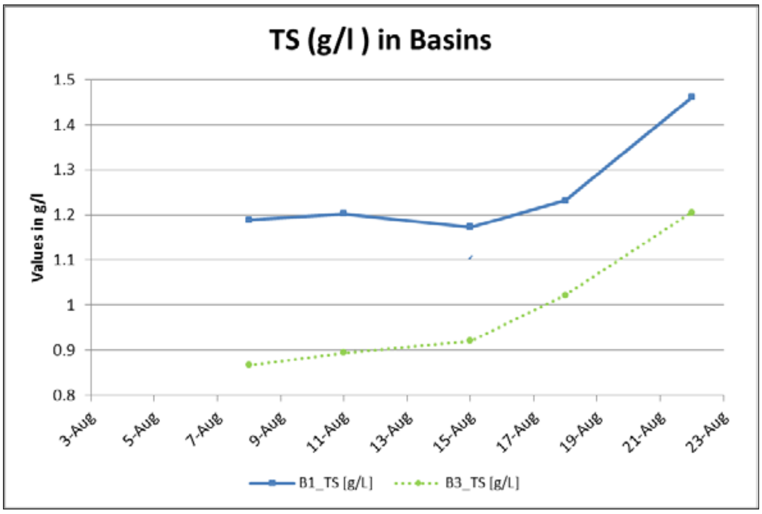

Figure 9: Total Solid (g/l) in Basins.

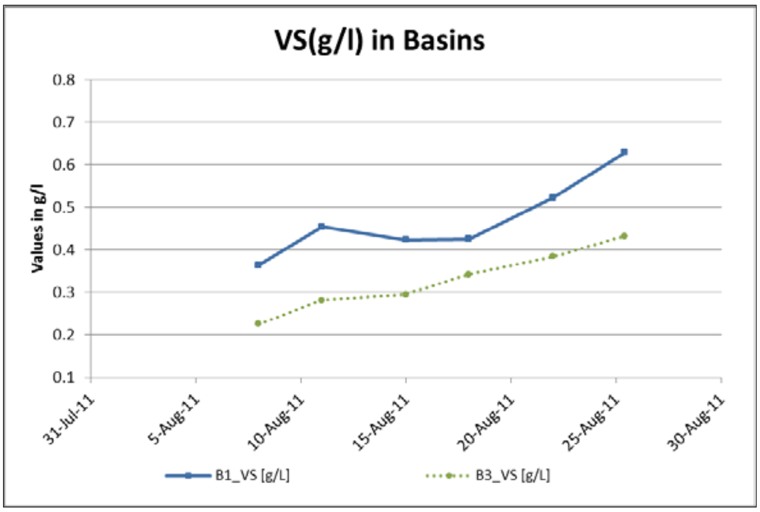

Figure 10: Volatile Solid (g/l) in the basins.

3.1.6 Settling properties of algae

The settling property of algae from all basins was investigated and is shown in Figure 11. It showed a good settleable property, as nearly all the algal-bacterial biomass settled to the bottom of glass cylinder within 20 min. From this, the settleability could be guaranteed during long-term operation. A microscopic photograph of the developed algae- Chlorella and Scenedesmus are shown in Figure 12. There may be some factors responsible for the settling process, such as the algae cell surface properties, extracellular polymeric substances (EPS) and the content of cations, which will influence the formation and the stability of the settleable algal-bacterial biomass (Gutzeit et al., 2005).

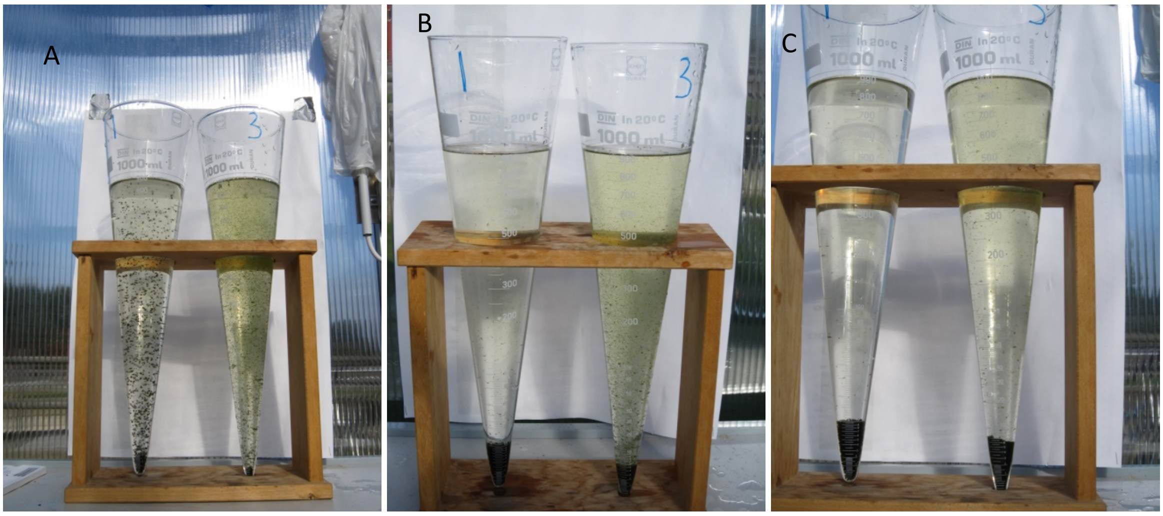

Figure 11: Settleability of algal-bacterial biomass (A) Initial completely mixed sample (B) After 3 min of sedimentation (C) After 15 mins of sedimentation.

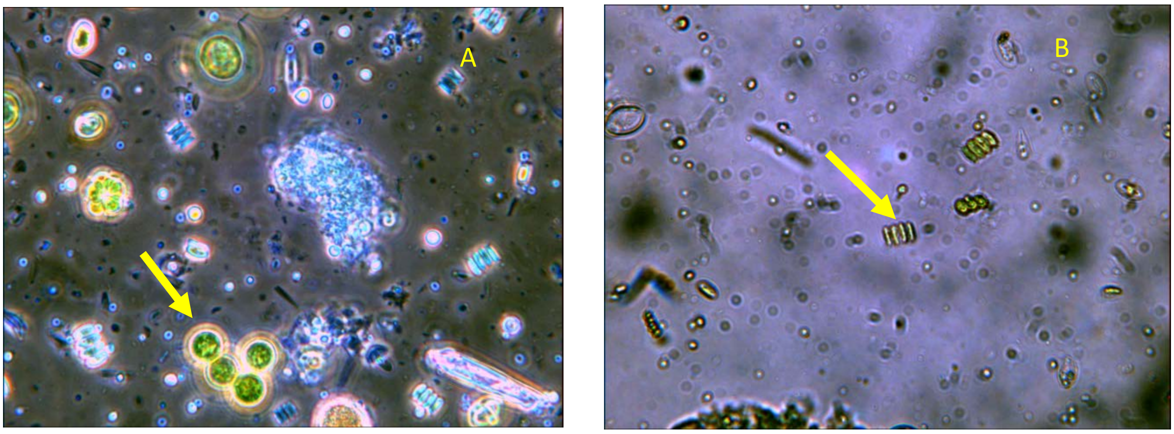

Figure 12: Microscopic view of Chlorella and Scenedesmus.

3.2 Result of Lab Scale Batch Experiment in Nepal

3.2.1 pH, Temperature and Conductivity

Recorded pH during the treatment is shown in Figure 13. The actual residence time depends upon the initial wastewater characteristics. There was only a slight change in pH value in the basins avoiding some exceptional values.

The temperature of the wastewater was between 16-23°C from 19.10.2011 to 18.11.2011. Here it is possible to see the temperature was within the best temperature range reported for algal biomass development as shown in Figure 14.

Every basin starts with different concentration, so the initial conductivity values differ from each basin. The conductivity value decreases with the treatment time but in some cases later the conductivity starts to increase at the end of the experiment as shown in Figure 15.

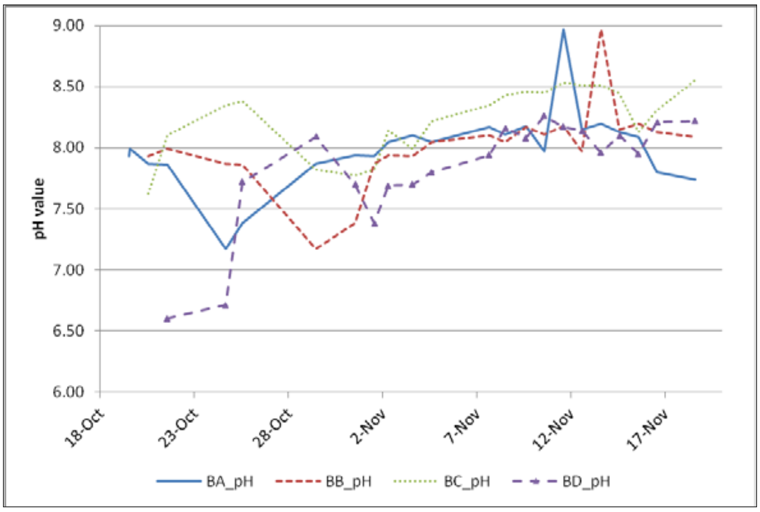

Figure 13: pH value in Basins in Lab Scale Project.

