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Institut für Tropentechnologie

Betzdorfer Str.2

50679 Köln

itt@fh-koeln.de

http://www.tt.fh-koeln.de

Lektorat/Layout: Dipl.-Ing. Nicole Kretschmer, Dipl.-Übers. Kerstin Düwell,

Guénola Kahlert M.A., Dipl.-Ing. Frank Woringen

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INHALT

VORWORT

„Aqua fons vitae „ (Wasser ist die Quelle des Lebens), die universale Bedeutung dieses Wortes dringt dem Bewohner der Trockenregionen fortwährend ins Bewusstsein. Der Kölner sieht zwar täglich die Mauerreste des römischen Aquäduktes, der die Römer vor 2000 Jahren mit frischem Wasser aus der Eifel versorgte, dabei tropft ihm aber meistens soviel Regen auf den Kopf, dass er nie an Durst als einer Folge von Wassermangel denkt, sondern eher als einer „Sehnsucht" nach dem hier so beliebten einheimischen Getränk, das „Kölsch", genannt wird. Dass die Sicherstellung der täglichen Versorgung mit sauberem Trinkwasser einen hohen technischen und organisatorischen Aufwand erfordert, wird ihm allenfalls bei Betrachtung der Wasserrechnung bewusst.

Wasser ist nicht nur in Trockenregionen dieser Welt ein ebenso lebenswichtiger Faktor wie das Brot, sondern auch in den Regionen hoher Niederschläge, wie etwa den feuchten Tropen, wenn auch die Problematik eine völlig andere ist. Die Versorgung mit „sauberem" Wasser ist in beiden entgegengesetzten Klimagebieten ein komplexes Problem, das hohe interdisziplinäre und technische Anforderungen stellt. Andere Funktionen des Wassers, wie z.B. die Energiegewinnung über Wasserkraftwerke, konkurrieren um die Nutzung in der Bewässerung und komplizieren damit die Technik der nachhaltigen Wasserbereitstellung und Wasserverwendung. „Nachhaltig" heißt in diesem Zusammenhang soweit wie möglich „schonend", um die Wasserqualität und die Wasserquantität langfristig trotz steigender Nutzungsansprüche zu bewahren. In Forschung und Lehre hat deshalb das Wasserthema international in viele Hochschuldisziplinen Eingang gefunden.

Wir haben auch hier in Deutschland immer schon gute Hydrologen, Hydrogeologen, Wasserbauingenieure, Kulturtechniker, Umwelttechniker und andere Spezialisten ausgebildet, die sich jeweils mit Grundwasser, Wasserqualität, Flussregulierung, Wasserver- und -entsorgung, Rückhaltebecken oder Dammbau befasst haben. Die traditionelle Organisation der Wasserversorgung in Deutschland ist in vieler Hinsicht sogar beispielhaft und wurde von anderen Ländern als Muster genommen.

Die Komplexität und räumliche, überregionale und übernationale Dimension des Wasserproblems (Knappheit, Qualität, Verteilung etc.) erfordert aber nicht nur den guten Spezialisten, sondern einen Fachmann, der durch eine zusätzliche Ausbildung die Kompetenz zur interdisziplinären Zusammenarbeit besitzt. Das Wasserproblem muss, wenn man auf nachhaltiges Wassermanagement abzielt, im Zusammenhang mit dem gesamten Flusseinzugsgebiet gesehen werden, weil alles, was im Flusseinzugsgebiet über die Bodennutzung direkt und durch Klimaeinflüsse indirekt Oberflächen- und Grundwasser beeinflusst in einem „Kausalnetz", also im Wirkungsgefüge der Einflussfaktoren steht. Klimaregionen und Flusseinzugsgebiete überlagern staatliche, kulturelle und humangesellschaftliche Grenzen. Deshalb sind Maßnahmen zur langfristigen Absicherung der Wasserversorgung und Erhaltung oder Wiederherstellung der Wasserqualität oft an überstaatliche Regelungen und Vereinbarungen gebunden. Insofern ist dabei auch die normative Forschung gefragt, die Ziel-Mittel-Beziehungen zum Gegenstand hat. Dabei muss es immer das Ziel sein, die normativen Elemente in die Funktionsmodelle zu integrieren.

Die Analyse und Beeinflussung dieser Einflussfaktoren im Wirkungsgefüge verlangen Qualifikationen, deren Vermittlung wir in unserem postgraduierten Studiengang „Technologie- und Ressourcenmanagement in den Tropen und Subtropen" unter dem Motto „Interdisziplinär-International-Interkulturell" anstreben. In diesem Masterstudiengang, der ab Wintersemester 2003-2004 in reformierter modularer Struktur anläuft, haben wir die dazu gehörigen Ausbildungselemente noch mehr als bisher berücksichtigt, Wasser und Wassermanagement erscheint darin mit einem eigenen Studienschwerpunkt. Der interdisziplinäre Ansatz ist darüber hinaus in allen unseren Forschungsprojekten ein richtungweisendes Prinzip, dessen Verwirklichung durch Kooperationen mit in- und ausländischen Hochschulen sowie solchen innerhalb der eigenen möglich ist. Die Forschung am ITT ist der Agenda 21 verpflichtet, deren Forderungen seit Rio de Janeiro 1992 und Johannesburg 2002 immer tiefer in das Bewusstsein der Weltöffentlichkeit eindringt. Forschung in diesem Sinne muss eo ipso Schnittstellenforschung sein, eine Allee zu neuen Erkenntnissen im Umgang mit den Ressourcen dieser Welt.

Der vorliegende Band 2 unserer neuen Schriftenreihe ist eine Sammlung von wissenschaftlichen Arbeiten von Mitwirkenden des ITT zum Thema Wasser und ein Nachweis des Stellenwertes im Rahmen der Schwerpunkte.

Prof. Dr. Hartmut Gaese

Geschäftsführender Direktor

PLANT IRRIGATION USING ANAEROBICALLY TREATED WASTEWATER: LABORATORY TEST FOR CITRUS NURSERY PLANTS AND FULL SCALE TEST FOR EUCALYPTUS TREES[4]

D. Jeison[1], R. Chamy[2], S Gandolfo[3] and E. Salgado[3]

[1] Department of Chemical Engineering, Universidad de La Frontera, Chile

[2] School of Biochemical Engineering, Universidad Católica de Valparaíso, Chile

[3] Faculty of Agronomy, Universidad Católica de Valparaíso, Chile.

email: esalgado@ucv.cl

[4] Project funded by DG/UCV and Capel Co. Part of the collaborative work with the Institute for Technology in the Tropics at the University of Applied Sciences Cologne, Germany

Abstract

Agro-industries usually produce high amounts of wastewater, and frequently are located close to agricultural activities. Agricultural use of treated wastewater therefore might represent a unique opportunity to solve, both, the problem of water supply for irrigation and the disposal of treated water at the same time. This article is the result of collaborative work done with the largest Chilean pisco producing company (pisco is a distilled drink from wine prepared from Muscatel grapes). It involves laboratory experiments in order to establish anaerobic treatability of wastewater and the use of that water for irrigation. In order to confirm previous laboratory results, a full scale anaerobic plant was built, and the treated water was used to irrigate 3000 eucalyptus trees. Results showed, both at laboratory and full scale plant, that the anaerobic method is suitable for treatment of pisco wastewater, and also that the nutrient content of the treated water can be beneficial for plant growth, reducing the need of fertilizers.

Keywords: wastewater treatment, wastewater use, irrigation, citrus, eucalyptus

1 Introduction

Problems like adequate treatment and disposal of agro-industrial wastewater and the development of new water sources for irrigation, can be related and solved at the same time, using the proper technology. Anaerobic digestion appears as an interesting alternative, since it has proven that it is a suitable treatment for a wide spectrum of industrial wastes (Lettinga *et al* 1997, Spiece 1996). The important amount of nutrients that are present in the treated agro-industrial wastewater (like phosphorus and nitrogen) make it interesting for use in irrigation.

Thus, the combined system – anaerobic treatment and irrigation — can help to solve a wide variety of problems, such as:

Reduce environmental impact of pollutants, since an adequate treatment for wastewater is provided,

- There is no need of post treatment since presence of nutrients is in fact desired. Nutrient content in treated wastewater reduces fertilizer requirements.
- There is no concern about treated wastewater disposal, since it is being used for irrigation
- Extra water for irrigation is made available at no, or minimum, extra cost

The fact that usually agro-industries are located very close to agricultural activities and the huge amount of water that cleaning operations require, represents a good opportunity to use treated wastewater for irrigation of small plots used with high value crops.

Later considerations could be very well applied to the Chilean pisco industry. Pisco is a liquor prepared by distillation of wine made from Muscatel grapes. As any distillation process, it produces highly concentrated wastewater: vinasses originated as a residue. Residual process-water from cleaning operations of maceration, sedimentation and fermentation tanks is also generated.

Anaerobic digestion of pisco wastewater offers some opportunities to take advantages, such as: biogas can be obtained and used in steam production, required for distillation; sludge can be employed for soil improvement; treated water can be use for irrigation. This last point is extremely important in the case of the Chilean pisco industry since the region where that industry is located faces strong water scarcity. Finally, the ability of anaerobic digestion for being stopped through long periods of time is also valuable since the pisco industry has almost no activity, or waste generation, from 3 to 5 months per year.

This study deals with the application of anaerobic digestion processes to treat wastewater from the Chilean pisco industry, focusing on benefits of reusing treated water for irrigation purposes. This paper summarizes a 3-year collaborative work with the main Chilean pisco producer company.

Since wastewater characteristics from the pisco industry are particular, the results of this investigation cannot be directly extended to other agro-industries, but they can reveal an important field of application.

2 Methods

Operation of laboratory reactors

Two 5 L laboratory reactors, an UASB and an EGSB, were used in order to study the anaerobic treatability of the wastewater. The reactor dimensions are listed in Table 1. EGSB and UASB reactors were operated at superficial liquid velocities of 7 and 0.8 m/h respectively. These values were obtained applying different levels of recirculation rates. Both reactors were fed with wine vinasses, kept refrigerated at 4ºC until they were used, obtained periodically from the pisco industry. Table 2 presents the characterization of wine vinasses. Both digesters were seeded with anaerobic granular sludge from a full scale UASB treating brewery wastewater. pH was controlled by the addition of sodium hydroxide, at a concentration of 2.5 g/L. The reactors were operated at 30ºC, for a period of 8 months. All analyses were made according to Standard Methods (APHA 1992).

Table 1. Laboratory reactors dimensions.

	UASB	EGSB
Volume (L)	4.5	4.7
Diameter (cm)	10	6
Height (cm)	60	160
Height/diameter relation	6	27

Table 2. Vinasse characterization.

Parameter	Units	Value
Total COD	mg/L	37800
Soluble COD	mg/L	34400
BOD_5	mg/L	13500
Total solids	mg/L	25226
Volatile solids	mg/L	20588
Total suspended solids	mg/L	1526
Volatile suspended solids	mg/L	1495
Acidity	mg $CaCO_3$/L	1719
pH		3.0

Agricultural utilization of treated wastewater

Several experiments were performed to analyze irrigation properties of treated wastewater. Lemon nursery plants were used as a standard culture. Several irrigation regimes and fertilization degrees were tested, using normal irrigation water, raw wastewater and anaerobically treated wastewater. Irrigation requirements were determined daily as a Class A pan evaporation percentage (FAO 1977). Fertilization was applied every two days through the irrigation water and was weekly complemented by foliar applications. The amount of applications was determined as a percentage in relation to the standard requirements for same age nursery plants. Table 3 presents the experimental trials (levels of irrigation and fertilization) used in the irrigation study. A completely random experimental design was used with four replications.

Table 3. Experimental conditions of irrigation experiments: fertilization applied for each type of water and level of irrigation.

	Irrigation (class A pan evaporation percentage)			
Type of water	100%	200%	300%	400%
Treated wastewater	No fertilization	No fertilization	No fertilization	No fertilization
	50% [1]	50%	50%	50%
	100%	100%	100%	100%
	150%	150%	150%	150%
Untreated wastewater	100%			
Normal irrigation water	100%			

Percentages in reference to conventional (100%) fertilization

Supplementary experiments were carried out using different levels of dilution of treated wastewater (25, 50, 75 and 100%), in order to evaluate the effect of its salt content. An irrigation level of 400% was used in these experiments. Parameters obtained during plant growth were:

- Growing rates of apical shoot and diameter of stem, at 20 cm height, in reference to the relevant characteristics of the plant to be grafted (commercial factor).
- Volume, pH and electrical conductivity of water percolating from plant growing pots.
- Class A pan evaporation (mm/day) to program daily irrigation.

These experiments were conducted for a period of 4 month, and started 4 month after the start-up of the reactors in order to accumulate enough treated water. Treated water was maintained refrigerated until its utilization.

Full scale implementation

Based on a complete wastewater characterization carried out during grape harvest in 1998, a 60 m^3 UASB digester was designed and built in the smallest production plant of the pisco company. This reactor is considered full scale for this production plant since it was conceived to treat all wastewater generated, but at the same time, at the company level, it is a pilot installation, since positive results can bring to the application of this treatment technology for the rest of production installations.

The reactor was started-up with sludge obtained from a full scale UASB digester, treating brewery wastewater. During the start-up period, the reactor was fed only with vinasses. Afterwards it began to treat all wastewater generated in the production plant. pH was controlled on line by the addition of sodium hydroxide.

In order to study the use of treated water for agricultural applications, 3000 eucalyptus trees were planted in a terrain beside the production plant. Corn plants were also planted with the purpose of serving as wind barriers to protect growing trees. The growth of this tree plantation is being followed in order to confirm results obtained in the laboratory experiments.

3 Results and Discussion

Operation of laboratory reactors.

Operation of laboratory anaerobic reactors showed applicability of anaerobic digestion processes for the treatment of Chilean pisco industry's wastewater. After a 5-week period of start-up, the reactors were able to treat an organic loading rate of 20 gCOD/Ld, which was maintained during the study. Table 4 shows the main operational conditions for both reactors over its operation. High biogas production was observed in both reactors, being close to 500 mL per gram of removed COD. Considering that methane concentration in biogas was 65%, this means that about 90% of the inlet COD was transformed into methane.

Growth of acidogenic biomass over EGSB digester granules generated problems during the reactor operation: granules became less dense, producing a continuous sludge washout. This can be appreciated in Figure 1 which shows the solid content of granules from both reactors after 120 days of operation.

Table 4. Laboratory scale reactors average operational conditions during its operation.

	UASB	EGSB
Organic loading rate (gCOD/Ld)	20	20
COD removal rate (%)	93	89
Hydraulic retention time (d)	1.8	1.8
pH	6.7-7.0	6.7-7.0
Biogas production (ml/g removed COD)	490	490
Methane concentration in biogas (%)	65	65

Granules from the EGSB reactor present a lower solid content in comparison to UASB granules. This phenomenon seems to be related to the content of non acidified organic matter and it can seriously affect operation of EGSB reactors (Alphenaar 1994, van Lier *et al* 1997, Jeison 1999). In order to maintain a constant sludge concentration in the EGSB reactor, seed sludge was continuously added during its operation. The UASB reactor presented a much more stable operation. Due to its stable operation and lower investments and operational costs, the UASB digester was chosen as the most appropriate treatment technology.