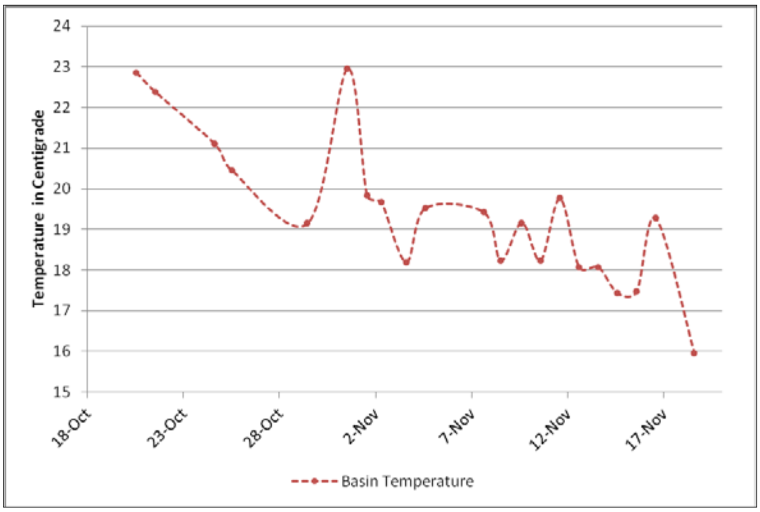

Figure 14: Temperature in Basins in Lab Scale Project.

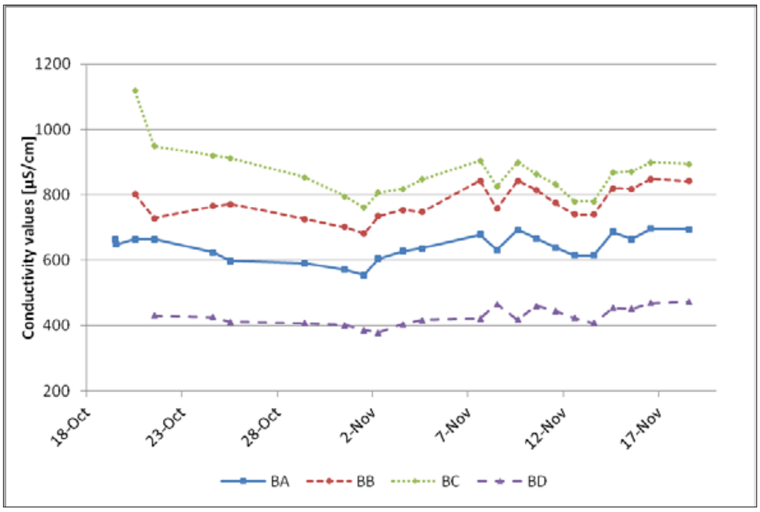

Figure 15: Conductivity in Basins in Lab Scale Project.

3.2.2 Removal of Phosphorus in Lab Scale Experiment in Nepal

The removal of PO_4-P during the treatment is shown in Figure 16. The Phosphate-P concentration in each basin decreases gradually but at the end of the experiment the PO_4-P concentration again starts to increase. There are several possibilities trying to explain this process. This could be due to the interference of specific bacterial activities, some of algae they could die and release the Phosphorus from their cell mass. The Phosphate removal efficiency in Basin A, B, C and D considering the whole cycle are 90%, 83.8%, 94.4% and 91.7% respectively. Phosphorus accumulation into the biomass was still the main mechanism in this system.

Phosphorus can be eliminated through both, biotic phosphorous assimilation into the biomass and abiotic phosphorous precipitation (Godos et al., 2009). Nurdogan and Oswald (1995) reported on abiotic P removal which took place mainly in the form of orthophosphate precipitation at high pH (9-11). In our system, the pH below 9 was not sufficient to promote this removal mechanism.

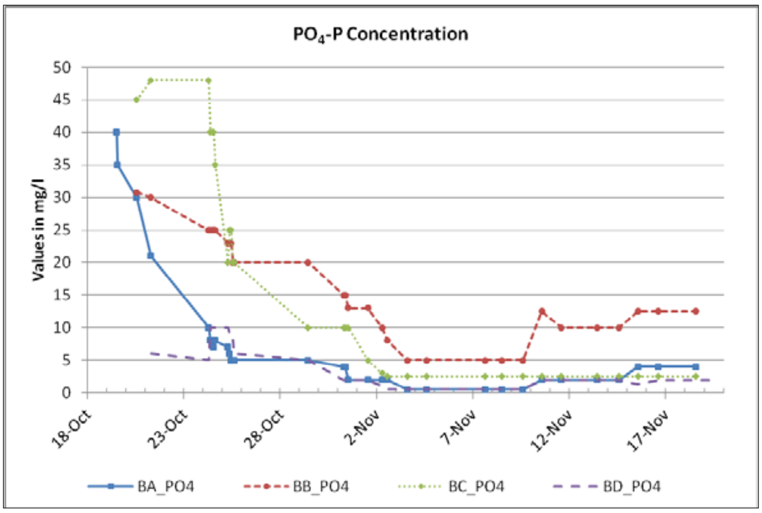

Figure 16: Phosphate-P Concentration in Basins in Lab Scale Project in Nepal.

3.2.3 Removal of Nitrogen in Lab Scale Experiment in Nepal

The removal of NH_4-N and NO_3-N during the treatment is shown in Figure 17, 18, 19 and 20. The NH_4-N was totally reduced in all basins but later at the end of the experiment it again started to increase slowly. This could be due to the death or toxic phase of algae. The Ammonium-N efficiency in Basin A, B, C and D are 100%, 99.4%, 99.9% and 100% respectively.

It seems that the level of ammonium reduced drastically whereas the level of NO_3 has increased. It is because of the conversion of ammonium to nitrate due to nitrification process for the removal of nutrient in wastewater. In the Figure 17, it also shows that the level of NH_4-N concentration decreases, and the value of NO_3-N is also quite low. It is due to the denitrification process in the wastewater treatment. In the denitrification process, the nitrate converts into Nitrogen and release freely in the atmosphere. However, the Total Nitrogen concentration reduced gradually in each basin.

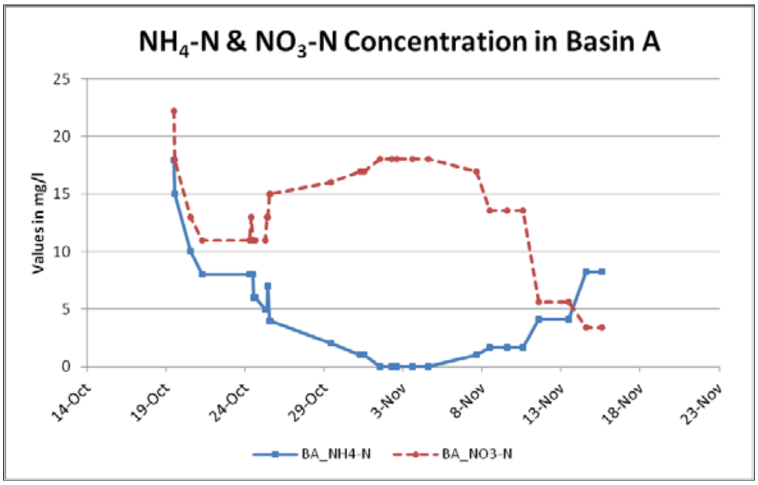

Figure 17: NH_4-N and NO_3-N Concentration in Basin A.

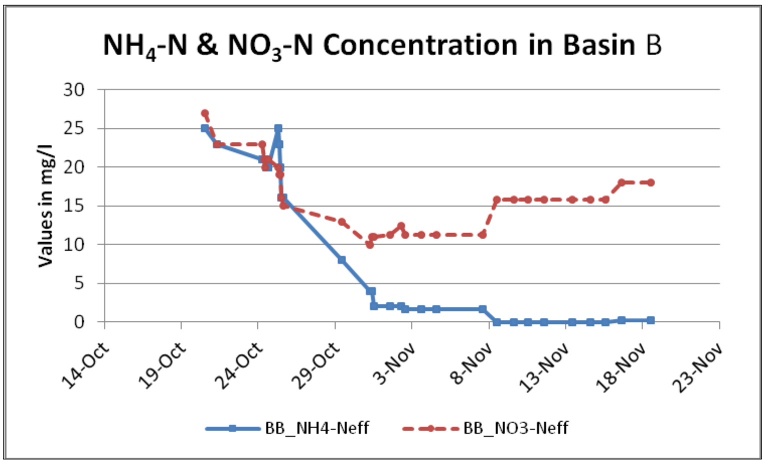

Figure 18: NH_4-N and NO_3-N Concentration in Basin B.

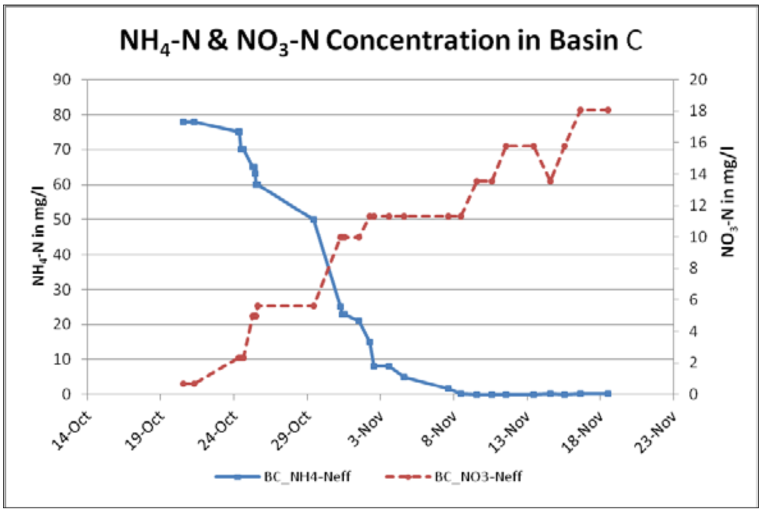

Figure 19: NH_4-N and NO_3-N Concentration in Basin C.

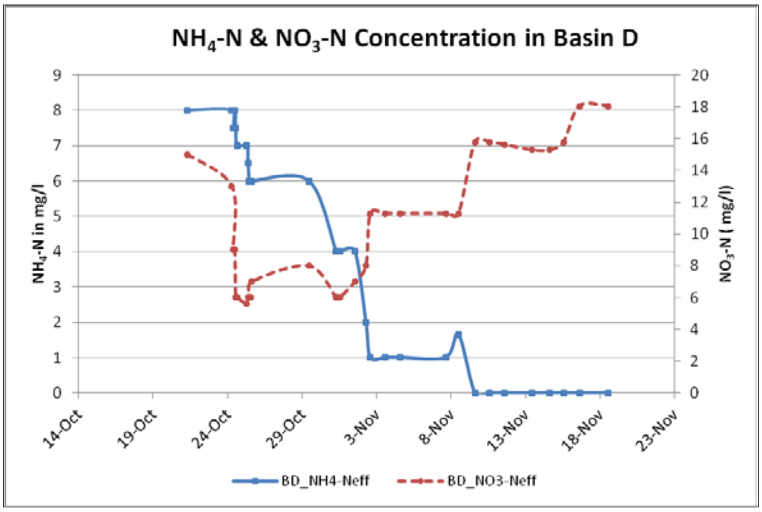

Figure 20: NH_4-N and NO_3-N Concentration in Basin D.

3.3 Comparison of the result between Pilot Algae Project, Suderburg and Lab scale research, Nepal

From the above results and discussion, now we can compare the result in Pilot Algae Project in Suderburg, Germany and Lab scale research in Nepal. The Tables 3 and 4 give the brief overview of the results in Suderburg, Germany and Nepal.

Table 3: Overall result in Pilot Algae Project, Suderburg. B = Basin; E = efficiency; R = Removal rate; CB = Concentration in Biomass; ATS = Average TS rate; AVS = Average VS rate.

B	Phosphate-P			Total Nitrogen			ATS	AVS
	E	R	CB	E	R	CB		
	[%]	[g/(m^2.d)]	[mg P/g VS]	[%]	[g/(m^2.d)]	[mg N/g VS]	[g/(m^2.d)]	[g/(m^2.d)]
1	50.6	0.045	9.55	87.9	0.41	32.83	3.62	3.36
3	65.3	0.031	5.99	83.7	0.33	32.37	4.61	2.52

Table 4: Overall result in Lab scale Algae project, Nepal.

Basin	Phosphate-P		Total Nitrogen	
	Efficiency	Removal rate	Efficiency	Removal rate
	[%]	[g/(m^2.d)]	[%]	[g/(m^2.d)]
Basin A	90	0.109	72.68	0.145
Basin B	83.76	0.088	78.76	0.29
Basin C	94.44	0.098	85.46	0.63
Basin D	91.67	0.041	69.66	0.0762

When we compare the removal efficiency and the removal rate of phosphorus in the pilot project, Suderburg and in Lab Scale research, Nepal it seems to be in Nepal there is rapid Phosphate-P reduction in very short time. There are several reasons could try to explain this point. The further increased algal biomass might have less effect on the uptake rate since the nutrient uptake by algae also depends upon other factors. The main factors would be temperature and light. In Nepal, the temperature was between 16-23°C during research time and was conducted in normal outside environment, so there was sufficient natural light intensity and temperature for the algal growth. Nitrogen and phosphorus utilization by algae depends on various factors such as the media composition, initial nutrient concentration of the media, light intensity, mixing, nitrogen/phosphorus ratio and light/dark cycle.

4 Conclusions

Pilot Algae Project in Suderburg MWTP and Lab scale research in ENPHO Laboratory, Nepal was set up to conduct research on removal of nutrient in wastewater by using Algae Culture. The result in Pilot Algae Project, Suderburg shows that the average removal efficiency of Total N in basin 1 and 3 are 87.9% and 83.7% respectively. The average removal efficiency of PO_4-P in basin 1 and 3 are 50.6% and 65.3% respectively.

The result in Lab scale Algae research in Nepal shows that the removal efficiency of Ammonium-N was almost 100%. The average Phosphate-P removal efficiency in Basin A, B, C and D considering the whole cycle are 90%, 83.7%, 94.4% and 91.7% respectively. This proves that Nitrogen and Phosphorus was efficiently removed in Nepal and shows the further possibility of using Algae Culture for advanced wastewater treatment in conventional or constructed wetland plant in Nepal. In Nepal, especially Kathmandu valley there is availability of sufficient natural light 2556 sunshine hours annually and approximatey 7.0 sunlight hours for each day and average temperature during summer season varies from 28-30ºC and in winter season, the average temperature is 10ºC (data source of the Nepal Bureau of Standards & Metrology, "Weather Meteorology" year 2005) which is very important for algal growth. It is an energy efficient system which does not require chemical for wastewater treatment and does not require extra high energy cost for aeration. So this kind of technology is more suitable, sustainable and alternative technology for country like Nepal.

This study was based on removal of nutrient by using algae culture during the batch test which is not sufficient for Municipal Wastewater Treatment Plant. Continuous mode or Sequential Bathch Reactor will proof the applicability of this method in waste water treatment.

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Water contamination: A review of biological and chemical pollutants from livestock farm wastes

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Abstract

This review focuses on the effects that agricultural wastes, particularly wastes from livestock farms, can have on water. Huge amounts of wastes are produced; the manure and urine are normally funneled into massive lagoons. If they break or leak, they send microorganisms, nitrates and other contaminants into drinking water bodies. The manure is commonly sprayed as fertilizer, bringing more harmful substances into water.

It is well-known that the widespread use of antibiotics in the livestock industry involves dangers. Large-scale animal factories often add antibiotics and other pharmaceuticals to animal feed to promote growth, or to compensate for illness resulting from crowding. Manure can also contain traces of salt and heavy metals, which can end up in bodies of water and accumulate in sediments, concentrating as they move up the food chain.

Keywords: *Meat, manure, water pollution, antibiotics, nitrates*

1 Price of waste in industrial farming

According to the Worldwatch Institute (2013), global meat production increased steadily in the last decades, with harmful effects on the environment, public health and the economy. Worldwide meat production tripled over the last fourty years and increased 20 % in the last decade. Worldwide, per capita meat consumption increased from 41.3 kilograms in 2009 to 41.9 kilograms in 2010. People in the developing world eat 32 kg of meat a year on average, compared to 80 kg per person in the industrial world. In the US, people eat 122 kg per person per year, in France 89 kg, Argentina 91 kg, Mexico 63 kg, and Camboya 16 kg (Spiegel, 2008). Between 1980 and 2005, the per capita milk consumption in developing countries almost doubled, and egg consumption increased fivefold (Onegreenplanet, 2012). Demand for livestock products will further increase, particularly in developing countries (see Table 1 for the increase in animal population from 1970 to 2010). Much of the growth in meat, milk and eggs production is due to the rise of industrial animal farms, also known as factory farming. But intensive animal production is facing growing international criticism, the main issues being the environment, the animals living conditions (figure 1 shows the difference between animals raised in small and in factory farms), and the occupational diseases.

At present, in the USA, 99.9% of chickens, 99% of turkeys, 95% of pigs, and 78% of cattle are raised on factory farms or Concentrated Animal Feeding Operations (CAFO's) (Safran Foer, 2009). According to a report from the US Department of Agriculture, 96% percent of turkeys were raised in facilities that produced at least 30000 birds per year. Production has increased almost 7-fold in the last 50 years, but the turkeys come from 150000 fewer farms (Steuer and Rogers, 2012).