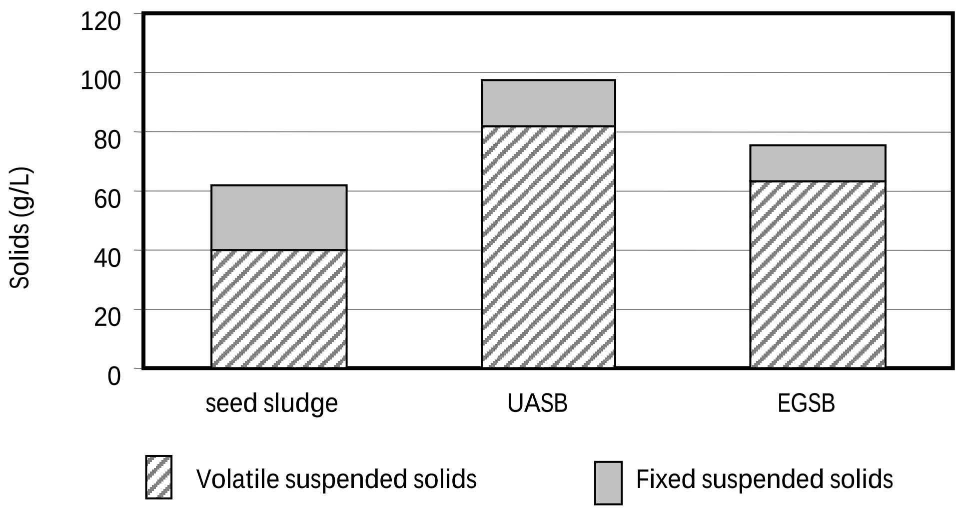

Figure 1. Solids content of seed sludge and laboratory reactors sludge after 120 days of operation.

Agricultural utilization of treated wastewater

Experiments conducted to establish the possibility of using treated water for agricultural purposes showed good results. Figures 2 and 3 present the influence of irrigation regimes and fertilization levels over nursery plant growth, expressed as the percentage of increment of the diameter and height of the plants throughout the experiment.

The analysis of the measurements suggests that there is an effect of irrigation level over the diameter and height of the plants. The diameter of the plant shows a tendency to greater increments in those treatments that have a 100% and 150% complement of fertilization and in the endowment of water with 100% and 400% of pan evaporation (Figure 2). Even though a tendency to increase plant height as water applied increases could be expected, a higher accumulation of sodium is also produced, which counterchecks this tendency (Figure 4). A high concentration of this ion is known to produce a notorious damage on the plant leaves, a phenomenon that was observed in the experiments. This observation is supported by the fact that the treated water presented an important content of sodium due to the pH control.

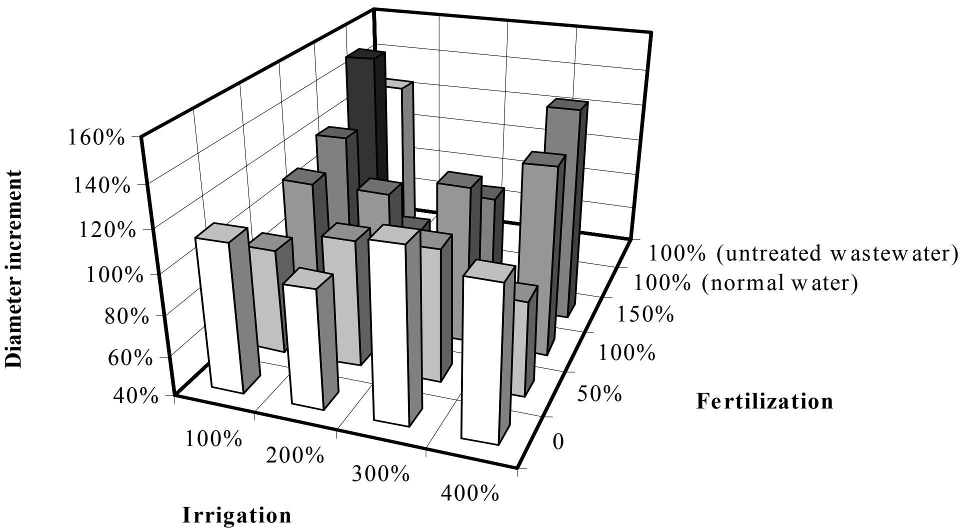

Figure 2. Influence of percentage of irrigation and fertilization on the stem diameter increment of nursery plants.

Dilution of treated water did not show a clear effect over plant height (Figure 4). However, it is clear that dilution has an effect on the diameter of plants (Figure 5). There is a tendency to an increment of the diameter as treated water increases in proportion. This clearly means that a greater diameter is obtained as a result of higher levels of final salinity in irrigation water. This is an important factor for nurseries because the idea is to get the maximum diameter as soon as possible in order to graft the plants earlier. This result can be related to one or both of the following factors: An important micronutrient contribution of treated water, or to a salinity effect that stimulated more the cell multiplication than expansion, resulting in greater diameter growth.

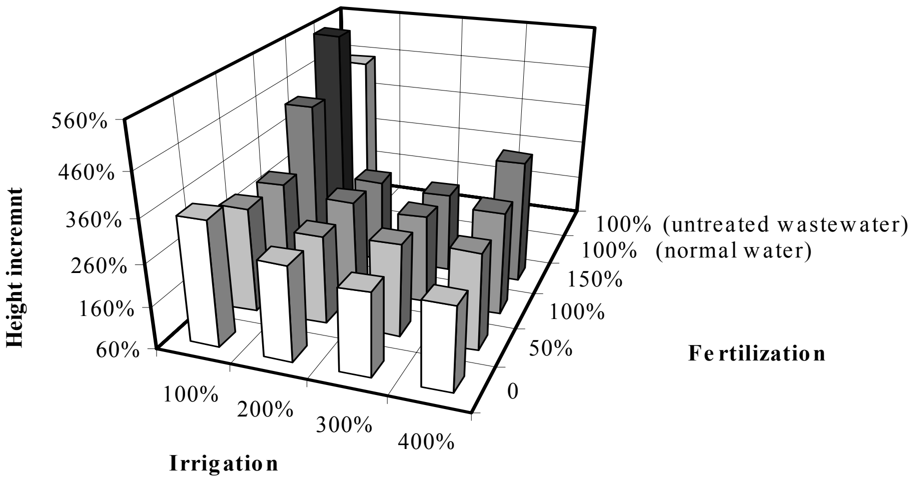

Figure 3. Influence of percentage of irrigation and fertilization on the increment of height in nursery plants.

Results show that agricultural use of anaerobically treated wastewater is possible, by giving a good use of its nutrient content (nitrogen, phosphorus). Therefore, nitrogen can be kept associated to life forms, reducing also utilization of fertilizers, and avoiding the need of water post-treatment (nitrification-denitrification).

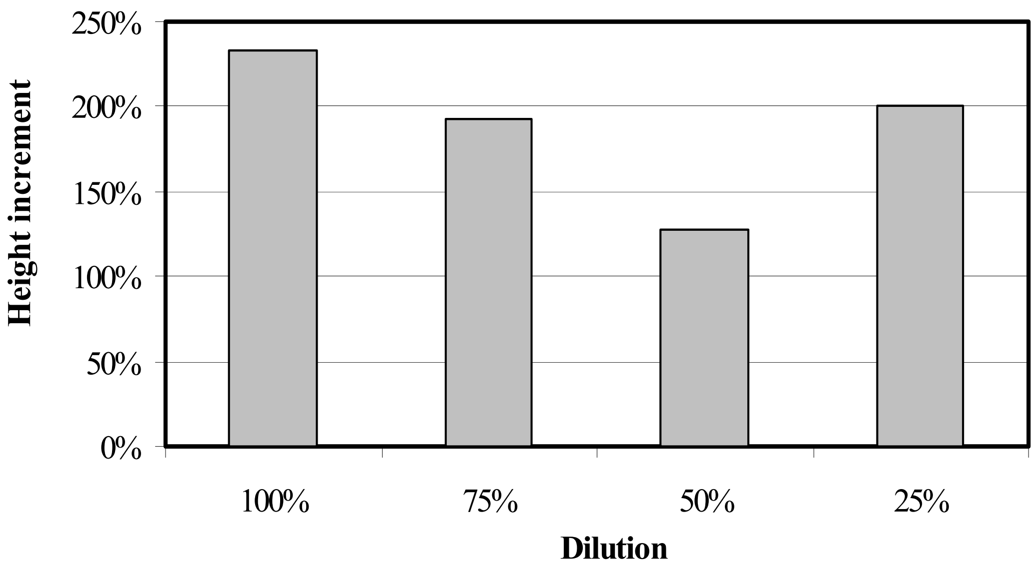

Figure 4. Treated wastewater dilution effect on plant height (a dilution of 100% corresponds to normal water).

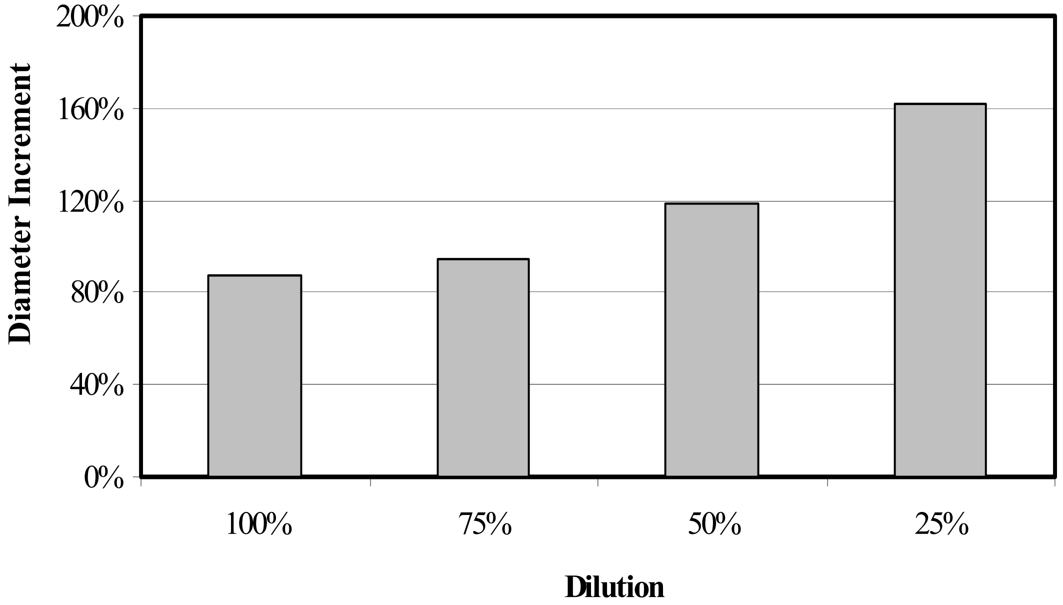

Figure 5. Treated wastewater dilution effect on plants diameter (a dilution of 100% corresponds to normal water).

Table 5 presents the characterization of anaerobic granular sludge. Its composition presents an important nutritional content (N, P, Ca, Mg), indicating that it could be used for soil improvement. Preliminary results (not shown) of an investigation that is being carried out in the Faculty of Agronomy at UCV verify that hypothesis.

Table 5. Characterization of the anaerobic granular sludge.

Parameter	Units	Results
Nitrogen	%	5.29
Phosphorus	%	1.45
Potassium	%	0.32
Calcium	%	4.5
Magnesium	%	0.42
Zinc	ppm	293
Manganese	ppm	182
Iron	ppm	13031
Copper	ppm	365
Boron	ppm	8.16

Full scale UASB implementation

The construction of the UASB reactor was finished in November 2000. The start up procedure took place for approximately 75 days. Figure 6 presents the organic loading rate and the COD removal during the start-up of the UASB reactor. From day 36 to 41 there was a decrease in the COD removal due to the discharge of slurry from sedimentation operation. It produced an increment (not measured) in the total solids content, changing the characteristics of the wastewater. Once this discharge was finished the COD removal recovered. Figure 7 presents the reactor operation for the following 8 months. High levels of COD removal were attained during the whole period (close to 95%).

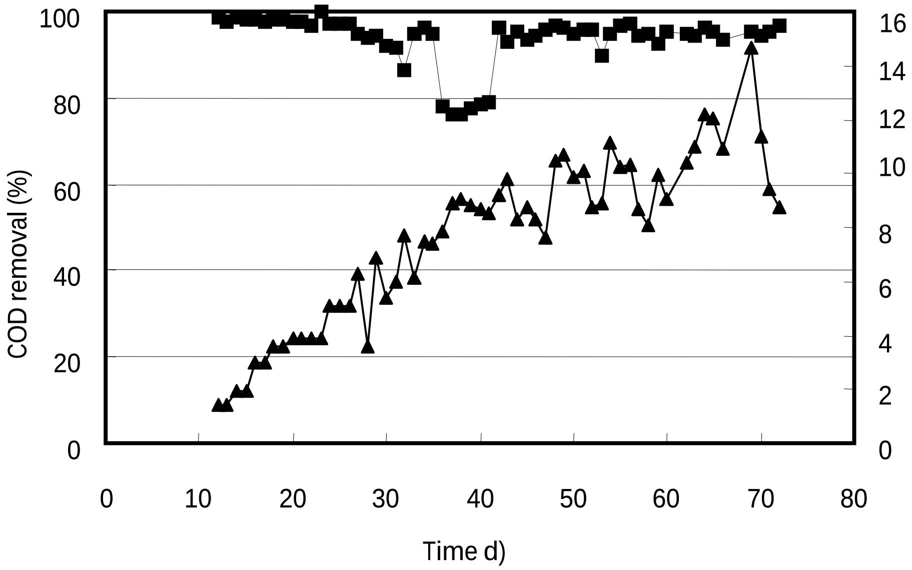

Figure 6: Organic loading rate and COD removal rates during start up of UASB reactor. (♦) Organic loading rate, ( ) COD removal.

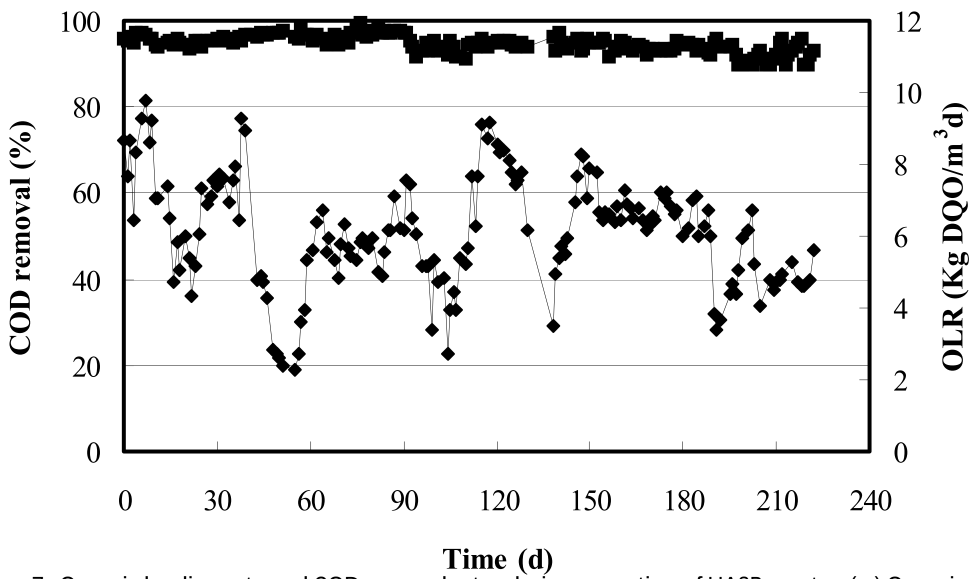

Figure 7. Organic loading rate and COD removal rates during operation of UASB reactor. (♦) Organic loading rate, ( ) COD removal.

During the first weeks after plantation of eucalyptus trees, some problems were detected on their leaves. This problem was related to the high content of sodium in treated water, due to the use of sodium hydroxide for pH control, a situation which was also detected during laboratory experiments. The sodium hydroxide utilization was close to 2 g/L, during the first weeks of start-up. At organic loading rates over 6 kgCOD/m^{3}d, biogas production was large enough to provide an important level of alkalinity by CO_2 dissolution, and therefore the use of NaOH was considerably reduced (to less than 20% of its original value). Exposure of plants to high levels of sodium occurred for a short period of time and did not produce a permanent damage to the trees. Anyway, this is a problem that should be seriously considered, especially during digesters start-up period, or during operation at low values of organic loading rate.

Development of trees was completely normal. Rate of growth was the expected for a plantation under normal conditions. This is considered as a good result, since no fertilizer of any kind was used, and soil conditions were not adequate, the terrain where tree plantation was placed had been used for several years to dispose wastewater by soil infiltration.

4 Conclusions

Anaerobic digestion is a suitable technology for treatment of wastewater generated during Chilean pisco production. This industry offers an opportunity to exploit all advantages of anaerobic digestion by wastewater treatment. Use of anaerobically treated wastewater for agricultural purposes is not only feasible but also convenient since nutrient content of the treated wastewater can improve plant growth. This is of great importance for agro-industrial activities like the pisco production, since they generate high amounts of wastewater and they are usually located close to agricultural activities. Anaerobic sludge showed also good nutritional levels, which means that it could be used for soil improvement. A negative effect of sodium on leaves was observed. This aspect should be taken into consideration in alkalinity control system on operations of anaerobic digesters.

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THE DYNAMICS OF WATER USER ASSOCIATIONS IN A LARGE-SCALE IRRIGATION SYSTEM IN THAILAND

Sabine Höynck and Armin Rieser

Abstract

The management of a large-scale irrigation system requires the co-ordination of activities among various groups and individuals. The establishment of such a system does not only consist of constructing infrastructure and planning optimal water allocation, there are also a range of fundamental socio-economic changes involved which had often not been sufficiently considered during the planning stage (DIEMER & HUIBERS 1996, p. 2). The explanation for this lies partly in the unpredictability of socio-economic development and also in the extended time frame of social organisation which lag behind technological change. This "cultural lag" surpasses common development project time frames, some would refer to a period of at least 50 years for socially stabilising the irrigation system (LUSK 1991, p. 86).

The enthusiasm and belief in technical innovation in former times (1960s and 1970s) was connected to an optimism of the water management on tertiary level in so far, as it was expected that "...water control on local level would automatically evolve, simply because it was needed" (FREEMAN 1991, 42). The problem of not knowing how social systems will react to changes and how they will perform in a new setting can not be eliminated totally due to the uniqueness and complexity of socio-technical systems. However, experience with irrigation projects is growing and might be helpful for better planning future changes in irrigation systems.

This paper deals with the evolution of Water User Associations (WUA) in a large-scale gravity irrigation system in Thailand. The WUA have been implemented starting in the late 1980s by the national irrigation agency, the Royal Irrigation Department (RID), to organise farmer governed O&M on tertiary level (one WUG for one service unit) while main system O&M has remained under the regime of RID. Farmers organisation has been initiated by RID officers, prescribing organisational structures and O&M fees collection. Continuous support has been restricted to pilot service areas.

After having existed for more then a decade, conclusions on the sustainability of farmer associations can be drawn without waiting for another forty years to pass by. It could be observed that the adaptation of legally prescribed organisational structures has been only valid for a minority of the service units and some general weaknesses of these structures can be observed. On the other hand, a multitude of informal organisations have developed which show ways for improving participation of water users.

A major assumption underlying this paper is that farmers motivation for participation is a pre-condition for the sustainability of WUA. The actual participation situation, the motivation factors for participation, and the environmental and dynamic influences on farmers motivation for participation are analysed.

Keywords: Thailand, large scale irrigation, irrigation organisation, farmers associations

1 The case study of Phitsanulok irrigation system, Thailand

The observations and conclusions drawn here are based on data collection, interviews, and observations in Phitsanulok Irrigation System in 1996 and 1997, an RID managed irrigation scheme conveying water to the rice-based farming systems of approximately 30,000 water users on 91,580 ha of potential irrigation area. The project construction lasted from 1977 to 1985. The system started to operate in parts of the scheme before completion, in 1983. A characteristic of the irrigation scheme is the long and narrow shape and a correspondingly long main canal. The length of this (179 km) and some lateral canals (up to 89 km) in combination with low gradients imposes problems on the management of the main conveyance system insofar as the frame for timely reaction to actual water delivery inadequacies – local water scarcity or excess water is very narrow.

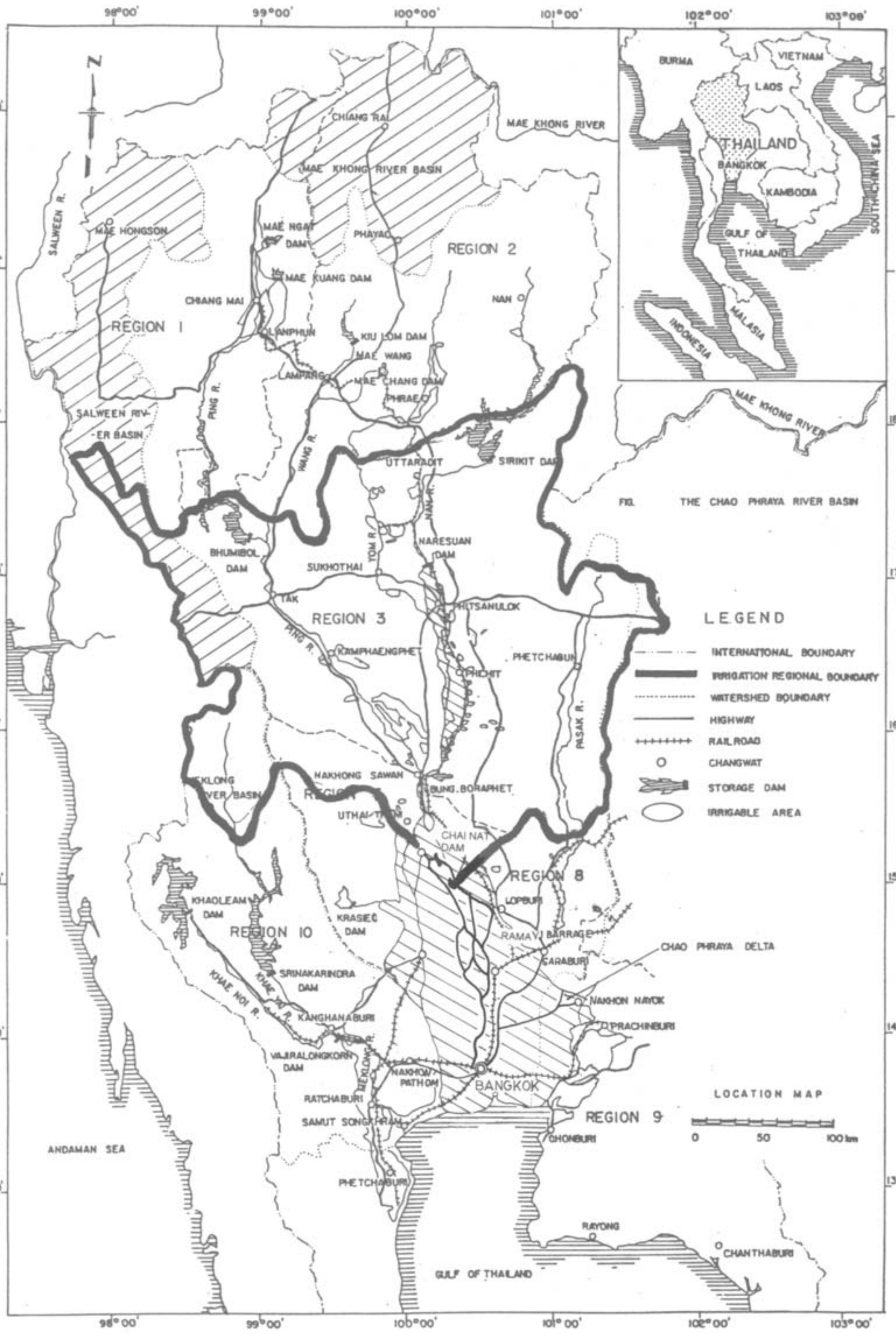

Figure 1: Phitsanulok Irrigation System

The issue of organising farmers was considered by establishing two types of WUA at different distribution levels, at tertiary level and at an intermediate level.

Water User Associations at Tertiary Level – Water User Groups (WUG)

Water User Groups (WUG) were formed at the lowest distribution level of the irrigation system, for the canal system which directly divert irrigation water to the farm plots. The land ownership of the command area of one farm ditch determines the membership in one WUG. At the initiating stage of organising water users, the land owners were called to a constitutional meeting to sign a membership form under supervision of irrigation agency officers. At this occasion, a chairperson as well as an assistant of the chairperson were elected. This process started with single cases in 1983 and ceased in 1990. In 1992 a total of 513 WUG was recorded which is about 40 % of all service units (Royal Irrigation Department – Regional Office 3 1992). The remaining 60 % of service units, most of them in the tail region of the irrigation system, have never been formally organised. There are approximately 1,120 service units in the irrigation area with an average service area of 82 ha for an average of 26 water users.

The organisational set-up including the definition of an appropriate fee for financing tertiary level O&M has been prescribed by the Land Consolidation Decree from 1974. According to this legal document, owners must contribute that fee and provide necessary labour force for maintenance. In reality, though, this regulation is barely enforced because the WUG do not provide any legal authority for fee collection by the chairpersons. Exceptions were only found in pilot areas where RID officers continuously exert their influence to support WUG leaders. Commonly, WUG have not been guided for continuous work. Up to now, they fail to play a role in operation and a minor role for organising maintenance. Still, there has been created a sense of membership in the group of water users of a service unit which contributes to the organisation of maintenance in rather informal ways.

Water User Associations at Intermediate Level – Water User Co-operatives

In some areas, for larger commands comprising about 40 service units (WUG), Water User Co-operatives (WUC) were founded according to the Thai legislation for agricultural co-operatives. Membership in those co-operative is not compulsory, so the membership rate varies very much from co-operative to co-operative. Nine of eleven planned WUC have been erected so far in the head-reach sub-system of Phitsanulok Irrigation System. They unite 26 to 503 members representing 2 to 37 % of the farmers of the respective co-operative area. RID strongly supports those co-operatives in administration and organising meetings to compensate a major failure of the WUG: The lack of formal structures to collect and administrate the O&M fee. It is even considered to make the payment of the O&M fee to the WUC not only compulsory for the actual members but also for all water users. By now, the WUC do not seem to be sustainable as an association of water users since the major incentive for membership is the possibility of obtaining subsidised inputs and credits and to receive a profit share from the credit and marketing activities of the co-operative.

If one day the WUC were supposed to be strongly involved in intermediate level irrigation system management, their organisational structures would have to be changed fundamentally with a stronger responsibility to the groups of water users at tertiary level and a real influence on the main system management. By now, the WUC are neither represented in decision making by the irrigation agency, nor do they fulfil any O&M tasks, so they will not be included in the following analysis of status, threats and chances of WUA in Phitsanulok Irrigation System.

2 Incentives and motives for participation in water user associations

When talking about organising farmers, this can not be a one-time process of establishing organisational structures. Activities undertaken by persons not forming part of the local rural communities of organising farmers' groups are always intruding into existing, mostly informal organisational structures. This intrusion results in different adaptation processes of the new organisational type. With time proceeding, the established organisational form will change. Continuous participation of the members depends on the individual assessment of the advantage of participation in comparison to non-participation.

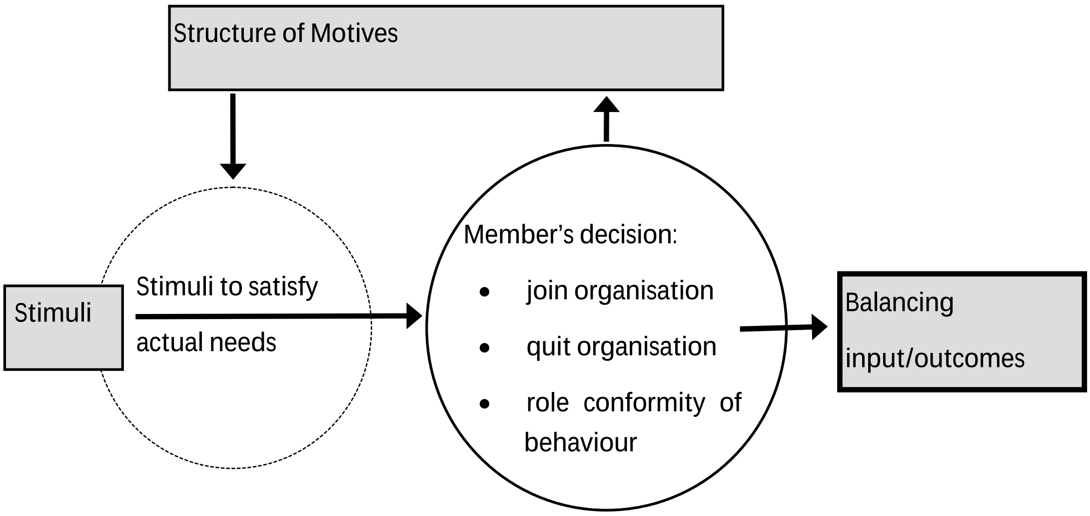

Figure 2: Farmers Contribution to the Farmers Association in Response to Stimuli (based on BARNARD (1938) and SIMON (1947) in HENTZE (1991))

The question of a successful farmers organisation is not restricted to the membership in an association, the decision whether to "join an organisation" or "quit and organisation" (Figure 2). A successful farmers association has to be sustainable (RDI 1995, p.1), meaning that members do not quit the organisation and perform in conformity with their roles. For the different phases of the life-cycle of a WUA, different factors influence the membership and participation of farmers. Apart of positive factors for participation there is unfortunately also a wide range of factors negatively influencing participation in farmers association.

Table 1: Positive and negative factors for participation in WUG

type of need	incentives and motivators	disincentives and frustration factors
economic needs: existence needs and economic security	income increase related to participation	no/insufficient income/security increase through participation
	an increase of security of the economic system for the farm household	income/security increase also without participation alternatives to WUA activities more effective
	represent the diverging individual interest against other individuals	individual diverging interests not represented in group
	influencing environmental conditions via channel of a group representative	the environment does not react to group claims the environment does not respond more to group than to individual
	financial reward for activities for the benefit of the group	no reward for activities for benefit of group
social needs: relatedness needs and growth needs	socialisation need, the urge to be member and not outsider	membership not/no more important because other social units are more important the group of outsiders is also strong
	the sense of having common interests	experience that others have different interests change of interests/ loosing common interest
	feeling stronger in the group, also related to a strong group leader, to influence the environmental conditions	disappointment with the success of the group leader or the success of the group no need for influencing environmental conditions no expected benefit in influencing environment
	a forum of achieving fair treatment and obtaining a fair share of benefits, either by consensus or through the authority of a leader	perception of being treated unfair by community or leader envy for benefit received by other members lack of authority of leader
	receiving acknowledgement for activities within the group, e.g. by becoming an elected representative	envy for acknowledgement obtained by other group members loosing acknowledgement once obtained
behavioural needs general security need to strive for avoidance	preservation of economic security by not being excluded from the local mutual assistance network	the local social security system is independent from the group membership outside social security systems develop the local mutual assistance network has failed
	preservation of social security by avoiding threats from group members	group pressure in case of non-conformity not perceived/not experienced as a threat

During the phase of establishing WUA, the incentives and motives refer to expectations of the individual from the organisation rather than to experiences. Positive fulfilment of those expectations, at least for some crucial elements, is the pre-condition for the persistence of WUA. Negative factors might be known from the beginning but others evolve over time. Serious problems occur when **negative experiences** are made, for example when the WUA does not create the expected increase of justice among the water users. Those disappointments are dangerous for the sustainability of a group which commonly irreversibly generate a negative attitude towards an organisation. To repair a damaged community is more complicated than creating new structures.