Table 1: Animal population 1970-2010, (FAO, taken from Worldwatch, 2012)

	1970, million	2010, million	Increase, %
Cattle	1081	1428	32
Goats	377	921	144
Pig	547	965	76
Sheep	1063	1078	1
Ducks	256	1187	364
Rabbits	136	769	465
Turkeys	178	449	152
Geese	54	359	565
Chicken	5.2 billion	19.4 billion	273


Figure 1: Left: cow with calf at a farm close to Prague. Right: Dairy cow from industrial farm (ISCOWP, 2011).

In his book Eating Animals, J. Safran Foer states that in the past 50 years, "whereas the average cost of a new house increased in the US nearly 1500%, new cars more than 1400%, the price of milk only 350%, and eggs and chicken meat haven't even doubled. Thanks to factory farming, animal protein costs less today than at any time in history, unless one also takes into account the externalized costs: farm subsidies, environmental impact, human disease, and so on … which make the price historically high".

Worrying about the rapid increase of industrial farming is the potential to contaminate water, soil and air, mainly because of the massive amounts of manure it produces. Unfortunately, the US government lacks of federal guidelines regulating the fate of this manure. In other countries the situation is not different.

In Mexico, the livestock industry evolved in the last decades into a system of large, intensive farming units, particularly poultry and pig farms. On the other hand, most of cattle production is done under extensive conditions. The settlement of factory farms has been promoted since Mexico signed the North American Free Trade Agreement. Standards on emissions into the atmosphere, environmental impact, hazardous wastes, noise, and natural resources were formulated for controlling: the gases release, odors generation, under-utilization of nitrogen and phosphorus, improper use of persistent chemicals, zoonotic diseases, and the disposal of huge amounts of manure and wastewaters (Pérez Espejo, 2006).

Main issue in the country is contamination of water resources, highly vulnerable due to their scarcity. Mexico has only 0.1% of world's fresh water (Pérez Espejo, 2006). In regard to water, 3 standards have been issued, and particularly the Mexican Official Standard (MOS 001, On Wastewater Discharges, 1997), defines the maximum permissible limits (MPLs) of pollutants in wastewater discharges to national waters. Particularly the pig production in Mexico concentrates where water is most scarce:

- *in the Lerma River basins in the high plateaus in the geographic center (La Piedad area in the states of Michoacán and Guanajuato, with around 300 farms, 1.5 million pigs).*
- *the semi-arid, northwestern coastal states of Sonora and Sinaloa.*
- *the Yucatan peninsula.*

Authorities and producers ignore environmental effects of pig farms for two reasons: lack of specific regulations, and no economic incentives to meet the standards. Another problem is the lack of ''internalization'' of environmental costs (Pérez Espejo, 2001, 2006): medical and remediation expenses, income loss due to disappearance of aquatic species, biodiversity loss, odors and deteriorated landscapes by accumulation of waste on the banks of rivers, tributaries and the roads nearby.

Besides, there is only little information about the environmental cost from waste and wastewater from pig plants. The producers lack information on quality and quantity of wastewater, and some of them do not know how much water they consume, and the amount of wastewater generated. The Mexican farmers do not pay for the water they use, some farms have no sprayfields, and some lack of space to build a treatment plant and the waste is discharged without any treatment into water bodies. According to a research in La Piedad area involving some pig farms (Pérez-Espejo, 2006a), all the farms studied have at least one parameter that exceeds the MPLs, and all farms exceed the MPLs for fecal coliforms … this should imply a fee payment per amount of discharged wastewater, but no one pays for it.

A typical pig factory farm in the US produces 7.2 million pounds manure, a broiler operation 6.6 million pounds, and a typical cattle feedlot 344 million pounds (Safran Foer, 2009). In 2011, 248 million turkeys raised in the United States produced more than 2 million tons of waste (Steuer and Rogers, 2012). Animal agriculture in the US overall generates about one billion tons of manure each year. Animals in factory farms produce 130 times as much waste as human population, 87000 pounds manure/second. Each pig produces 2-4 times as much waste as a person (EPA, 1997). The waste excretion rate per pig varies according to type and size (Pérez Espejo, 2006):

- *piglets, weaners, milking sows ~8% of their live weight/day.*
- *growing and finishing pigs 7%.*
- *breeding stock, boars, gestating, dry sows (animals with limited access to food) ~3%.*

Possible danger points in the environment, particularly for water from uncontrolled animal waste, are (Agricultural Waste Management Field Handbook, 2009):

- *Well water contaminated by bacteria and nitrates because of leaching through soil.*
- *Waste applied at high rates: Nitrate toxicity and other N-related diseases in cattle grazing cool-season grasses; leaching of NO_3^- and microorganisms through soil, fractured rock, and sinkholes.*
- *Discharging lagoons, runoffs from open feedlots, and cattle in creeks: (a) Organic matter creates low dissolved oxygen levels in stream; (b) Ammonia concentration reaches toxic limits for fish; and (c) Stream is enriched with nutrients, creating eutrophic conditions in downstream lakes.*
- *Runoffs from fields where livestock waste is spread and there are not conservation practices on land: P and NH_4^- attached to eroded soil particles and soluble nutrients reach stream, creating eutrophic conditions in downstream lakes.*
- *Eutrophic conditions: Excess algae and aquatic weeds created by contributions from the last two items; nitrite poisoning (brown-blood disease) in fish because of high N levels in bottom muds when spring overturn occurs.*
- *Leaching of nutrients and bacteria from poorly sealed lagoons: May contaminate groundwater or enter stream as interflow.*

2 Chemical pollutants from factory farms

Pollution from livestock farms threatens humans, fish and ecosystems. Run-offs creep into waterways, and poisonous gases evaporate into the air. Workers and people living near to farms are at risk due to gases from lagoons and irrigation pivots associated with sprayfields (as manure is generally disposed of by spreading onto agricultural fields). Lagoons emit toxic gases such as ammonia, hydrogen sulfide, carbon monoxide, hydrogen cyanide and methane (Tietz, 2007; Agricultural Waste Management Field Handbook, 2009).

Poultry litter is a mixture of feed, excreta, feathers, and sometimes bedding material. The dried litter is sometimes mixed with animal feed, but is mainly disposed of by land application as a fertilizer (Stephenson et al., 1990). Poultry litter is more toxic than other animal wastes, mainly because of the feed additives, metabolic wastes, topical pesticides and the bedding material (Gupta et al., 1997). Antioxidants are added to retard degradation of vitamins in feed, tranquilizers to keep flocks quiet in the farm and before transport and topical pesticides to combat flies, lice, beetles, and mice (Gupta et al., 1997; North and Bell, 1990). Toxicity of the bedding material depends of the kind and source of it.

2.1 Nitrogen and phosphorus

Nitrogen and phosphorus are the main pollutants of concern for water quality (Table 2 shows the intake and excretion of nitrogen and phosphorus by farmed animals). Essential for plant, animal and human life, in excessive amounts are harmful, causing:

- *drinking water contamination.*

- *toxic and nontoxic algal blooms (impair recreational waters, killing aquatic life).*
- *climatic change from greenhouse gas (conversion of nitrates to nitrous oxide).*
- *acidification of soils and aquatic ecosystems.*
- *changes to coastal marine fisheries.*

Phosphor and nitrogen create “dead zones” in downstream waters, and the lack of oxygen kills aquatic life. Nitrates seeping from lagoons and sprayfields into groundwater increase the risk of blue baby syndrome (methemoglominemia), which can be deadly. Levels > 10 mg/l in water increase the health risk to elderly, children younger than 5 years old, and sick people with suppressed immune system. High levels of nitrates in drinking water near pig operations are linked to spontaneous abortions.

Table 2: Nutrient intake and excretions by different animals, kg/year (De Wit et al., 1997); * Less productive situations.

	Intake		Retention		Excretion		% N excreted in mineral form
	N	P	N	P	N	P	
Dairy cow	163.7	22.6	34.1	5.9	129.6	16.7	69
*	39.1	6.7	3.2	0.6	35.8	6.1	50
Sow	46	11.0	14.0	3.0	32.0	8.0	73
*	18.3	5.4	3.2	0.7	15.1	4.7	64
Growing pig	20	3.9	6.0	1.3	14.0	2.5	78
*	9.8	2.9	2.7	0.6	7.1	2.3	59
Layer hen	1.2	0.3	0.4	0.0	0.9	0.2	82
*	0.6	0.2	0.1	0.0	0.5	0.1	70
Broiler	1.1	0.2	0.5	0.1	0.6	0.1	83
*	0.4	0.1	0.1	0.0	0.3	0.1	60

Phosphorus, on the contrary, is not considered toxic to human and animals (the same applies to potassium, another constituent of animal waste), and is held by soil particles, depending on pH, by adsorption on clay or oxides, or forming low-solubility compounds (Fe, Al and Mn phosphates at acidic pH, and calcium phosphate at pH > 6). Phosphorus contaminates water only when manure is discharged directly into the water bodies.