Individuals might have joined the WUA expecting advantages from this and certainly not expecting any disadvantage for their own position. To submit to collective action by complying with the role-conform behaviour comprise two aspects: 1. to allocate household resources in group activities and 2. to co-ordinating individual irrigation activities with the WUA. Collective action thus is more expensive than individual action and it limits the liberty of the individual which he would choose to avoid (LUSK & PARLIN 1991, p. 14). A possible reaction to this situation is to firstly test whether there is a difference for their personal benefit if they behave in conformity with their assigned roles or not. If the individual boycott is not sanctioned this will be an example for other farmers who might also retreat, raising the risk of conflicts among participants and free-riders.

The counteraction of positive factors, referred to as the **incentives** or **motivators** to join and participate in a WUA, and the negative factors, referred to as **disincentives** and **frustration factors**, are presented in Table 1.

Based on the motivation theories for human behaviour it is assumed, that the individual farmer seeks to satisfy simultaneously individual and household needs. Environmental conditions, the individual/household situation, and the impact of the irrigation system and irrigation organisation on the individual/household situation are assessed towards fulfilling the needs of the individual or the household. It is differentiated between economic needs, social needs, and behavioural needs. This grouping is based on the content theories of motive structures which are rather descriptive motivation theories. These needs might also be labelled as general motives which are addressed by motivators for participating in irrigation organisation.

Economic Needs

The economic needs comprise the physiological needs (primary needs) according to MASLOW (1970 in HENTZE 1991, p.30), the existence needs according to ALDERFER (1969 in HENTZE 1991, p. 31) and the extrinsic need "income" according to HERZBERG (1966 in HENTZE 1991, p. 33). In short: The individual expects an overcompensation of his/her input to the WUA finance and activities. An increase of income security is an equally or maybe even more important economic gain in comparison to the level of potential average income increase.

The expectation and the experience of achieving economic benefits from the irrigation system is a prerequisite for participation in a WUA. This major motivating factor for participation is counteracted by three possible negative factors in the individual scenario:

1. The experienced benefit is not related to participation. Non-participation is not sanctioned, so especially head-reach farmers receive their beneficial share of water also without contributing to the WUA activities.
2. The expected or experienced benefit is insufficient, a situation especially relevant for tail-end farmers who are more likely exposed to unreliable water deliveries.
3. Benefits from participation in WUA can be substituted with other activities which are considered cheaper, more comfortable, and/or more effective.

”To disconnect farmer payment of assessments, whether in cash or kind, from water delivery is to virtually invite free ridership and organizational decay” (FREEMAN 1991, p. 55). This central logic of FREEMAN’s observation of irrigation systems in different continents is related to the three negative factors as listed above: Free ridership is the starting point of the ”organizational decay” inducing or strengthening the negative factors No. 2 and No. 3.

Economic factors can also be the main drive for participation with the ”social” purpose of exerting group pressure against outsiders, like other group of farmers or the irrigation agency, or for avoiding to be an outsider, whose interests are not represented. Homogenous as well as diverging interests might drive farmers to participation but only as long as they perceive and experience that the group existence and the individual participation has a positive impact on the personal situation.

The major problem of participation is to take collective action with the free-willing participation of all members. In an inhomogeneous group, people are more or less reluctant to join work activities, e.g. local leaders like village headmen would not simply work together with the group of “common” farmers in the canal shovelling for maintenance. It is quite common to collect a fee instead of participating personally. This system might be extended to pay those who are willing to work more than their required share. Such a financial reward system tends to be more sustainable than a purely honour or group-feeling bases system which is rather based on short-term enthusiasm. It offers incentives for allocating labour resources of the group of farmers according to availability and skills and transparency for the individual contribution to the collective finance and activities.

Social Needs

Social needs are quite a wide range of needs concerning the individual position within the community. The more basic social needs are the relatedness needs (related to ALDERFER in HENTZE 1991, 32) which covers the need of the individual to be part of a group, the basis for a sense of community. The general development of the opening economic systems in rural areas of Thailand is connected to a loosening of community bonds at any level of social integration but they are still comparatively strong in relation to developments in urban areas.

The most important community for the farmer is the family, followed by the village community. The social ties of water user communities are normally less strong than those of family and village, so the need to be a member instead of an outsider is stronger if WUA members live in the same village. Inhomogeneous groups from different villages and with a significant share of land owners not living nearby, e.g. from municipal areas, tend to be weaker in terms of solidarity.

The sense of common interests is a very strong factor for joining a WUA, e.g. if the group wants to enforce more water from the agency or against farmers not forming part of the WUG (outsiders). The awareness of common interests diminishes in the course of time. A deterioration of farmers solidarity with disadvantaged downstream farmers was also observed in South India (MOLLINGA & BOLDING 1996, p.29). In the absence of common problems affecting the interests of members the motivation effect of common interests turns to zero. Farmers in Phitsanulok Irrigation System do rarely expect the WUA to address their irrigation related problems, they do firstly see themselves capable to solve problems individually (Table 2).

Table 2: Identification of the most important person or institution for solving water related problems of farmers from selected areas in Phitsanulok Irrigation System

	irrigation agency		WUA		village headmen		farmers themselves		politicians	
	No. of cases	%	No. of cases	%	No. of cases	%	No. of cases	%	No. of cases	%
head sub-system	28	31%	1	1%	17	19%	42	47%	1	1%
middle sub-system	17	34%	0	0%	6	12%	21	42%	6	12%
tail sub-system	37	29%	1	1%	37	29%	48	37%	6	5%
total sample	82	37%	2	1%	60	27%	111	51%	13	6%

A special case occurs when a former common problem ceases to exist for part of the members. Two developments in the communities of irrigators have had such an effect in Phitsanulok Irrigation System: Mechanisation plus changed planting methods have substantially reduced the need to co-operate in agricultural production. The application of groundwater pumped from private wells has created a certain degree of independence from irrigation system water for a large share of farmers. Although farmers generally prefer to obtain water from the cheaper gravity system, there is drastically reduced willingness to allocate household resources in the commonly managed irrigation system which in fact lies beyond the individual and WUG control.

A positive factor for participation is the aim of individuals to seek fairness by democratic ways. This requires the perception of an unfair treatment of the individual in the absence of community representation. A homogeneous group of small-scale, comparatively poor farms is the most promising constellation for such a group. The need for strength is obvious, common interests against richer and/or more influential competitors for resources are easy to define.

In the course of time equality perception tends to deteriorate because individual interests are being pursued, e.g. simply by the more or less advantageous plot location in terms of irrigation water. This requires conflict management by strong leaders of a necessary degree of natural or institutional authority.

In Phitsanulok Irrigation System most service units are characterised by heterogeneous farm and income structures. The factor of common interests under such circumstances are limited but disadvantaged farmers may seek democratic justice within a farmer association. A source of frustration in this constellation has been the inability of WUG to control richer and more powerful farmers. It was reported that in single cases more powerful persons improve their own situation by assuming leading roles in WUG. As long as democratic principles are overruled in rural societies by patronage relationships and bribery, the representation of the interests of disadvantaged farmers can hardly develop. Small-scale, poor and/or tail-end farmers are frustrated and advantaged farmers do not need to compromise.

The growth need of human beings as the third element of ALDERFERS ERG-Theory (Existence needs, Relatedness needs and Growth needs) is a set of higher needs, summarising the self-esteem needs, ego-needs and self-actualisation needs described by MASLOW (SCHOLZ 1993, p. 419) which here is only related to in the social context of a WUA.

Some individuals are stronger motivated than others to follow higher goals by delivering economically non-rewarded work for the community. Patronage in the traditional sense of Thai society requires that the more powerful of a community represent the interests of the less powerful, probably economically dependent society members, against outsiders. So, besides being the source of unfairness, the uneven distribution of farm land and income might also bring forth a stable social structure of strong social leaders and followers who trust these leaders to act for the common benefit. In the process of individualisation and opening economic systems there is a tendency of more competitors in the rural society with more players, but less room for benevolent patronage for the really poor, a group which in Phitsanulok Irrigation System is getting rare. A reliance on the rural patron system might turn into a social time-bomb (see also RABIBHADANA, 1993).

Behavioural Needs

The last aspect is a link of economic and social needs under consideration of the conservative attitude of human behaviour in their efforts to preserve existing social links instead of seeking totally new relationships. Based on empirical analysis, MCCLELLAND (in SCHOLZ 1992, 424) has defined two features of human behaviour as counteractive to performance orientation of employees: the need to be member and find social security within a group, and the effort to avoid unpleasant incidents.

This conservative attitude, here summarised as ”behavioural needs”, is ambiguous for the success or failure of a WUA. Positively, social relationships once established can be maintained despite of problems. Negatively, new relationships are ranked less important than existing relationships avoiding the evolution of a tight community of persons with heterogeneous backgrounds and community links. This conservative attitude also inheres the risk of insufficient openness to new members. It was found in the study area that heirs of the farms or immigrants were not integrated in the WUG.

The motivation factors derived from the assumption of a prevailing behavioural need is the fear of disintegrating from the rural community and thus maybe also loosing economic security. Opposing the community leads to hardship for the family if it is exposed to hostility, maybe even to physical violence. On the other hand the environment of the WUA might also exert opposing pressures, e.g. by an influential personality whose interests run against the WUA interests.

In general, the behavioural needs are the motivators for farmers to maintain a stable status which initially supports the tendency to follow the majority of community members and to follow orders from acknowledged authorities, e.g. RID officials, village or sub-district headmen, or other regional leaders. This is the behaviour to date prevailing with the side-effect, that community activities need some kind of supervision.

In the long run, the conservative factors loose their influence on the decision. The social, economic, and demographic features of the farm households have a strong influence on the conservative attitude. Fundamental changes might need a new generation of more progress and growth oriented younger farmers. Any farmer is open to gradual changes which do not inhere the risk of total failure but of slight improvement. Above all, the economic assessment will dominate the future development of participation. Social benefit assessment will also play an important role but only if a minimum of economic benefit is realised.

The motivation theories give clues on the interaction of the different types of needs according to an order of needs (MASLOW in HENTZE 1991, p. 30), the constellation of need fulfilment (ALDERFER in HENTZE 1991, p. 31ff), the counteraction of motivation and frustration (HERZBERG in HENTZE 1991, p. 33ff) and the personality feature of the acting individual (e.g. MCGREGOR in SCHOLZ 1993, p. 404 ff, MCCLELLAND in SCHOLZ 1993, p. 424 ff).

3 Changes in the need structure in Phitsanulok irrigation system

Farmers in Phitsanulok Irrigation System have widely adapted intensified cropping systems since irrigation was introduced. High yielding variety (HYV) rice, predominately varieties developed in Thailand, is the dominant crop throughout the irrigated area. The plantation of these varieties allows the widely applied labour saving wet broadcasting method of pre-germinated seeds on well puddled, levelled and inundated fields. After three (dry season) to four (wet season) months, the relatively short straw varieties can be harvested by combined harvesters rented from local entrepreneurs including the labour force for driving the combines and bagging the produce. Former village community work in agriculture is reduced to transporting the produce to roads, where it can be picked up by contracted transporters to be sold privately at district markets.

In contrast to the pre-irrigation system time, most of the farmers practice dry season plantation. In flood-prone areas, the dry season crop is the economically more relevant annual activities. Areas seriously affected by wet season losses have shown sharply reduced planting areas for the wet season, where the cropping intensities are as low as 66 % instead of the planned 100 %. Apart of specifically dry years with virtually no dry season plantation, the extend of dry season area has rapidly grown from being under the targeted area in the first five years to being by far exceeded nowadays, with an average of 69 % in the representative seasons during the years 1991 to 1996 instead of the targeted 33 % (RIESER et al. 1999, p.120).

This development is to a high degree related to the spreading of private tube-wells which are used to supplement irrigation system delivery (70 % of the farms) or to serve as the unique irrigation source (about 5 %). Portable pumps are used by 86 % of the farmers, 26 % even have more than one pump in use. The general trend is towards increasingly independent irrigation system farmers: Economically independent because of improved household cash-flows and better access to credit and product markets, agronomically independent by being generally more independent from labour force availability, and by applying supplementary water at the amount and time needed.

In this opening economic system the individual assessment of the benefit in participating is more likely to calculate opportunity costs for the time lost in assemblies and joint working events. Labour force in opening economy is getting scarcer even in periods of low agricultural labour requirements due to increased off-farm income opportunities. Household security might be obtained at lower costs or at a higher level from non-participative activities. In the absence of law enforcement for financial and working participation in WUA it must be suspected that the water user communities have been weakened by the actual situation. The results from farm surveys (HÖYNCK 2002) in the irrigation system areas are somewhat positively surprising, which might be related to the rule that older "systems tend to be more stable and free of conflict" (FREEMAN 1991, 95).

The activities in irrigated rice farming have developed to be highly mechanised on farm level and on specialised tasks like harvesting by private contractors. In Phitsanulok Irrigation System, the method of hiring private contractors with their machinery is locally extended for executing maintenance tasks. It is much easier to control the individual's payment of the share for the private contractor than to organise community working events. This kind of co-operation is being rather successfully managed by informal groups in Phitsanulok Irrigation System.

There are tasks in tertiary level O&M which do not require the labour input of all farmers. The individual can thus be motivated to well perform community tasks by receiving payment related to the extra activities. In the opposite direction, the lack of extra payment for extra work leads to reducing or ceasing such activities. Elected chairpersons of WUG in Phitsanulok Irrigation System do generally not perform organisation and representation tasks for honour alone. Embedded in a patron relationship to the Royal Irrigation Department there is a perception among the water users that the chairpersons should be paid by the RID.

4 Analysis of the Participation situation in Phitsanulok irrigation System

It was found that there is a wide range of ways of organising joint activities, differing from the designed organisation type, but functioning to some degree in almost all parts of the system. In the actual situation, farmers participation in WUG as far as existing or in the informal associations at tertiary level is quite satisfactory, since there are no serious problems related to the lack of participation: Conflict level is rather low, agricultural productivity is satisfactory and independent from the rate of participation, the dry season cropping intensity is even higher than targeted at 69 % instead of 33 % (RIESER et al. 1999, p. 120).

As can be seen in Figure 2 and Figure 3, the awareness of membership in a WUG is to a certain degree independent of the farmer's participation in maintenance activities. The recognition of the WUG and the chairperson of the WUG varies very much among different service units and sometimes even within a service unit where all farmers should be members of the same WUG. The distribution of WUG awareness does not correspond to the water adequacy of the conveyance system which is more reliable in the head reach (C 5, C 17/18) than in the tail reach (C 90/91 and C 106). Explanations for the differences found among the areas are related to location specific circumstances, e.g. the strength or weakness of the leader and specifically more or less recent efforts of irrigation agency officers to strengthen WUG.

Figure 3 shows that the actual participation rate is not as bad as might be expected from the membership rate in WUG. The general awareness of the benefit of the irrigation conveyance system seems to be a prevailing motivator to join maintenance activities. These activities are not executed routinely following official WUG regulations but rather according to self-organised activities in case of need for small WUG as prevailing in the tail-reach of the system. In larger service units, irrigation agency field staff regularly address farmers to execute maintenance activities, often supported by village headmen.

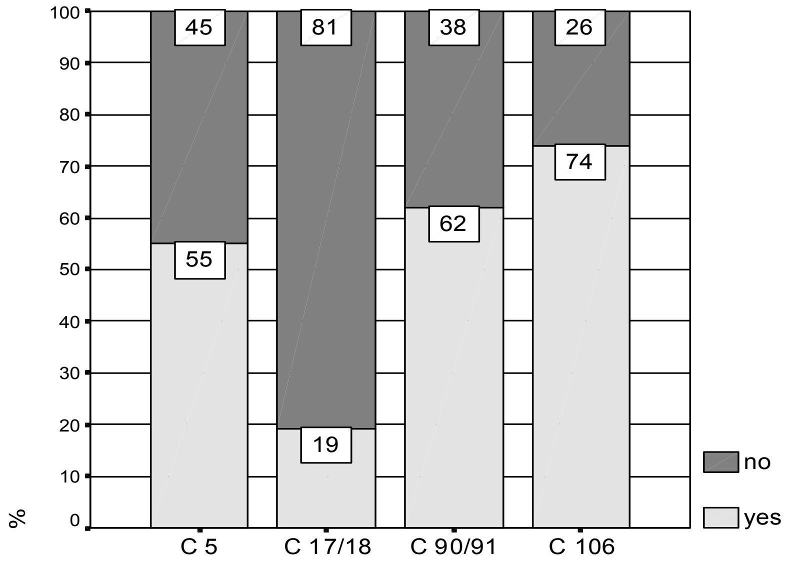

Figure 2: Share of farmers considering themselves to be members of a WUG and who do not consider themselves to be members in samples of selected lateral canal service areas

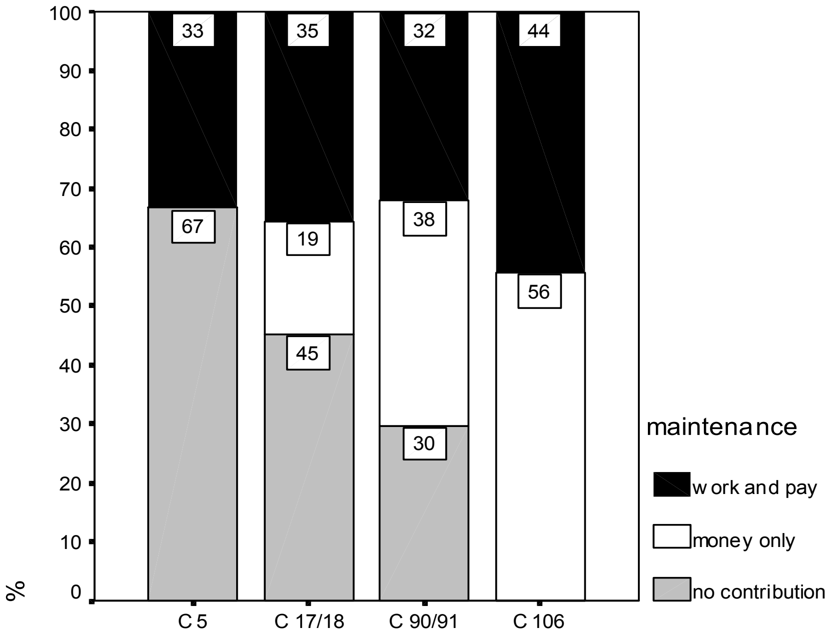

Figure 3: Forms of participation in maintenance of farmers in samples of selected lateral canal service areas1

It was revealed that the highest share of non-participants is found in the most head-ward area of the sample, in C 5, although this is the area most strongly relying on irrigation system water. The water situation would be expected to be a very strong motivator for participation in community system activities but it was found that frustration and the lack of control measures are stronger factors for farmers behaviour. Service units are comparative large by number with up to 86 members in one unit. Additionally, water delivery is sufficient for most farmers independent from their participation. Mutual control in the large service unit does not impose group pressure on individual farmers who are rather concerned with their direct neighbours. In a service unit with 86 water users with a branching farm ditch, farmers defined their WUG only for that smaller part of the service unit, a subdivision which is much more sensible than the official one.

Tables 3 and 4 show the relationship of participation in WUG meetings and in maintenance meetings to the farmers perception of water distribution fairness and his/her evaluation of the service unit/WUG quality. An interdependency of perceived “water distribution fairness” with “general satisfaction with the service unit irrigation system” appears to be obvious. Still, for the “participation in WUG meetings” on the other side, there is no such clear picture for the “participation in maintenance activities”. Whether farmers consider water distribution as unfair or not does not seem to influence their decision whether to stay away from maintenance or not.

An important interactive negative factor for participation in WUG meetings was characterised as ”indifference” summarising the cases of farmers not giving statements, not seeing fairness problems, or not caring about the WUG.

In the actual situation, this indifferent attitude is neutral in terms of conflict potential and thus no immediate problem, but it weakens the water user community because of the lack of interest of that large share of indifferent farmers. Interest representation facing the irrigation agency is by now mainly done by influential individual persons, including political manoeuvres.

The irrigator’s communities generally failed when operation issues of co-ordinating planting and water use had to managed. Water shortage from 1992 to 1994 has brought forth a political plan to promote water-saving planting systems for the dry season, especially soybean which was adapted in a very limited area by disappointingly few farmers (reported by the program co-ordinator from the provincial agricultural extension office). The more sensitive water demand of that crop was not successfully handled by the irrigation community, especially when neighbouring plots were planted with rice.

An interesting aspect in this context is the development of conflicts which were reported to be rare and not serious in most of the irrigation system area with a decreasing trend. The increased flexibility of farmers, specifically by pumping water from alternative sources, has diminished the need to openly fight water rights. Instead of open conflicts, a quiet fight is going on which again is strongest in the sampled head reach areas: 70 % of the farmers have suffered interference in their individual water application from other farmers. Only a minority of the farmers declared to have sought for a way to communicate the problem with the interfering farmer.

Table 3: Interdependence of participation frequency in WUG meetings and farmer perception of water distribution fairness and the general satisfaction level with the service unit irrigation system

participation frequency in WUG meetings	evaluation of water distribution			evaluation of WUG and service unit in general		
	fair	unfair	indifferent	positive or to be improved	negative	indifferent
always (N=97)	93%	2%	5%	82%	4%	13%
sometimes (N=41)	83%	0%	17%	61%	10%	29%
never (N=59)	39%	3%	58%	37%	24%	39%
no WUG (N=55)	35%	7%	58%	40%	24%	36%

Table 4: Interdependence of participation frequency in maintenance activities and farmer perception of water distribution fairness and the general satisfaction level with the service unit irrigation system

participation frequency in maintenance	evaluation of water distribution			evaluation of WUG and service unit in general		
	fair	unfair	indifferent1	positive or to be improved	negative	indifferent2
always (N=83)	54%	14%	31%	66%	2%	31%
mostly (N=61)	66%	7%	28%	69%	5%	26%
rarely (N=37)	62%	14%	24%	76%	3%	22%
never (N=55)	61%	17%	22%	61%	3%	36%

Farmers expectation towards the irrigation agency is the free of charge service of irrigation water delivery through a main conveyance system owned and operated by the irrigation agency. Irrigation officers are respected as the normally benevolently deciding persons concerning water delivery. Irrigation officers can also help in the rather rare cases of open conflicts. The idea of paying for the irrigation service and of maintaining infrastructure beyond the service unit outlet has not yet been an issue in the head sub-system.

In the tail-reach area, where the irrigation agency employs much less staff for O&M per acreage than in the head reach area, some interviewed farmers have reported of having organised the dredging of a lateral canal themselves by collecting the needed amount of money from the farmers of all service units at that lateral canal. For maintenance and in case of need, the farmer communities show a high capacity of organising and executing themselves, even if doing so without having organised as a WUG and without collecting and administrating money as foreseen by the irrigation agency according to legislation.

In terms of operation there seems to be a general consensus among the farmers that everybody should help himself as well as possible even if opposing the interest of some unknown faraway member of the large water user community. Pumping from higher order canals and the manipulation of minor control structures is done openly by such a large share of the farmers that a sanctioning of all would be impossible.

This kind of small-scale anarchy limits the motivation effect of the factor for seeking community strength to achieve benefits from two sides: Those "little" anonymous individuals with the opportunity to benefit from the unauthorised water use should not try to wake the sleeping lion of an irrigation authority by appearing in an easy-to-grab community. The disadvantaged farmers suffering from reduced water conveyance through the main channel are frustrated by the lack of the solidarity from the side of the "canal-pumpers". Supported by the opportunity of ground water pumping, tail-end farmers seem to accept their situation as being slightly disadvantage by the fate of having the plot located less advantageous than others.

5 Challenges and chances for the community of water users in the future

"No Problem" Forever?

"No problem" is a very common term used in Thai conversation which was also applied for the irrigation and community situation at tertiary level. Although the situation is not at an optimum, water is rarely shared equally, irrigation water delivery does not match the cropping pattern, and maintenance is sometimes lacking behind, there is a general perception that the irrigation system as a whole serves the needs of all farmers.

This "no problem"-peace depends on two factors:

- Groundwater or alternative water source pumping buffers inadequacies of the water conveyance system and allows independent agronomic decisions. Most of the problem cases were found in areas where groundwater resources were not easily accessible.
- The irrigation agency serves the farmers free of charge going as far as organising tertiary maintenance activities for the farmers. How should farmers complain about something that is for free?

Easy going non-co-ordinate irrigation activities of the farmers will turn into a serious problem in the most likely case of reduced financial engagement of the state. Like the public sector all over the world, the irrigation sector of Thailand will suffer strong pressure to reduce public costs (CARNEY 1998) and increasing farmers participation in O&M responsibility and some kind of a service fee are inevitable. The above mentioned disadvantaged farmers will not accept their fate anymore if they have to pay for a service not benefiting them, so ways to control the sharing of resources have to be introduced. In the actual situation, neither the irrigation agency nor the water users seem to be too eager to share responsibilities and to be mutually accountable which is very obvious for the irrigation agency staff.

Facing the Main Obstacles for Participation in Phitsanulok Irrigation System

One obstacle to participation was found to be the large number of water users in some service units. Naturally, co-ordination of water application is more complicated and secret interference in other farmers irrigation practices is easier in large service units, too. On the other hand, in large groups it is easier to devise specialised task to single group members which they are paid for and which can be controlled by the others. RID staff should support the farmers in designing a financial compensation system in such groups. Since those systems are further subdivided through division boxes, the WUGs might also be subdivided for maintenance issues which actually is done already based on the initiative of individuals.

Another obstacle for participation is the design of WUG as a group of land owners. The ownership structure in the system has changed since irrigation system construction, nowadays it is much more common to operate on rented farm land (about 40 % of the farm land according to the farm survey of 1996). The land operators should be those who have to pay and have to decide on water issues, even if this means that powerful landlords loose some influence. Switching from a land owner to a land operator definition of WUG membership would put an end to excuses for non-participation or exclusion of tenants, operating heirs and spouses of absentee farmers.

A third obstacle is the absence of interest for the irrigation system or the farmers community of the "indifferent" farmers (Table 3). The lack of interest in the system can be rooted in a very unsatisfactory water delivery. It should be clearly defined who is entitled to receive water or not. If water delivery to that farm is not possible, it should be removed from the delivery plan. Such a situation of not-receiving exist in the design area but the problem has not been really tackled officially, so the problem of compensation could be avoided. When talking about compensation this means to admit that there exist some kind of property rights for receiving water which quickly leads into the discussion of water pricing. Declaring water to be an economic good is a sensitive issue in Thailand, where water is viewed rather spiritual and non-tradable which unfortunately does not prevent the waste and pollution of that national asset.

Rethinking the Farmers Role – Participation and Water Pricing

Rethinking the role of farmers, the water right issue must be considered in the future. Since farmers nowadays get water delivered for free they also have no right to claim in case that water delivery is inadequate. A water right and water pricing system would require the irrigation agency to be accountable to the paying water users which consequently would strengthen the farmers interest to have a say in the water allocation, directly on tertiary level and through representatives at the interface to RID.

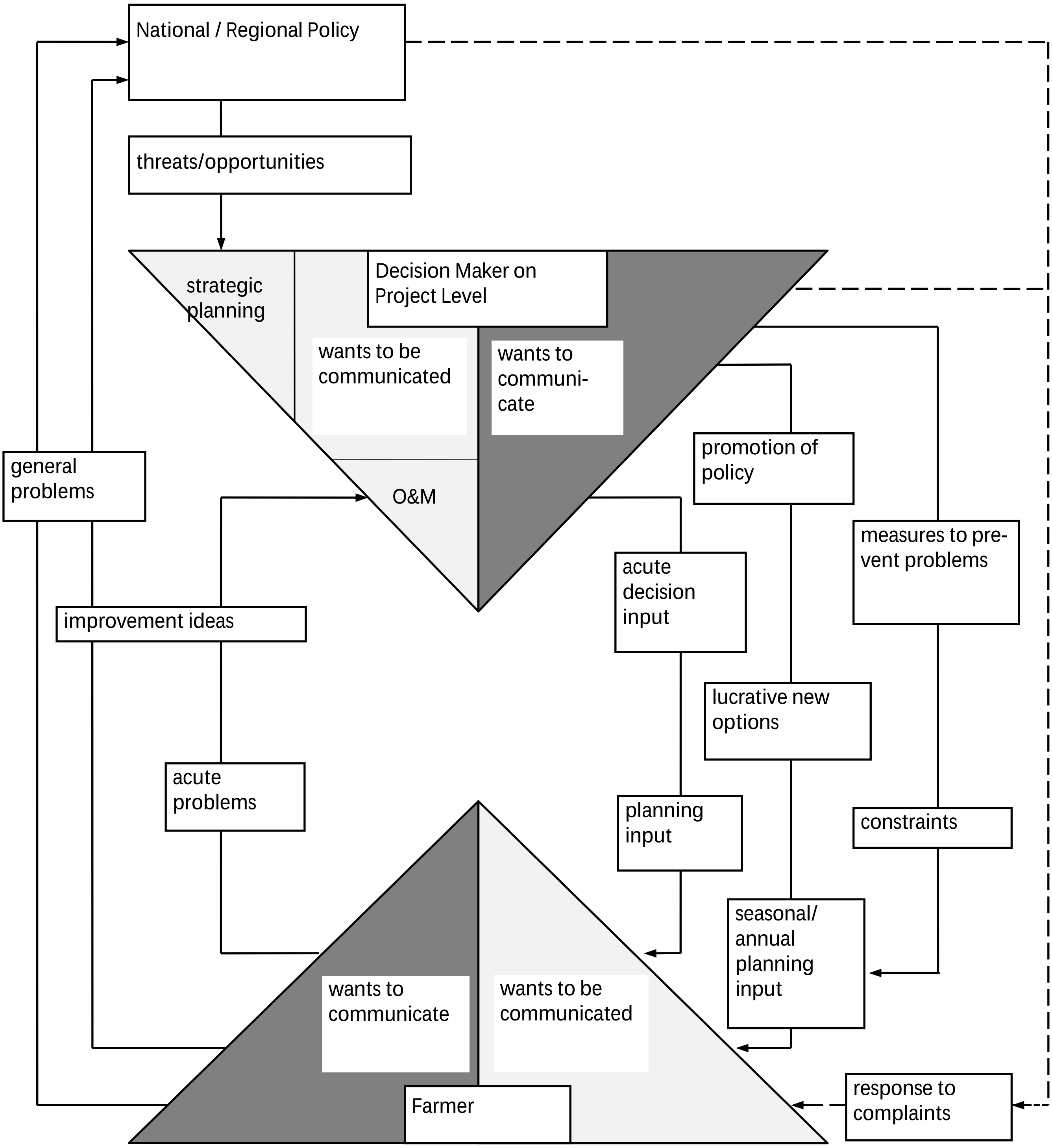

Figure 4: Communication potentials for better integration of farmers

The role of the irrigation agency for strengthening the tertiary level farmer organisation is crucial. Irrigation agency staff is highly esteemed for their expertise, as the authority to which farmers will submit in case of conflicts, and, probably most important, as those who can open or close down the water flows to their fields. In the extraordinary case of close supervision of RID officers farmers even perform as a WUG according to the Land Consolidation Act of 1974. Since farmers are rather controlled than supported in that specific case, this should not be the example which to follow for all the irrigation system are. Considering the high time requirements for these supervision activities this close supervision model is also too costly.