2.2 Heavy metals and selenium

Manure run-offs can also contain traces of salt and heavy metals, which can end up in water bodies and accumulate in sediments, contributing to contamination of surface water and groundwater. Trace elements such as zinc, copper, cobalt, iron, manganese and selenium are added to feed rations to maintain health and promote growth (Gupta et al., 1997, Petersen et al., 2007). Metals added to poultry feed include copper, manganese, iron and zinc. Both Zn and Cu are required in trace amounts as poultry enzyme co-factors. Iron and copper are added to prevent anemia; selenium prevents oxidative damage to cells; and zinc and manganese to ensure proper eggshell deposition and feather development. Copper is added to growing pig diets as a cost effective method of enhancing performance, and is thought to act as an anti-bacterial agent in the gut. Zinc is also used in weaner pig diets for the control of postweaning scours. Other heavy metals may be present in animal diets as a result of contamination of mineral supplements (e.g., some limestone added to laying hen feeds may contain relatively high levels of Cd). In Europe the permitted levels of Cu and Zn in livestock diets have been lowered to reduce their environmental impact (Commision Regulation (EC), 2003).

Water-soluble components are readily available for uptake by plants and soil organisms, and concentrate as they make their way up the food chain. If metals accumulate in sediments, aquatic biota, plant and animal tissue, the reproduction and immune systems of aquatic and avian species may be harmed (Zn contaminates plants, Cu and Se poison aquatic and terrestrial life). Fields fertilized with poultry litter over a long time showed increased As, Cd, Zn, Cu and Mn concentrations in soil than fields not receiving litter (Rutherford et al., 2003). According to the US Fish and Wildlife Service (2004), concentrations of Al, As, Cd, Cu, Fe, Ni, Pb, Se, and Zn in water from wetlands created with swine wastewater in Nebraska exceeded the aquatic life water quality criteria. Human health is also impacted by heavy metals exposure; illnesses associated include skin and internal-organ cancer, vascular complications from As, liver dysfunction, and hair and nail loss from Se (Marks, 2001).

2.3 Arsenic

One of the major environmental pollutants: high carcionogenicity, phytotoxicity, and biotoxicity. Present in most of the litter from commercial broiler chicken operations in the US and other countries due to use of additive roxarsone (3-nitro-4-hydroxyphenylarsonic acid), for control of coccidial intestinal parasites and therefore for improvement of the feed efficiency. In 2000, ~ 5.8 billion chickens were fed roxarsone in the US (Wershaw et al., 1999). The practice of feeding organoarsenic reagents to poultry results in elevated As amounts in the litter, with concentrations in the range of 20-40 mg/kg (Jackson and Bertsch, 2001).

If poultry litter is applied to agricultural fields, As is released and may result in As in surface and groundwater, and in uptake by plants. As only a few ppm of the roxarsone remains in the chicken meat (FDA limit: 0.5 parts per million in chicken muscle tissue), most of this compound is excreted unchanged. But its degradation product, 3-amino-4-hydroxyphenylarsonic acid, can be detected in the urine of hens fed roxarsone. According to the U.S. Geological Survey (Rutherford et al., 2003; Wershaw et al., 1999), approximately 10^6 kilograms per year of roxarsone and its degradation products are introduced into the environment from the disposal of litter spread onto agricultural fields, resulting in localized arsenic pollution. In spite of the fact that no studies have been conducted on the fate of roxarsone or the degradation pathways of the compound in soils and natural waters, possible environmental degradation products are 3-amino-4-hydroxyphenylarsonic acid, methylarsines, and AsO_4^{3-}.

Arai et al. (2003) investigated the solid-state chemical speciation, desorbability, and total levels of As in poultry litter and long-term amended agricultural soils. Despite the long-term amendments of As-containing litter, they found no significant As accumulation in the surface soils, suggesting that As has probably been transported via leaching, surface runoff, surface erosion and/or uptake by agricultural crops. As no evidence for significant accumulation in agricultural crops (e.g., corn) was found in former studies, Arai et al. (2003) also suggested the importance of hydrogeological transport paths with respect to the fate of As.

3 Antibiotics abuse and biological risk of waste in industrial farming

“Some experts say we are moving back to the pre-antibiotic era. No. This will be a post-antibiotic era.” stated recently Margaret Chan (head of the World Health Organization, WHO) at the conference on Combating Antimicrobial Resistance: Time for Action (Copenhage, 2012), asking for restrictions in the use of antibiotics in food production to therapeutic purposes. “Worldwide, the fact that greater quantities of antibiotics are used in healthy animals than in unhealthy humans is a cause for great concern.”

Some studies have suggested a link between the agricultural use of antibiotics and antibiotic-resistant human infections. Accorging to a global study mapping human diseases coming from animals (tuberculosis, AIDS, bird flu), 13 diseases are responsible for 2.4 billion illness cases and 2.2 million deaths a year (Kelland, 2012). The majority of infections and deaths occur in poor or middle-income countries, but US, Europe, Brazil and parts of Southeast Asia are becoming hotspots of "emerging zoonoses", especially virulent or drug resistant. The exploding demand for livestock products means the problem is likely to get worse. Kelland cites John McDermott from the International Food Policy Research Institute: “in booming livestock sectors in developing nations the fastest growing areas are poultry and pigs - putting the potential disease risk emphasis on flu”.

From March to May 2009 the US Center for Disease Control and Prevention in Atlanta reported about a novel Influenza A (H1N1) Virus Infection in Mexico (CDC, 2009). On April 12, Mexico responded to a request for verification by the WHO of an outbreak of acute respiratory illness in the community of La Gloria, Veracruz, located close to a massive network of US-owned industrial pig farms. The inhabitants had long complained about health problems and groundwater contamination, and the outbreak helped to stop the building of more farms. On April 15-17, the Mexican Secretary of Health received a notification of clusters of severe pneumonia occurring mostly in Mexico City and San Luis Potosi. On April 23, several cases of severe respiratory illness were confirmed as the swine-origin influenza A (H1N1) virus (S-OIV) infection.

Warmblooded animals have countless microorganisms, including bacteria, viruses, parasites, and fungi (Agricultural Waste Management Field Handbook, 2009). Some are pathogenic (disease-causing). Animal waste and tainted water nurse more than 100 microbial pathogens, among others: salmonella, cryptosporidium, streptococci and girardia, and cause diseases such as acute gastroenteritis, fever and kidney failure (Tietz, 2007). In a study carried out by Cho and Kim (2000), the impact of livestock wastewater on changes in the bacterial communities in groundwater was investigated; these communities in subsurface aquifers were analyzed by characterizing their 16S rDNA sequences. Phylogenetic analysis of the sequences from a subset of the RFLP patterns showed that the Cytophaga-Flexibacter-Bacteroides and low-G1C gram-positive groups originating from livestock wastewater were responsible for the change in the bacterial community in groundwater.

On most farms, where thousands of animals are crowded into small areas, huge amounts of wastes are produced, the manure and urine are funneled into massive lagoons. These often break or leak, sending microorganisms and other contaminants into drinking water supplies. The manure is commonly sprayed as fertilizer, bringing more harmful substances into water. Due to the high consumption and their poor degradability during wastewater treatment (if treatment takes place, not always the case in Mexico or even in the US), in many cases these pharmaceuticals are not completely eliminated, and they are detected in receiving waters, entering the environment and the food chain, contributing to the rise of antibiotic-resistant bacteria, making difficult the treatment of human diseases.

Big-scale farming is contributing in an important degree to the growth of antibiotic-resistant microorganism for the simply reason that these factories consume big amounts of antimicrobials. Antimicrobials are often introduced for growth promotion into feed and water of industrially raised animals. In 2010, 13.2 million kg of antimicrobials were sold to the US poultry and livestock industries, ~80% of all antimicrobial sales (Dawood, 2012). 75 % of the antibiotics used on livestock are not absorbed by the animals and are excreted in waste, posing a serious risk to public health (Worldwatch.org, 2013). Some studies showed how antibiotic use in animal husbandry is contributing to resistance in diseases not traditionally associated with food, including drug-resistant urinary tract infections and methicillin-resistant Staphylococcus aureus, also known as MRSA (Price et al, 2012, Steuer and Rogers, 2012).