The general perception in RID is that participation is the attendance of farmers in meetings, when farmers are informed about the next season irrigation plans. This is obviously not enough since commonly farmers do not adapt their irrigated agriculture plans to these announcements, basing their personal cropping decisions on ground-water availability, flood risk, or other specific circumstances. The irrigation agency should not go to tell the farmers what is going to come, this could be also done by sending letters. They should ask representatives of the farmers to find out about the problems, needs and wishes of the farmers before an water allocation committee takes the final allocation decision.

RID can use its good reputation among the farmers to propose an election system, a financial compensation system, and a water use co-ordination system and to support elected leaders with their authority if necessary. Every farmer should be aware that an irrigation agency employee is open to their problems although they should firstly be solved among the water users.

The rather one-sidedly tuned communication channels of the irrigation agency to the farmers, not caring to much whether received by all water users or not, has to be switched to mutual communication (Figure 4).

The lack of motivation for farmers results from the expectation, that farmers will have to pay more although they can not expect a corresponding economic return. They have to specify or modify their role in the community, which opposes their conservative attitude. Instead of a radical cut it is therefore proposed to very soon start to gradually include farmers in the irrigation system responsibilities, in field observations, in controlling water flows, and the maintenance requirements for irrigation and drainage canals. Representatives or the community of farmers should control those activities. The introduction of payments must be done but should carefully be prepared. It must be expected that for some farms the introduction of a fee turns farming into an economically unfeasible issue putting especially the low intensity inefficient farming systems under pressure.

Apart of social considerations it should also be considered in the national equity system that the actual situation supports inefficient natural and financial resource use of water, soil and public expenditure which has to be amended.

The actual participation situation in tertiary level WUA is not a sufficient fundament yet to take over the load of irrigation system O&M to be executed efficiently and fairly and to be sustained from the farmers financial resources. The positive features to built upon are

- the generally well established sense of community creating solidarity if perceived to be necessary and if a social leader takes that responsibility
- the willingness to pay for common services, if they are clearly related to that payment. Raising funds for specific maintenance tasks is the positive example to be extended for other community task in the future.

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WASTEWATER REUSE FOR AGRICULTURE

Nicole Kretschmer, Lars Ribbe, Hartmut Gaese

Abstract

The present paper is based on a literature review and aims to tackle the most important aspects regarding the topic wastewater reuse with some recent examples, focusing on reuse in agriculture. Still in some countries the institutional and legal framework is weak or not existent or only referring to international standards (guidelines or laws) which are very general and most of the times demand very cost intensive solutions. An integrated planning approach is therefore necessary in case reuse of wastewater shall be one management alternative in a water stressed basin. Here the technological, economical and health aspect as well as the legal framework have to be considered. Therefore reuse of water is an interdisciplinary challenge for the present and for the future.

Keywords: Reuse of wastewater, irrigation, guidelines for water reuse, treatment, integrated approach, public acceptance

1 Introduction

An examination of the average residence times in the natural water cycle shows that, on the average, water that is used once then discharged and flows to the ocean will not return again as rain for about 2600 years. Groundwater residence times are often even longer (VEN-TE, 2001). This fact, as well as different studies about the world water problems, for example a release of the United Nations which predict a severe water shortage for about 2.7 billions people in the year 2025, urge us to develop and implement new water management strategies. One of the “Bonn keys” of the International Conference on Freshwater at the end of 2001 was decentralization, which means the development of small water cycles on a local level. One recommended target of the Johannesburg Summits (2002) is the increase of water productivity in agriculture to enable food security for all people without increasing water diverted for agriculture over that used in the year 2000 (HRH, 2002).

Seventy percent of world water use, including all the water diverted from rivers and pumped from underground, is used for irrigation, 20 percent is used by industry, and 10 percent goes to residences. The freshwater withdraw in agriculture and the industry worldwide is shown in the next figure.

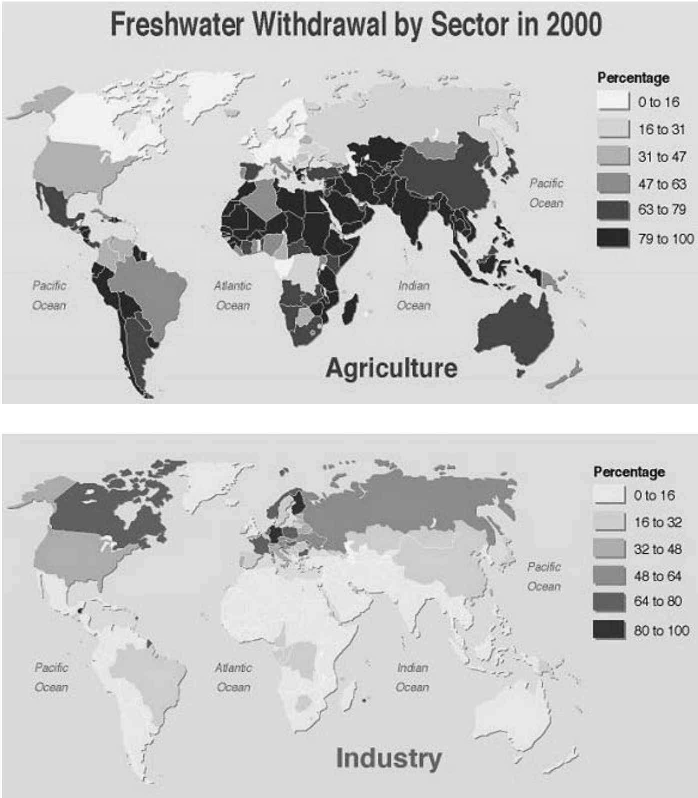

Figure 1: Freshwater withdraw worldwide by sector in 2000: Source World Resources 2000-2001. People and Ecosystems, Washington DC 2000

Thus if the world is facing a water shortage, it is also facing a food shortage. Water deficits, which are already spurring heavy grain imports in numerous smaller countries, may soon do the same in larger countries, such as China or India (Earth Policy Institute, 2002).

An example showing the severity of water scarcity in numbers has been done by a World Bank study of the water balance in the North China Plain. The study calculated an annual deficit of 37 billion tons of water. Using the rule of thumb of 1,000 tons of water to produce 1 ton of grain, this is equal to 37 million tons of grain - enough to feed 111 million Chinese at their current level of consumption. In effect, 111 million Chinese are being fed with grain produced with water that belongs to their children. Scores of other countries are running up regional water deficits, including nearly all of those in Central Asia, the Middle East, and North Africa, plus India, Pakistan, and the United States (Earth Policy Institute, 2002).

Therefore water supply and sanitation will be one of the main future challenges in a world of growing population and industrialisation. The growing awareness of water resource scarcity, the competition for water resources and the negative impact of contaminated water on human health and the environment demand the development of adequate strategies in water management. Next to the development of new management strategies to supply fresh water, the issue of treating and recycling wastewater will play an important role in tackling the existing and occurring problems. Here the shortage of water is usually the main driving force for conservation of water.

This conservation is realized through pricing reforms, wastewater treatment technologies and wastewater reuse.

Wastewater reuse is not a recent invention. There are indicators that wastewater was used back for irrigation in ancient Greece and in the Minan civilisation (ca. 3000 – 1000 BC) (ANGELAKIS ET AL., 1999;

ASANO AND LEVIN, 1996).

During 1950-60, interests in applying wastewater on land in the western hemisphere as wastewater treatment technology advanced and quality of treated effluents steadfastly improved. Land application became a cost-effective alternative of discharging effluent into surface water bodies (ASANO T., 1998).

2 Possibilities of reuse

Two major types of reuse have been developed and practiced throughout the world:

(1) potable uses

- direct, use of reclaimed water to augment drinking water supply following high levels of treatment
- indirect after passing through the natural environment

(2) non-potable uses

- irrigated agriculture
- use for irrigating parks, public places of forestry (fastest reuse application in Europe: Irrigation of golf courses)
- use for aquaculture
- aquifer recharge (indirect reuse)
- or uses in industry and urban settlements

The following graph shows the percentage of total water reuse per sector for California, Florida and Japan. It can be observed that in agricultural irrigation the water reuse overall is highest, but strongly dependent on the regional context. In Japan the reuse for example is highest in the industrial and commercial sector.

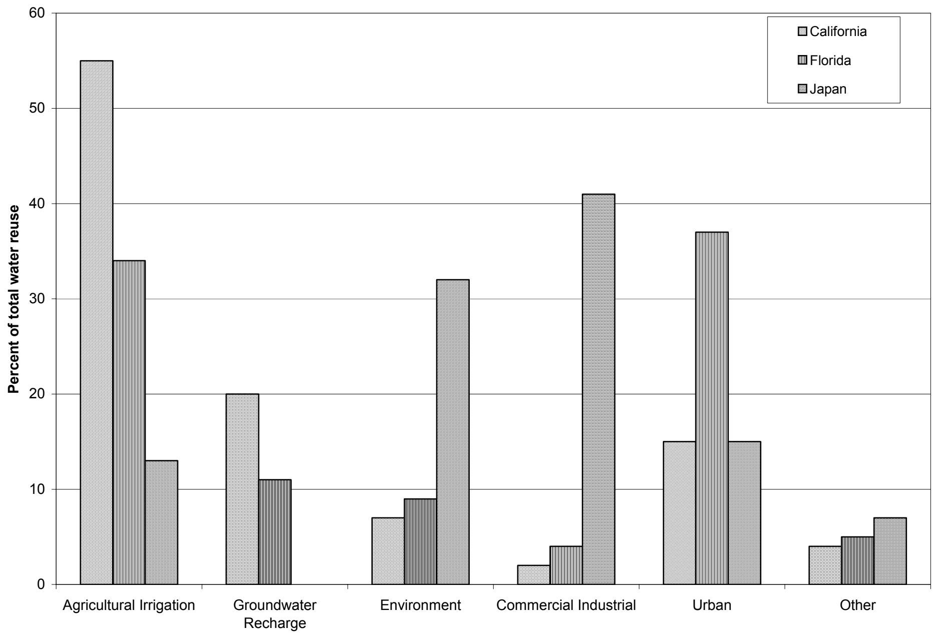

Figure 3: Comparison of distribution of reclaimed water applications in California, Florida, and Japan [Source: Asano T. 1998]

The integration of wastewater reuse in the existing water management master plans has been essentially geared towards agricultural irrigation (LAZAROVA V. ET AL, 2000).

The wastewater used in irrigation can be from different sources. It can be completely untreated municipal or industrial wastewater, mechanically purified wastewater or particularly or fully purified wastewater treated biologically (DONTA, A., 1997).

When considering wastewater reuse for irrigation an evaluation of the advantages, disadvantages and possible risks has to be made. The following table summarizes the advantages, disadvantages and possible risks regarding water conservation, different substances in the water and influences regarding the soil.

Advantages	Disadvantages	Risks
Improvement of the economic efficiency of investments in wastewater disposal and irrigation Conservation of freshwater sources Recharge of aquifers through infiltration water (natural treatment)	Wastewater is normally produced continuously throughout the year, whereas wastewater irrigation is mostly limited to the growing season.	Potential harm to groundwater due to heavy metal, nitrate and organic matter
Use of the nutrients of the wastewater (e.g. nitrogen and phosphate) ⇒ reduction of the use of synthetic fertilizer ⇒ improvement of soil properties (soil fertility; higher yields)	Some substances that can be present in wastewater in such concentrations that they are toxic for plants or lead to environmental damage	Potential harm to human health by spreading pathogenic germs
Reduction of treatment costs: Soil treatment of the pre-treated wastewater via irrigation (no tertiary treatment necessary, highly dependent on the source of wastewater)		Potential harm to the soil due to heavy metal accumulation and acidification
Beneficial influence of a small natural water cycle		
Reduction of environmental impacts (e.g. eutrophication and minimum discharge requirements)		

Table 1: Advantages, disadvantages and possible risks of wastewater reuse

By summarizing the positive and negative aspects it can be stated that wastewater, even when treated, is often associated with health and environmental risks. In addition, there is often a time gap between supply of wastewater and demand by irrigated agriculture, making sometimes costly storage capacities necessary.

3 Different sources of wastewater

Most of the examples and recent research papers are dealing with reuse of municipal wastewaters. Nevertheless it is worth to study the potential of using industrial wastewater for irrigation considering that around 20 per cent of worldwide water production are used in the industrial sector compared to 7 per cent in the municipal sector.

Among industrial wastewater it is predominantly wastewater from food processing industries that has high potential to be reused in agriculture since the main constituents are organic substances. Förster et al. (1988) investigated already in the 80s the impact on the soil, the plants and the different yields of the crops when irrigated with wastewater from food processing industries. The main outcomes were positive by means of no neg. accumulation of harmful substances in the soil and higher yields of some crops. Table 2 specifies some food processing industries which could be employed for wastewater reuse.

Source of wastewater	Pre-treatment	Contaminants	N mg/l	P mg/l	K mg/l
Distilleries	mechanical purif. neutralization	Alkali, Acids, Soda, Chlorine-compounds	25	1	20
Brewery/Malting	mechanical purif. neutralization	Yeast, Carbohydrates, settleable solids	40	5	50
Fish processing	mechanical purif. fat separation, dilution, chlorination, desodoration	scale, fats, oils, org. acids, Salt, H_2O_2	500	-	-
Potato flour	mechanical purif.	none	550	140	95
Canning	mechanical purif. neutralization, desodoration	salts, organic acids, detergents, corrosive substances	60	10	35
Diary	mechanical purification	disinfectants	35	10	20
Starch	mechanical purification, neutralization, dilution	salts, acids	300	45	415
Cider	mechanical purif. neutralization, precipitation	detergents	870	160	-
Sugar	mechanical purif.	strontium, tar, prussic (cyanic) acid	50	10	-

\- no data

Table 2: Selected food industries, treatment and composition of wastewater [SOURCE: KRETZSCHMAR, 1990]

4 Quality of the reused wastewater

The options for sustainable reuse projects are related to the quality of the effluent, and the environmental risk associated with land application for a variety of crops and activities. Patterson (2000) points at the different regulations existing for domestic and industrial effluent at an example of Australia which is valid worldwide. He describes the households as a high potential of pollution since they are able to discharge "a cocktail of chemicals at varying concentrations, together with biodegradable and non-biodegradable solids" without any concern as to the ramifications of those discharges either on the treatment system or the expected final quality of the discharged water. Whereas discharges from commercial and industrial premises into sewers are under greater scrutiny as government councils implement licensing and monitoring programs.

As already mentioned by specifying some advantages, agriculture can be understood as a land treatment system as part of the treatment cycle and is considered as the nutrient recycling part of the loop. The soil as a bioreactor and its capacity to attenuate contaminants are taken into account. Nevertheless quality requirements of the treated wastewater used for irrigation purposes have to be met (JUANICO, 1993 cited in BAHARI A. 1999).

The most important criteria for evaluation of the treated wastewater are as follows:

- Salinity (especially important in arid zones)
- Heavy metals and harmful organic substances
- Pathogenic germs

In table 3 the most important water quality parameters and their significance are listed (in the case of municipal wastewater reuse further microbiological investigations have to be done) (refer to the next paragraph: Hygienic considerations).

Parameter	Significance	Approximate Range in Treated Wastewater
Total Suspended solids (TSS)	TSS can lead to sludge deposits and anaerobic conditions. Excessive amounts cause clogging of irrigation systems Measures of particles in wastewater can be related to microbial contamination, turbidity. Can interfere with disinfection effectiveness	< 1 to 30 mg/l
Organic indicators TOC Degradable Organics (COD, BOD)	 Measure of organic carbon Their biological decomposition can lead to depletion of oxygen. For irrigation only excessive amounts cause problems. Low to moderate concentrations are beneficial.	 1 – 20 mg/l 10 – 30 mg/l
Nutrients N,P,K	When discharged into the aquatic environment they lead to eutrophication. In irrigation they are beneficial, nutrient source. Nitrate in excessive amounts, however, may lead to groundwater contamination.	N: 10 to 30 mg/l P: 0.1 to 30 mg/l
Stable organics (e.g. phenols, pesticides, chlorinated hydrocarbons)	Some are toxic in the environment, accumulation processes in the soil.	
pH	Affects metal solubility and alkalinity and structure of soil, and plant growth.	
Heavy metals (Cd, Zn, Ni., etc.)	Accumulation processes in the soil, toxicity for plants	
Pathogenic organisms	Measure of microbial health risks due to enteric viruses, pathogenic bacteria and protozoa	Coliform organisms: < 1 to 104 /100 ml other pathogens: Controlled by treatment technology
Dissolved Inorganics (TDS, EC, SAR)	Excessive salinity may damage crops. Chloride, Sodium and Boron are toxic to some crops, extensive sodium may cause permeability problems	

Table 3: Physio-chemical parameters, their significance and approximate ranges for treated wastewater [SAR= Sodium adsorption ratio, for detailed information refer to ASANO, TAKASHI, 1998]

The goal of each water reuse project is to protect public health without necessarily discouraging wastewater reclamation and reuse. Regulatory approaches stipulate water quality standards in conjunction with requirements for treatment, sampling and monitoring. These standards or guidelines are highly dependent on the kind of water use.

Table 4 schematically depicts the various consumptive uses of reclaimed wastewater together with their respective water quality considerations in a more or less scending order of quality requirements (SHELEF, 1991).

Consumptive Use	Removal of Pathogens	Chlorine Residual or other Disinfection	Removal of Susp. Solids & Turbidity	Presence of Dissolved Oxygen	Removal of BOD & COD	Removal of Nutrients	Removal of Taste, Odor and Color	Removal of Trace Organics & Metals	Removal of Excess Salinity
Landscape & Forest Irrig.	x	–	x	x	x	–	x	x	0
Irrig. of Restricted Crops (Groups A&B*)	x	–	x	x	x	–	x	x	0
Irrig. of Limited Crops (Group C*)	xx	xx	xx	xx	xx	–	x	xx	x
Irrig. of all Crops & Produce (Group D*)	xxx	xxx	xxx	xx	xxx	–	xx	xxx	x
Groundwater Recharge	xxx	xx	xxx	xx	xxx	xxx	xxx	xxxx	–
Industrial Reuse	xx	xx	xxx	xxx	xxx	xxx	xxx	xx	xx
Dual Urban Systems- Toilet Flushing and Gardening	xxxx	xxxx	xxxx	xxxx	xxxx	xxx	xxxx	xxxx	xx
Potable Reuse	xxxxx	xxxxx	xxxxx	xxxx	xxxxx	xxxx	xxxxx	xxxxx	xxx

(–) No need ; (0) usually not essential ; (x) slight need ; (xx) moderate need ; (xxx) strong need ; (xxxx) stringent requirements ; (xxxxx) very stringent requirements

Table 4: Consumptive user of reclaimed wastewater and qualitative water quality requirements [source: SHELEF 1991]

Obviously the landscape and forest irrigation has the lowest requirements concerning the treatment of effluent, compared to the potable reuse. But also the requirements of irrigation of limited crops (crops that need further processing) are not high and therefore in economic terms applicable. The table shows that not only the source of the wastewater and therefore the substances in the effluent but also the planned reuse is important for evaluating the necessary kind of treatment.

IDELOVITCH E., RINGSKOG K. 1997 and SHELEF G. 1996 explain the distinction between restricted and unrestricted irrigation (depending on the kind of crop):

(1) Restricted

- use of low quality effluents in limited areas and for specific crops only
- Restrictions are imposed based on the type of soil, the proximity of the irrigated area to a potable aquifer, irrigation method, crop harvesting technique, and fertilizer application rate
- Simple and low cost, in general only applicable to small amounts of wastewater, used in specific locations, where areas and crops are well-defined and unlikely to change
- Imposed crop limitation must be enforced and controlled
- Farmers must be trained to handle the low-quality effluent

(2) Unrestricted

- Use of high quality effluents, instead of freshwater, to irrigate any crop on any type of soil, which means without limitations
- Contact and even accidental drinking do not pose health risks
- Crops without any restriction include also vegetables eaten raw.
- The quality standard can even vary during irrigation and non irrigation period. It might be higher during interim periods when irrigation is not practiced to ensure a relatively safe discharge to receiving water bodies.

Table 5 provides values on water quality as a general guideline for interpretation of water quality for irrigation, depending on the degree of restriction.

Degree of Restriction of use				
Parameter	Units	Slight to None	Moderate	Severe
Salinity, Ecw	dS/m or µmhos/cm	< 0.7 dS/m	0.7 – 3.0 µmhos/cm	> 3.0 µmhos/cm
Total dissolved Solids, TDS	mg/l	< 450	450 - 2000	> 2000
Total suspended solids, TSS	mg/l	< 50	50 - 100	> 100
Bicarbonate, (HCO3-)	mg/l	< 90	90 - 500	> 500
Boron (B)	mg/l	< 0.7	0.7 - 3.0	> 3.0
Chloride (Cl-), sensitive crops	mg/l	< 140	140 - 350	> 350
Chloride (Cl-), sprinklers	mg/l	< 100	> 100	> 100
Chloride (Cl2), total residual	mg/l	< 1.0	1.0 - 5.0	> 5.0
Hydrogen Sulfide (H2S)	mg/l	< 0.5	0.5 - 2.0	> 2.0
Iron (Fe), drip irrigation	mg/l	< 0.1	0.1 - 1.5	> 1.5
Manganese (Mn), drip irrigation	mg/l	< 0.1	0.1 – 1.5	> 1.5
Nitrogen (N), total	mg/l	< 5	5 - 30	> 30
Sodium (Na+), sensitive crops	mg/l	< 100	> 100	> 100
Sodium (Na+), sprinklers	mg/l	< 70	> 70	> 70
SAR	mg/l	< 3	3 - 9	> 9

Table 5: Guidelines for interpretation of Water Quality for Irrigation [source: AYERS AND WESTCOTT (1985)]

5 Hygienic considerations

Predominantly with domestic sewage the issue of contamination with bacteria or viruses is extremely important. However, also with industrial wastewater pathogens might occur and should at least once in the beginning be analyzed.

Usually the coliform bacteria is taken as an indicator organism. In 1985 World Bank, UNEP, UNDP and WHO released a study giving recommendations for irrigation water used for raw consumable crops: Coliform bacteria ≤ 1000/100 ml; Helminths eggs: ≤ 1 (Note: European rivers, for example, have a count of coliform bacteria around 100/100 ml).

UNEP (1997) consider the protection of public health, especially that of workers and consumers for one of the most critical steps in any reuse program. To this end, it is most important to neutralize or eliminate any infectious agents or pathogenic organisms that may be present in the wastewater. For some reuse applications, such as irrigation of non-food crop plants, secondary treatment may be acceptable. For other applications, further disinfection, by such methods as chlorination or ozonation, may be necessary. Table 6 presents a range of typical survival times for potential pathogens in water and other media.

Pathogen	Freshwater and sewage	Crops	Soil
Viruses	< 120 but usually < 50	< 60 but usually < 15	< 100 but usually <20
Bacteria	< 60 but usually < 30	< 30 but usually < 15	< 70 but usually <20
Protozoa	< 30 but usually < 15	< 10 but usually < 2	< 70 but usually <20
Helminth	Many Month	< 60 but usually < 30	Many Month

Table 6: Typical Pathogen Survival Times at 20 - 30°C (in days); [Source: U.S. Environmental Protection Agency, Process Design Manual: Guidelines for Water Reuse. Cincinnati, Ohio, 1992 (Report No. EPA-625/R-92-004)]

6 Existing international quality standards/regulations and guidelines

EPA 1992: Guidelines for water reuse: Beside the reclaimed water quality guidelines, recommended monitoring and setback distances are given

WHO 1989: “Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture“, they take into account the treatment process, irrigation system and the crops to be irrigated. This set of guidelines is controversial but has allowed a real development of wastewater reuse (BAHRI A. 1999)

FAO 1985 (Quality criteria) determine the degree of suitability of a given effluent of irrigation (AYERS AND WESTCOT, 1985), for specific values refer to FAO Irrigation and Drainage Paper 47 (FAO, 1991)

The requirements are based primarily on defining the extent of needed treatment of wastewater together with numerical limits on bacteriological quality, turbidity and suspended solids. The Wastewater Reclamation Criteria adopted by California (see Table 7, first column) is one example: This regulation does not set any numerical limits, except for the bacteriological quality of water.

A comparison of international standards might help to develop guidelines for the reference area within each particular project. The following table summarizes some of the worldwide existing standards for reuse in agriculture. In many countries like USA and Spain only regional standards exist. A very limited number of European countries have guidelines or regulations on wastewater reclamation and reuse because first they usually do not need to reuse water and second their rivers have a sufficient dilution factor.

At the Third International Symposium on Wastewater Reclamation, Recycling and Reuse (Paris, 2000) the idea about the development of international guidelines for water recycling as a framework for national decision making was presented (ANDERSON, 2001). The international community is convinced that the health and environmental protection measures need to be tailored to suit the local balance between affordability and risk. As an recently drafted guideline, the Australian water recycling guidelines are presented. Here the attempt is done to link recycled water applications and grades of treatment (ANDERSON, 2001). The topic of national or even regional standards can be seen as an issue under discussion and still needs input from various professions and discussions between responsible institutions.

Next page:

Table 7: Comparison of selected water quality guidelines/standards (Adopted from ANGELAKIS ET AL. 1999, compare: EPA 1992, WHO 1989, Norma Chilena Oficial Nch 409 (1984)/1333 (1978)) for water reuse in agriculture (see following page)

[1] Spray Irrigation; advanced = Oxydation, coagulation, clarification, disinfection.

[2] As those of WHO with additional rules

[3] article 12 of the European Wastewater Directive (917271/ECC): 'Treated wastewater shall be reused whenever appropriate'. See also, ANGELAKIS, A.N. and ASANO, T. (2000)

[4] Zielvorgaben zum Schutz oberirdischer Gewässer Band I –III (1997,1998), Länderarbeitsgemeinschaft Wasser (LAWA)

Parameter	California[1] Ca/T-22(1978)	US EPA (1992)	WHO (1989)	Israel (1978)	Tunisia (1975)	Cyprus (1997)	Chile 1984/1978	France² (1991)	Italy (1977)	Germany
								EU guidelines (for water use in agriculture not existent until now)³		
Type	Law	Guidelines	Guidelines	Law	Law	Provisional standards	Guidelines	Guide-lines	law	Guidelines LAWA[4]
minimum treatment required	Advanced	Advanced	Stabilization ponds	Secondary	Stabilization ponds	Tertiary		Stabilizati on ponds	Secondar y	
BOD total (mg/l)		10		15	30	10				Only Heavy metals are considered in the guidelines
SS (mg/l)		5		15	30	10				
total colif. (MPN/100ml)	2.2	0		2.2					2	
feacal colif. (per 100 ml)		14 (which means not detectable)	1000			50	1000	1000		
Helmiths (eggs/100 cm3)	-	-	1		<1	0		1		
SAR									< 10	
main treatment process	Oxydation Clarification filtration disinfection	Filtration Disinfection	Stabilization ponds or equivalent	Long storage, disinfection	Stabilization ponds or equivalent	Filtration Disinfection		Stabilizati on ponds or equi-valent		

7 Selection of Treatment Method

The degree of treatment required and the extent of monitoring necessary depend on the specific application, as mentioned before.

Regarding the place of agriculture in the wastewater treatment cycle there are two possible approaches to reach the target water quality. First would be the use of technically proven wastewater processes or a conservative approach in which the role of the soil in the attenuation of contaminants is neglected. The second possibility is a step by step approach where agriculture is integrated as a land treatment system to the treatment cycle.

An example of possible treatments (in the Mediterranean region) in connection with the type of crop is shown in table 8.

Condition for use	Recommended Treatment
Irrigation of very restricted crops	Primary; anaerobic ponds; facultative ponds WHO (1989) Primary sedimentation and pretreatment
Irrigation of restricted crops	Stabilization ponds in series or aerated lagoons, followed by stabilization reservoirs WHO (1989): 8 -10 days retention in waste stabilization ponds (WSP)
Irrigation without restrictions	Stabilization ponds with polishing steps and reservoirs; or secondary: filtration (or equivalent) and disinfections WHO (1989): series of WSP

Table 8: Possible reuse preceding treatment (comparison: WHO (1989) and Shelef (1996))

In contrast Asano and Levine (1996) refer to the so called “Monterey Wastewater Reclamation Study for Agriculture”, which was a 10 years field study in the 1980s in California designed to evaluate the safety and feasibility of using reclaimed municipal wastewater to irrigate food crops that may be eaten raw (Engineering Science, 1987). This study as well as the Pomona Virus study (Sanitation Districts of Los Angeles County, 1977) provided conclusive evidence that effective virus removal can be accomplished through alternative tertiary treatment systems. A major benefit of these studies was the demonstration of lower cost alternatives for the production of reclaimed wastewater for irrigation processes. By comparison of the WHO guidelines and the criteria from California it is evident that the latter require less treatment and different monitoring conditions. The California criteria for example stipulate conventional biological wastewater treatment followed by tertiary treatment including filtration and chlorine disinfection to produce effluent that is virtually pathogen-free. In contrast the WHO guidelines emphasize that a series of stabilization ponds is necessary to meet microbiological water quality requirements.

In accordance with MURCOTT (1995) the ideal characteristics of water to be used in crop irrigation are: (a) high organic content; (b) high nutrient content (N, P); (c) low pathogen content and (d) low metal and toxic organic compounds contents. To fulfil these specifications, biological and physiochemical processes can be applied, combined with three levels of treatment: primary, secondary and tertiary (compare Table 9).

Process	Organic Contents	Nutrients N and P	Pathogens
Primary	High	High	High
Primary Advanced	Medium	Medium	Medium to low
Activated Sludge	Low	Medium	Medium to low

Table 9: Effluent quality of different processes (MURCOTT, 1995)

The Environmental Protection Agency of the United States (EPA) set up some guidelines for utilization of wastewater, indicating the type of treatment required, resultant water quality specifications, and appropriate setback distances, which are summarized in Table 10.

Type of Reuse	Treatment Required	Reclaimed Water Quality	Recommended Monitoring	Setback Distances
Irrigation of: Food crops commercially processed	Secondary Disinfection	pH = 6 - 9	pH weekly	300 ft from potable water supply wells
		BOD ≤ 30 mg/l	BOD weekly	
Orchards and Vineyards		SS = 30 mg/l	SS daily	100 ft from areas accessible to public
		FC ≤ 200/100 ml	FC daily	
		Cl2 residual = 1 mg/l min	Cl2 residual continuous	
Pasturage	Secondary Disinfection	pH = 6 - 9	pH weekly	300 ft from potable water supply wells
Pasturage for milking animals		BOD ≤ 30 mg/l	BOD weekly	
Pasture for livestock		SS = 30 mg/l	SS daily	100 ft from areas accessible to public
		FC ≤ 200/100 ml	FC daily	
		Cl2 residual = 1 mg/l min	Cl2 residual continuous	
Food crops not commercially processed	Secondary Filtration Disinfection	pH = 6 - 9	pH weekly	50 ft from potable water supply wells
		BOD ≤ 30 mg/l	BOD weekly	
		Turbidity ≤ 1 NTU	Turbidity daily	
		FC = 0/100 ml	FC daily	100 ft from areas accessible to public
		Cl2 residual = 1 mg/l min	Cl2 residual continuous	
Groundwater recharge	Site-specific and use-dependent	Site-specific and use-dependent	Depends on treatment and use	Site-specific

Table 10: Guidelines for water reuse [Source: EPA, Process Design Manual: Guidelines for Water Reuse, Cincinnati, Ohio, 1992: Report No. EPA-625/R-92-004] Legend: SS= suspended solids; FC= fecal coliforms

When dealing with decisions about possible treatment systems more and more examples of non conventional solutions are being designed, tested and evaluated. GEARHEART (1999) presents an example where constructed wetlands, a low cost alternative, serve as a part in a natural treatment system. The system under consideration had three components: oxidation ponds, wetland and UV disinfection). Even without the third component the system produces an effluent that can be used for a wide variety of reuse for irrigation and groundwater recharge. This shows that low cost possibilities can perform depending on the case quite well and should always be considered from decision makers.