Tetracycline and sulfonamide resistance genes were found in lagoons and groundwater near swine farms (Chee-Sanford et al., 2001). Research on transfer from antibiotics from soil into cereals, in areas with high livestock activity in Northrhine Westphalia (Germany), lead to findings of tetracycline, chlortetracycline, iso-chlortetracycline, demeclocycline, and doxycycline (Freitag et al., 2008). Correlation between medication and detected tetracycline concentrations in soil and grain were not found, maybe due to remobilisation of antibiotics. Transfer of substances (enrofloxacine, tetracycline, chlortetracycline, sulfadiazine and monensine) into vegetables was studied by Grote et al. (2009) in hydroponically grown plants, with the purpose of obtaining data on the situation of vegetables grown in agricultural practices with regard to antibiotic residues. The highest concentrations of antibiotics were found in roots (tetracycline and chlortetracycline ~10 mg/kg in cabbage, ~20 mg/kg in leek), enrofloxacine (~12 mg/kg in cabbage). Chlortetracycline caused yellowing of the plant vasculature in cabbage, monensine lesions on some leaves and leaf wilting, administration of enrofloxacine lead to a nearly complete bleaching of young leaves. Low amounts of enrofloxacine were metabolized to ciprofloxacine. This study demonstrated the high potential of some vegetables for uptake of several veterinary antibiotics, especially for tetracycline and enrofloxacine.

But not only manure can be an entry port of antibiotics into the environment. The US poultry industry raises annually 9 billion broiler chickens and 80 million turkeys (45 kg per capita consumption) (Love and col., 2012). For every 3-kg chicken, 1 kg byproducts are generated (heads, bones, viscera and feathers). 2 billion kg feathers are processed into meal (rendering), and used as fertilizer, biodiesel, bioplastic, animal feed ingredient for poultry, pig, ruminant, and fish feeds. Most of the feather meal is used domestically, and the remainder is exported to Taiwan, Ecuador, Honduras, Canada, Vietnam, Indonesia, and Thailand. Antimicrobials bioaccumulate in feathers and are not always completely destroyed during rendering, becoming a pathway for reentry of drugs into human food and, when used as fertilizer, into groundwater.

4 Conclusions

"It takes over 15,000 liters of water to produce an average kilo of beef. This compares with around 1,200 liters for a kg of maize and 1800 for a kilo of wheat" United Nations Educational, Scientific and Cultural Organization (Mekkonen and Hoekstra, 2010).

The high water consumption of the livestock industry is not the only problem related to water. Animal waste contains a number of contaminants that have the potential to contaminate surface and groundwater. The farm wastes contain a range of pollutants, including excess nutrients such as nitrogen and phosphorus, heavy metals and arsenic, and pharmaceutical such as antibiotics. Factory farm practices create an ideal breeding ground for dangerous antibiotic-resistant microorganisms. But consumers have some opportunities to take action, encouraging responsible meat and poultry production by buying products from animals raised without antibiotics, but mainly by reducing consumption of animal-based products.

"Termination of use of antibiotics in Denmark as growth promoters had a voluntary component on the part of industry, strongly motivated by consumer concerns. I congratulate industry for its responsible actions ... There is another lesson. Never underestimate the importance of consumer groups and civil society in combating antimicrobial resistance. They are important movers, shakers, and front-line players, especially in this age of social media" Margaret Chan (World Health Organization), Conference on Combating Antimicrobial Resistance: Time for Action, Denmark, 2012.

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Characterization of industrial textile effluent for the irrigation of halophytic plants

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Abstract

This work characterizes the physico-chemical parameters of industrial textile effluents, afterwards discussing alternatives for the use of these waters, by means of constructed wetlands with aquatic halophyte plants and in the irrigation of terrestrial halophytic plants. The industrial textile effluent, classified as C4S4, is indicated to be refined with aquatic halophytic plants and to irrigate terrestrial halophytic plants Erva Sal (Atriplex nummularia Lindl.), Sabiá (Mimosa caesalpinaefolia Benth), Capim da praia (Paspalum vaginatum), Capim de burro (Cynodon dactylon), Erva de lobo (Solanum lycocarpum), Major Gomes (Talinum triangulare), Vetiver (Vetiveria zizanioides) and Junco (Cyperus articulatus), an appropriate soil, water and halophytic plant management for these effluents being recommended..

Keywords: *textile effluent, halophytic plants, irrigation, constructed wetlands, reuse*

1 Introduction

The effluents from the waste water treatment plants of textile industries may cause environmental problems when they are released into the soil or into receiving bodies. It is necessary that these impacts be avoided or minimized by means of some forms of utilization of the treated waste or through complementary treatments which provide a refining of the same before their final use. Among the forms of utilization of treated waste is the irrigation of halophytic plants and the refining of the same, with the advantage of reducing their volume; aquatic halophytic plants in constructed wetland systems being utilized also provide the benefit of excellent landscape integration.

2 Material and methods

The CAGECE Waste Water Treatment Plant (ETE), ETE Pacajus, where the present research was developed, is situated in the municipality of Pacajus (4º 1' 21'' S e 38º 27' 38'' O, at 73 meters above sea level, a distance of 40 km from Fortaleza, the capital of Ceará).

The Waste Water Treatment Plant in Pacajus is composed of the following units: pre-treatment using grating, sand box and fine sifting; biological treament in an optional lake aerated with 12 aerators of 15 horsepower each; addition of nutrients (nitrogen and phosphorus); addition of coagulants, flaking and decantation; disinfection with chlorine.

The Waste Water Treatment Plant in Pacajus was designed for treating an average flow rate of 83 m³/h of waste water: 80m³/h of industrial waste water and 3 m³/h of domestic waste water. It also works with a flow rate above that projected since two other textile factories arose in the area and their waste water was connected to this water treatment plant. For this reason, the treatment is deficient and a bad smell occurs in the area and the final effluent comes out blue due to the indigo blue pigmentation.

The characterization of the final effluent was made from samples collected weekly during a period of 15 months (50 samples), the physico-chemical analysis being made from the following parameters: pH, bicarbonates, hardness, calcium, magnesium, conductivity, chlorides, sulphates, iron, sodium, potassium, nitrites, nitrates, free ammonium, total solids, total suspended solids, dissolved solids, BOD5 and COD, all by the methods recommended by APHA (1992).

The bacteriological analysis was made by evaluating the fecal coliforms and total coliforms, observing the methods of APHA (1992). Also determined were the relationship of absorption of sodium and the COD/ BOD5 relationship.

3 Results

Table 1 presents the analysis of the values of the diverse parameters of the quality of the final effluent of the waste water treatment plant (ETE Pacajus) which were utilized in the research in the period from April 2000 to June of 2001.

The average pH value found in the final effluent was 8.24, falling within the permissible limits for irrigation waters, which is 8.24 (Ayers and Westcott, 1991) and also within the range of 6.0 to 9.0 established by the CONAMA Resolution #20 of 06/18/86 for waters belongings to the classes 1, 2 and 3.

The use of effluents for irrigation with a pH higher than 8.4 may result in the deterioration of the irrigation equipment through corrosion or incrustation, and the availability of ions which are toxic to the plants, such as chloride, sodium and boron, where damage to the cultures and to the soil may be provoked individually or in combination with these ions (Ayers and Westcott, 1991).

Taking care of the industrial effluent, which has the possibility of containing heavy metals such as chromium, cobalt, copper and zinc, it is important to emphasize that the elevated pH of the effluent, on being released into the soil, may raise the pH of the same and make the heavy metals less soluble and less available to the plants, through the tendency to form precipitates with hydroxides and carbonates (Simao and Siqueira, 2001; Wong, 1998).

In fine-textured soils, the maintenance of pH between 6 and 8.5 permits continual irrigation for a period greater than 20 years with effluents with the following maximum proportions of heavy metals: chromium – 1 mg/L; cobalt – 5 mg/L; copper – 5 mg/L and zinc – 10 mg/L, without damage being caused to the cultures (Bouwer and Idelovitch, 1987). These values are higher than those permitted by the CONAMA Resolution #20 of 06/18/86 for the classes of irrigation (1, 2 and 3), which are: for chromium, 0.05 mg/L; cobalt, 0.2 mg/L;

copper, 0.02 mg/L (classes 1 and 2) and 0.5 mg/L (class 3) and zinc, 0.18 mg/L (classes 1 and 2) and 0.5 mg/L (class 3).

The average hardness value found in the final effluent was 407.7 mg/L. According to Von Sperling (1996), this final effluent may be classified as very hard, since it presence a hardness higher than 300 mg/L. Hardness in the final effluent results in the presence of carbonates ($CaCO_3$).

The average value of calcium found in the final effluent was 71.84 mg/L. Calcium is a macro nutrient essential to plant growth and its supply in acid soils is a benefit for greater production (Feigin et al., 1991). The presence of calcium in the irrigation water diminishes the values of the sodium absorption relationship.

Table 1: Results of the parameters of the quality of the final effluent of the ETE in weekly samples (total of 50 samples) in the period from April 2000 to June of 2001. Pacajus, Ceará. Source: CAGECE (2001).

PARAMETERS	AVERAGE VALUE OF FINAL EFFLUENT	STANDARD DEVIATION OF THE FINAL EFFLUENT	LEVEL OF SIGNIFICANCE
pH	8.2398	.21372	0.000
Bicarbonates	931.7200 mg/L	351.97478	0.000
Hardness	407.7200 mg/L	313.06386	0.000
Calcium	71.8360 mg/L	86.44808	0.000
Magnesium	55.4392 mg/L	44.20054	0.000
Relationship of the Absorption of Sodium (RAS)	148.4237	55.36484	0.000
Electric conductivity (CE)	5782.2840 uS/cm	1102.52521	0.000
Chlorides	503.4200 mg/L	105.09997	0.000
Sulphates	506.2524 mg/L	225,79282	0.000
Iron	2.5908 mg/L	2,03203	0.000
Sodium	1047.8640 mg/L	329.54866	0.000
Potassium	365.2920 mg/L	131.78451	0.000
Nitrites	0.9522 mg/L	0.79746	0.000
Nitrates	5.7036 mg/L	1.89853	0.017
Free ammonium	7.3104 mg/L	3.91853	0.000
Total solids	3931.6800 mg/L	891.64451	0.000
Suspended solids	246.1400 mg/L	614.28684	0.016
Dissolved solids	3692.3600 mg/L	986.05702	0.000
BOD5	203.0400 mg/L	124.23890	0.000
COD	310.6600 mg/L	133.94449	0.000
COD/ BOD5	3.1152	5.60136	0.007
Faecal coliforms	772051.3 /100ml	3202209.587	0.000
Total coliforms	8423469 /100ml	29687295.61	0.000

The average value of magnesium found in the final effluent was 55.44 mg/L. Magnesium is a macro nutrient essential to the growth of the cultures, being important to chlorophyll formation. The presence of magnesium in the irrigation water diminishes the values of the sodium absorption relationship.

The average value of the Sodium Absorption Relationship, SAR found in the final effluent was 148.4 in the final effluent. This value is above the limit of > 8, which, according to Reichart (1978), indicates a very high risk of the diminishment of soil permeability. According to a classification developed by the North-American Department of Agriculture, the final effluent would be classified as able to promote a very strong risk of salification by presenting an average value of SAR > 26. Utilizing the classification of Bernardo (1987), the final effluent is classified as S4 – water with a high sodium concentration (SAR > 43.75).

The average value of electrical conductivity in the final effluent was 5782.3 µS/cm. According to Bernardo (1987), the final effluent is classified as C4 – water with a very high salinity (CE between 2.250 and 5.000 µS/cm at 25 ºC). The chlorides (Cl^-) are ions occurring from the dissolution of salts (ex.: sodium chloride) (von Sperling, 1996). The average value of chlorides in the final effluent was 503.4 mg/L and this is considerably above the range of 140-350 mg/L, a range which, according to Bouwer and Idelovitch (1987), may affect the growth of some plants. According to the same author, the plants vary in relation to their sensitivity to the chlorides. It is also above the permissible limit of the CONAMA Resolution #20 of 06/18/86, which determines the limit of 250 mg/L of chlorides for the irrigation classes 1, 2 and 3.

The average value of sulphates in the final effluent was 506.3 mg/L. This value is above the limit permitted by the CONAMA Resolution #20 of 06/18/86, which established the limit of 250 mg/L of sulphates for the classes 1, 2 and 3. Sulphur is an important nutrient for plants and micro-organisms. Its deficiency causes necrosis in the stem and weakness in the new leaves (light-green leaves) (Zamberlan and Froncheti, 2001).

Iron has little sanitary significance in its concentrations, generally found in natural waters: in small concentrations, it causes problems in the color of the water and in certain concentrations it may cause taste and odor (von Sperling, 1996). It is a micro nutrient which is important in the formation of chlorophyll in plants and empowers the utilization of other nutrients. The average value of iron found in the final effluent was 2.59 mg/L, and is above the limit permitted by CONAMA Resolution #20 of 06/18/86 for classes 1 and 2, which is 0.3 mg/L, and below the limit permitted for class 3, which is 5.0 mg/L.

The average value of sodium in the final effluent was 1047.9 mg/L. Elevated concentrations of sodium in irrigation water may affect the structure and reduce hydraulic conductivity of fine-textured (Bouwer and Idelovitch, 1987), the specific case of the soil in the municipality which the research was developed. Sodium presents adverse effects in the cultures (which may not be halophyte) such as burning in the leaves and death of the plants. According to Bouwer & Idelovitch (1987), if the irrigation water is not absorbed by the leaves, such as in irrigation by sprinkling, there will not be problems if the sodium concentration is below 70 mg/L, but increasing problems of target intoxication by this element may be expected when the values surpass 70 mg/L. Sodium is an essential element in the metabolism of halophyte plants, such as erva sal (Atriplex nummularia) (FAO, 1996).

The average value of potassium in the final effluent was 365.3 mg/L. It is a macro nutrient essential to the growth of the cultures and necessary to the obtaining of high-quality products (fruits). It is cited by FAO (1996) as a nutrient which is essential to the metabolism of erva sal (Atriplex nummularia). In a general form, the proportion of potassium found in the soils is low. In the soils to be cultivated, it is recommended that fertilizer be used which contains it, such as saltpeter from Chile and potassium chloride. In the previous analysis made in the area of the ETE Pacajus, the content of potassium found was 39 mg/dm³, which is considered as low by Malavolta (1989).

The average value of nitrites in the final effluent was 0.952 mg/L. This value is within the limit of 1.0 mg/L permitted for classes 1, 2 and 3 by CONAMA Resolution #20 of 06/18/86. An excess of nitrites in the water or effluent used in irrigated may cause the conversion of nitrites into nitrates, which, in forage plants ingested by animals, may produce methemoglobin in place of hemoglobin in the blood, which may cause cyanosis, a fatal illness in animals (Bouwer and Idelovitch, 1987). The average value of nitrates in the final effluent was 5.7036 mg/L. This value is within the limit permitted by CONAMA Resolution #20 of 06/18/86 for the classes 1, 2 and 3, which is 10 mg/L. The excess of nitrates accumulated in forages may cause toxicity through the production of oxidizable gases, which are lethal to humans and animals (Bouwer and Idelovitch, 1987).

The nitrate is a form of nitrogen which is soluble in water and easily transported by solution of the soil, of the root zone to the groundwater and from there to the drainage networks, where it may contaminate potable water supplies; thus it is necessary to monitor the ground water as often as the residual water is used for irrigation.

Free ammonia is one of the principal forms of nitrogen which is assimilated by the plants (Bastos, 1999). The average value of free ammonium found in the final effluent was 7.31 mg/L. This value is above the limit of 0.2 mg/L established by CONAMA Resolution #20 of 06/18/86 for classes 1 and 2.

The excess of nitrogen in plants may be visually observed by means of the following symptoms: excessive plant growth, toppling, deficient flowering and deficient fruit production. These symptoms were absent in the erva sal plants (Atriplex nummularia Lindl.), sabiá (Mimosa caesalpinaefolia Benth.), capim da praia (Paspalum vaginatum) and capim de burro (Cynodon dactylon), which were irrigated with the final effluent, a fact which suggests the absence of excess of nitrogen in the final effluent of the ETE.

The total solids include the organic and inorganic solids, the suspended, dissolved and sedimentary (von Sperling, 1996). The average value of the total solids found in the final effluent of the Pacajus ETE was 3931.7 mg/L. The average value of the suspended solids determined in the final effluent was 246.1 mg/L. The depositing of excess suspended solids in the surface soil may obstruct it and consequently reduce the infiltration of water and aeration. Elevated concentrations of organic solids in effluents may cause the decline of oxygen in the root zones, even to the point of killing the cultures.

Using irrigation by sprinkling, the colloid particles may be deposited in the leaves, where they may reduce the photosynthetic activity and damage the appearance of the product. Increased concentrations of suspended solids in the irrigation water may interfere in the flow of water in pipes, sprinklers, drippers and hydraulic structures.

Suspended solids, the majority of which are of an organic nature, may negatively affect the efficiency of chlorination, since the bacteria and viruses may be protected by the organic particles from effective contact with the chlorine. They also defile the aesthetics of the use of residual waters for irrigation. For unrestricted irrigation, they may be removed by methods such as sand filtration, treatment via aquiferous soil by means of the recharging of the ground water to filter the effluent through the natural soil, sand and gravel (Bouwer and Idelovitch, 1987). The average value of the dissolved solids in the final effluent was 3692.4 mg/L. These solids are inorganic by nature and their polluting effect is associated with the salinity of the effluent, prejudicing the plantations (von Sperling, 1996). CONAMA Resolution #20 of 06/18/86 establishes the value limit of 500 mg/L of total dissolved solids for the classes 1, 2 and 3. It may be observed that it is much above this value in the final effluent, corresponding to more than 6 times the permitted limit for waters to be used for irrigation.

The Biochemical Oxygen Demand, BOD5, is one way of indirectly determining the proportion of organic material and is associated with the biodegradable fraction of the carbonaceous organic components (von Sperling, 1996). The average value of the BOD5 in the final effluent was 203 mg/L. The average BOD is above the limit permitted by the CONAMA Resolution #20 of 06/18/86, which is 3 mg/L for class 1, 2.5 mg/L for class and 10 mg/L for class 3.

The Chemical Oxygen Demand, COD, is another form of determining the proportion of organic material in the effluent and represents the quantity of oxygen required to chemically establish the carbonaceous organic material (von Sperling, 1996). The average value of the COD found in the final effluent was 310.7 mg/L.

The COD/ BOD5 relation measures the biodegradability of the effluents; when it is low, the biodegradable fraction is high, and when it is high, the biodegradable fraction is low (von Sperling, 1996; Henze, 1997). According to Henze (1997), when the value of the COD/ BOD5 relation is between 1.5 and 2.0, the relation is low, when it is between 2.0 – 2.5, it is typical and when it is between 2.5 and 3.5, it is high. The average value of the COD/ BOD5 relationship found in the final effluent was 3.12, which falls into the high range. Removing the extreme values which altered the average value in the final effluent, the average of 1.74 is obtained, which falls into the low range, signifying that the same possesses an elevated biodegradable fraction.

The concentrations of fecal coliforms in the final effluent presented an average value of 772051.13 CF/100 ml. According to CONAMA Resolution #20 of 06/18/86, the final effluent does not fall into any of the irrigation classes, since the limit for fecal coliforms for class 3 is 4000 CF/100 ml. In this class, the waters may be directed to the irrigation of arboreal cultures, cereal plants and forage plants. The increased concentrations of fecal coliforms in the final effluent are due to the fact that the textile industrial waste water is mixed with domestic waste water from the factory, the which furnishes nutrients to improve the treatment (CAGECE, 1999) and also to the fact that, during the research, the Pacajus ETE received the effluent from another textile industry; the fact being that the enlargement of the ETE was only concluded after the research was done. The average value of total coliforms found in the final effluent was 8.4×10^{6} CT/100 ml. This value is above those permitted by CONAMA Resolution #20 of 06/18/86 for the irrigation classes 1, 2 and 3, whose respective limits are 1.000, 5.000 and 20.000 CT/100 ml.

Based on the research of Silveira Neto (2003, 2006), the table 2 presents the indicated plants and industrial textile effluents.

Table 2: Halophyte plants indicated and industrial textile effluents

Plants	Principal uses	Type of irrigation recommended
Erva sal (Atriplex nummularia)	Forage, recuperation of salinized areas.	Localized
Sabiá (Mimosa caesalpinaefolia)	reflorescence	Localized
Capim da praia (Paspalum vaginatum)	Forage, waste refining.	Constructed wetlands
Capim de burro (Cynodon dactylon)	Forage, waste refining.	Constructed wetlands
Erva de lobo (Solanum lycocarpum)	Living fence, fruit-bearing, ornamental.	Localized
Major Gomes (Talinum triangulare)	Soil protection, ornamental, human and fauna alimentation.	Localized
Vetiver (Vetiveria zizanioides)	Soil protection, production of aromatic oils.	Constructed wetlands, localized.
Junco (Cyperus articulatus)	Craft work, soil protection, waste refining	Constructed wetlands

Analyzing the table 2, it may be affirmed that the final effluent from the Pacajus ETE may be reused for the production of the exotic plants Erva Sal (Atriplex nummularia Lindl.) and Vetiver (vetiveria zizanioides) and the native plants Sabiá (Mimosa caesalpinaefolia), capim da praia (Paspalum vaginatum), capim de burro (Cynodon dactylon), erva de lobo (Solanum lycocarpum), Major Gomes (Talinum triangulare) and junco (Cyperus articulatus).

Utilizing the final effluent for the production of cuttings of the erva sal (Atriplex nummularia), the same may be put in areas where the final effluent is emptied onto the soil and transferred to salty areas of the Northeast, as they have the potential to remove between 5 and 10t of sodium/ha./year and to incorporate organic material in the soil (Holanda et al., 2001) and, apart from their use as forage, produce high-quality firewood and charcoal (FAO, 1996). The erva sal (Atriplex nummularia) presents, in this form, a potential alternative for increase in agricultural production and the diminution of environmental impacts caused by the salinization of the soil.

The Sabiá (Mimosa caesalpinaefolia Benth.), which also developed better with the final effluent, presents the following characteristics of environmental interest: it is a native Northeastern plant, a pioneer, tolerates slightly acid soils and is a xerophile plant. Being a leguminous plant, it presents great potential for the rehabilitation of degraded areas, especially concerning biological supply and nitrogen cycling and furnishing forage with a high protein proportion. The leguminous forage plants are known as “protein banks”, as they complement the amino acids which the gramineous plants do not possess.

The Sabiá (Mimosa caesalpinaefolia Benth.) also serves in the bio-monitoring of heavy metals in the soil, indicating their presence principally by chlorosis of the leaves; it is also a phyto-remover of the same. Utilized as a living fence, it may minimize the environmental impacts of the aerosols generated by the ETE and in the locales where the effluent is released. The wood produced by the Sabiá (Mimosa caesalpinaefolia Benth.) is much used in the production of stakes in the Northeast of Brazil.

The gramineous plants capim da praia (Paspalum vaginatum) and capim de burro (Cynodon dactylon) may be cultivated in the constructed wetland system. This kind of cultivation presents the advantage of the production of forage without the contamination of the soil and the ground water of the region. The forage, produced and made available to the cattle ranchers of the region, would permit the diminishing of the impact made by the pasturing of ruminants in the countryside, with the compacting and exposition of the soil to erosion, due to over-pasturing and the consequent destruction of the flora.

Being gramineous plants adapted to the effluent and to the bio-solids of the same (a fact observed in the mud discharge zone) and freeing phytosiderophores in the exuding of the roots, the identification of chemical composition of the root exuding will allow the increase of the precision of the total bio-available quantities of heavy metals present in the soil.

These native gramineous plants present an elevated density of fasciculate roots which, in conjunction with the rhizomes and vegetal covering, provide recovering of the soil, avoiding the Aeolic erosion and minimizing the impact of rain and the release of effluent in the soil. Being a xerophile plant, it is recommended that the capim de burro (Cynodon dactylon) be put in areas which are more peripheral to the locales where the effluent would be released. The capim da praia (Paspalum vaginatum) may be planted in the margins adjacent to the effluent, being possible that the same may grow less where the soil remains submersed in the effluent.

The capim da praia (Paspalum vaginatum) produced with effluents of the ETE may be utilized to recover degraded areas of mangrove swamps, principally those near the cities. The association of the gramineous capim da praia (Paspalum vaginatum) or the capim de burro (Cynodon dactylon) with the leguminous Sabiá (Mimosa caesalpinaefolia Benth.) is a sustainable alternative in the production of native, balanced forage and may benefit the local fauna.

Considering that areas covered by any vegetation provide lower risk of salination of the soil (Gheyi, 2000), the areas where the final effluent is released may be used by means of reflorescence with these cited species, which present an alternative for living with and recuperation of the salinized areas and the prevention of erosion problems.

4 Conclusions and recommendations

The industrial textile effluent is indicated to be treated with aquatic halophyte plants by means of a system of constructed wetlands and for the irrigation of terrestrial halophyte plants, it being recommendable that an adequate soil, water and halophyte plant management be developed for these effluents.

According to Silveira Neto (2003) the treatment of the final effluent of the Pacajus Waste Treatment Plant utilizing the capim da praia (Paspalum vaginatum) and capim de burro (Cynodon dactylon) plants in constructed wetlands with subsurface flow presents as its principal advantage the reduction of the volume of effluent emptied onto the soil resulting from the variable of evapo-transpiration that is rather greater in these plants and the consequent reduction of their eviction in the soil. Noted also by this author were the owering of pH and the removal of the indigo blue pigmentation of the effluent. Constructed wetlands also create the possibility of the production of biomass fodder with gramineous plants which will benefit the fauna and an excellent landscape integration, permitting the nesting of birds and refuge for other animals of the fauna without favoring the proliferation of insects.

Silveira Neto (2006) affirms that the constructed wetland system to be built should be subsurface flow with the best average waste water residence time of 10 days. This author proposes that a vertical flow constructed wetland be built with capim da praia (Paspalum vaginatum) followed by another constructed wetland with horizontal flow with capim de burro (Cynodon dactylon) in order to benefit the biodiversity and to have a greater technical efficiency in this system.

An extra waste water plant unit with constructed wetlands, according to Silveira Neto (2006), requires an area of approximately 8.3 hectares, enough to process the sewage sludge also. This area is available, because of the CAGECE Waste Treatment Station Pacajus features of this area and its surroundings.

The technology of constructed wetlands in Brazil is recent; initiatives in construction of this technology for the treatment of industrial waste have been few in Brazil and none in Ceará for industrial textile waste. Apart from the little technology existing, the salinity of the textile effluent and the requirement of large areas limit the building of constructed wetlands for this type of industrial waste.

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