When talking about reuse in agriculture not only different treatment technologies have to be taken into consideration but also different irrigation technologies. For example already on surface and subsurface drip irrigation shows differences in soil moisture content, soil salinity, nitrogen, phosphorus and Potassium content (ORON et al, 2001).

8 Planning of Agricultural Reuse Projects (Integrating Planning Approach)

Agricultural reuse development as one waste water reuse option has to be integrated in water management and a watershed approach. It is a wastewater reuse option which has to be included with wastewater reclamation, in an overall planning effort for public health protection, environmental pollution control, and water resources management (ASANO AND LEVINE, 1996).

Therefore the planning and management of agricultural reuse projects need to consider institutional and legal, socio-economic, financial, environmental, technical and psychological aspects (LAZAROVA V. et al, 2000). Most of the aspects have still to be studied in more detail since they require the development of appropriate strategies and qualified bodies for local management of treatment and reuse projects. One important key issue is often the lack of the institutional settings and guidelines or measures to be able to implement a planned reuse project. Regulatory settings of directives can be a tool for helping to get public acceptance and willingness to implement reuse projects.

A number of questions are being addressed, that have to be answered before extensive wastewater reuse operations are implemented (BAHRI A., 1999). Table 11 gives a summarization of the important issues that have been addressed in the planning phase.

Planning Phase	Objective of Planning
Assess wastewater treatment and disposal needs	Evaluate quantity of wastewater available for reuse and disposal options
Assess water supply and demand	Evaluate dominant water use patterns
Analyse market for reclaimed water	Identify potential users of reclaimed water and associated water quantity and quality requirements
Conduct engineering and economic analysis	Determine treatment and distribution system requirements for potential users of reclaimed water
Develop implementation plan with financial analysis	Develop strategies, schedule, and financing options for implementation of project (including alternatives, which can be evaluated)

Table 11: Summary of Major Elements of Wastewater Reuse Planning [Source: TAKASHI ASANO [1998]]

During the stage of planning a systematic and phased approach to evaluate project feasibility is therefore advisable.

- The alternative formulation and analysis should consider the following major feasibility criteria:
- Engineering feasibility
- Economic feasibility
- Financial feasibility: Development of a construction financing plan and revenue program
- Institutional feasibility: Formal discussion with suppliers, wholesalers, retailers, and users of reclaimed water with the goal to reach an agreement on legal and operational responsibilities
- Environmental impact
- Social impact and public acceptance
- Market feasibility

The experience of other wastewater recycling projects emphasize on planning factors concerning the environmental impact and the public health:

- distance from irrigated land (economic criteria)
- distance from protection zones and surface water bodies
- wastewater quantities compared to crop water requirements/land capacities
- water balance at site, distance to aquifer
- temporal distribution of supply and demand
- type of agricultural use
- soil type and class
- Type of available water storage, distribution and irrigation technology
- composition of wastewater
- wastewater pre-treatment requirements
- selection of crops: forestry, orchards/fruit trees, crops which will be consumed cooked/processed or raw etc.

Integrated approach additionally contains the requirement of coordination and cooperation between wastewater treatment agencies and the reclaimed water users. So called participatory approaches based on water users associations are developing (in contrast to the generally adopted top-down approach). This might ensure safe and efficient use of effluent as well increase the reuse rate through more demand driven reuse (BAHRI A., 1999).

9 Economic considerations

To optimize the net benefits from implementation of waste water reuse, a well designed integrated planning process, as described before is essential. Conceptual level planning for wastewater reuse typically involves definition of the project, cost estimation, and identification of a potential reclaimed water market.

Furthermore social and economic benefits of agricultural wastewater reuse have to be assessed (BAHRI

A. 1999; HARUVY NAVA 1997,1998; HARUVY ET AL.1999 among other studies).

A distinction between economic and financial analysis has to be made. The objective of the economic analyses of wastewater reuse projects is to quantify impacts on society, whereas financial analysis are targeted on the local ability to raise money from project revenues, governmental grants, and loans to pay for the project.

- Economic analysis: Focus on the value of resources invested in a project to construct and operate it, measured in monetary terms and computed in terms of present value estimations
- Financial analysis: determines if a favoured economic option is financially viable (PORTER, 1984).

The marginal financial analysis to be considered consists of the following costs:

Capital costs (include leads payments, dept serving), operation and maintenance costs, energy costs, revenue and timing of expenditure and receipts (examples refer to BURGESS, 1991).

A cost-benefit analysis of reuse operations is useful. A water reuse project generates monetary and non-monetary benefits. Positive aspects like

- Value of water and nutrients
- Improvement in the environment, e.g. quality of receiving bodies
- Improvement in public health
- Benefits for wastewater agencies and local authorities:
- Reduction of effluent discharge and preservation of discharge capacity
- Elimination of certain treatment processes to meet mass limits
- Sale of recycled water

Possible negative aspects like:

- Risks of aquifer pollution mainly by pathogens and organic trace elements
- Health risk of contaminated crops
- Storage and conveyance costs
- Treatment costs

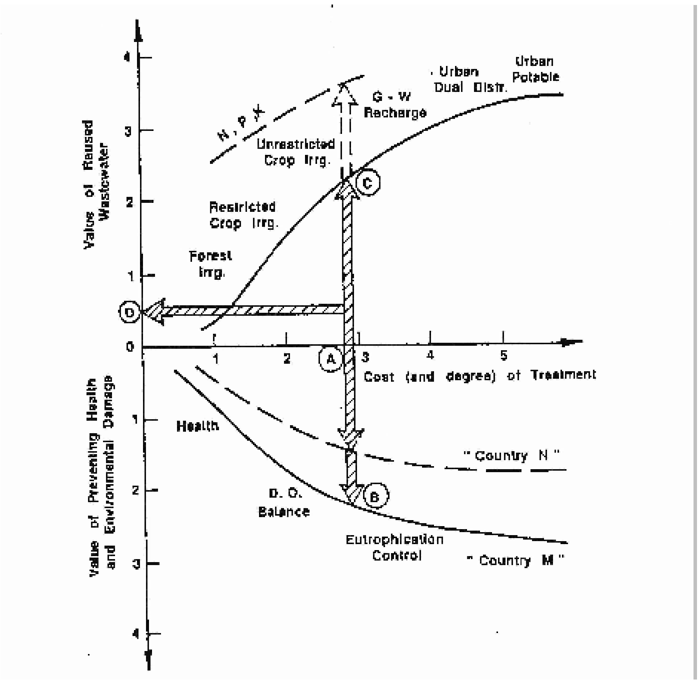

Figure 4: Benefits of wastewater reuse vs. costs of treatment (Source: SHELEF, G. 1991)

Figure 4 shows an conceptual economic justification made by delineation of the benefits gained by setting public health and environmental damage, achieved by a higher degree (and cost) of treatment and the growing benefit coincidentally gained by the higher quality of effluent to be reused.

It can be observed that the sum of the single benefits (A-B; A-C) is significantly greater than the costs of treatment (line A-D), resulting in an overall “profit”. Because the economic weight and expected benefit in health and environment might differ between countries, two different possibilities are shown. The positive value of agricultural nutrients (present in reused wastewater) should be considered as an extra bonus to this scheme.

BAHRI (1999) points out that there is often a lack of assessment of cost differentials between different alternatives of treatment concepts (treatment for reuse or treatment for sea or river outfall, the necessary transfer systems as well as the cost of fresh water).

The study of HARUVY et al. (1999) evaluates the beneficiary and hazardous effects of nutrients by irrigation with secondary water, by using an optimisation model. This model determines the monthly optimal treatment level while maximising the agricultural incomes, in the farmers point of view. As a result the added value increases with increasing nitrate concentration, but it is affected by possible hazards to crops. Adaptation of wastewater treatment levels to the regional mix of crops and to crop fertilization demands enhances agricultural incomes. One has to be carefully looking at the national point of view, this might lead to different results. There the analysis should also take account of environmental effects, such as nitrate leaching or salinity accumulation.

The paper of HARUVY (1997) demonstrates, in a simple way, how to tackle decision-making questions regarding the economic point of view of the reuse project. Various wastewater reclamation and reuse options (e.g. treatment levels, location of reuse) are compared by computing the net national benefit. A case study in Israel serves as an example. Here direct benefits as well as costs, indirect benefits and environmental damage have been considered. As a result the secondary treatment level and local irrigation (reuse option) was most beneficial, compared to southern conveyance and tertiary or secondary treatment. But still even this reuse options resulted in much more national benefit than the alternative of river disposal after tertiary treatment.

KHOURI NADIM et al. (1994) give guidelines for different scenarios which support an economic evaluation of a planned reuse project in agriculture. Differences between projects where irrigation already exists and wastewater can provide supplemental irrigation and projects without irrigation until now, where the benefits would be e.g. a higher production from existing farms are being described and mentioned to be considered while evaluating the economic benefit of a reuse project. The difficulty that positive as well as negative effects are not always quantifiable has to be realised and solved (e.g. environmental enhancements from the elimination of wastewater discharges).

The presented case study in XU P. et al (2000) about wastewater reuse on a French island makes one step forward. Here an integrated modelling of technical and economic issues has been realized. The economic sub-model estimates the economic efficiency of investments. Furthermore it makes clear that the evaluation of different scenarios is very important to come to comparable solutions. In addition it is stressed that water pricing is necessary and a way of water cost estimates is shown.

The financial analysis determines how the planned project can be financed, and if operating revenues can cover operating and dept services costs. Until now most of the water projects have been developed on the basis of subsidies and grants; only few projects have full cost recovery.

10 International experiences with waste water reuse projects (Selection)

Today in the EU water reuse is practiced predominantly in arid regions like Greece, Spain, and Italy. Israel, Jordan and Tunis are among the leading countries in wastewater reuse.

However, there are some experiences in Germany or Belgium as well. Wastewater of the city of Braunschweig, for example, has been reused since 1896. In 1996 there were 41 sites in Germany irrigated with domestic wastewater and 33 with industrial wastewater, the latter showing the following distribution: Sugar industry: 3, starch: 7, milk: 2, cleaning of vegetables: 2, sweets industry: 1, Distilleries: 13, agricultural cooperatives: 5 (DONTA, 1997).

Jeezrael Valley, Israel

Irrigation with reclaimed effluent is being performed in some areas in Israel for more than 30 years, in fact waste water reuse in irrigation was pioneered in the Jeezrael Valley, Israel (FRIEDLER, 1999). It is forecasted that in the near future, reclaimed effluents from various treatment schemes will form 80% of all irrigation water used in the previous mentioned valley, due to the increase in raw sewage production combined with a decrease in the amount of freshwater allocated for irrigation (due to freshwater shortages). In this project municipal wastewater is reclaimed as irrigation water. The project combines semi-intensive wastewater treatment plants (near to urban areas) with wastewater reservoirs (extensive treatment units, situated in rural areas) acting as an integral part of the treatment system. This idea enhances the systems performance and reduces costs because reservoirs are utilized as storage and furthermore as treatment units. The first results were effluents of high quality. When operating with all components the system is expected to release effluent of unrestricted irrigation quality.

Mexico City

The study describes and illustrates the problems related to wastewater treatment in mega-cities of the developing world. Here reuse in agriculture is used as a possibility to get rid of the wastewater without treatment. Untreated wastewater of about 75 m^3/s and the raw sewage of Mexico City is used to irrigate 85,000 ha of agricultural land in the neighboring state of Hidalgo. Besides the positive effects of freshwater conservation and higher agricultural production, which feeds and provides income to the local population, this method evokes a lot of diseases. The reason for the positive as well as for the negative side effects is the high content of organics, nitrogen and phosphorus nutrient as well as the fecal coliforms and debilitating parasites (here helminth eggs, 250 eggs/l). The high content of organic matter and plant nutrients in the water has improved the physical and chemical conditions of the soils. Soil organic matter increased and so did the crop harvest: the crop yield increased by 94 – 150 %. The irrigated area receives over 80kg/ha of nitrogen per year. Nevertheless a high prevalence of enteric and parasitic diseases among more than 100,000 workers had to be noticed. Here it can be seen that agricultural reuse is being advocated, but coupled with the need for secondary treatment prior to distribution. In the cited paper the authors urge to consider chemically enhanced primary treatment, which should produce an effluent that could be effectively disinfected (HAREMAN and MURCOTT, 1999)

Belgium

Not only in particular semiarid or arid regions reuse projects are realized. In the case of Belgium reuse has been implemented because of water quality issues (water scarcity isn't a problem there). A food processing industry, which freezes locally grown garden market products, has recycled all its wastewater by irrigating 550 ha of crops located around the factory. By adopting this solution, the processing plant was able to avoid paying a tax. Here the soil is only used as purification facility for the industrial effluent which consists of wastewater from washing and processing the vegetable and cleaning the building. Additionally it is worth to mention that since the early states of the project adaptations and technical adjustments in the industrial process have been made, such as minimizing the volume of process water or changing the method of vegetable processing (e.g. peeling with steam instead of soda). In short the project respects the environment, maintains the production potential of soils, preserves the quality of products, guarantees a regular supply to the firm, recycles nutritive elements and water in a natural cycle (GUILLAUME and XANTHOULIS, 1996).

Sharjah, United Arab Emirates

An interesting example for wastewater reuse, although not only related to agriculture, is the project in Sharjah, United Arab Emirates. It is one of the most water-poor states in the world, but its waste water recycling programme has enabled it to expand its green spaces and to conserve valuable groundwater supplies. The recycled wastewater is used for landscape and horticulture irrigation. To protect public health Sharjah established conditions and regulations for the safe use of recycled wastewater for irrigation (COOPER, 2001). Implemented projects like the previously mentioned in semi-arid or arid regions show again, that public acceptance and the willingness to implement such projects is highly connected with the grade of water scarcity in the country.

Trying to specify all interesting reuse projects would go beyond the scope of this work. There are certainly a number of examples in the Mediterranean region (arid and semi arid climate) such as Israel, Palestine and Jordan, but also in Europe where temperate climate prevails. Some examples for integrated resource management with water reuse are numerous islands in France (Noirmoutier, Porquerolles), Spain (Balearic and Canary), Italy (Sardinia, Sicily) and UK (LATAROVA V. 2000).

11 Public Acceptance

As mentioned in the introduction the psychological factor is essential for initiating, implementing and sustaining a long-term waste water reuse program. Therefore the development of sustainable water recycling schemes needs to include an understanding of the social and cultural aspects of water reuse. In absence of social support a reuse project may fail. Even for non-potable reuse purposes, the public attitude plays an important role, including the perception of water quality, willingness to pay or to accept any wastewater reuse project (LAZAROVA V. 2000).

By working on the public as well as on the institutional acceptance, one has also to keep in mind that wastewater reuse has different driving forces. First it is a supplemental water supply in water scarce regions and second it can be a viable alternative to the disposal of treated effluents in rivers and coastal waters and therewith a driving force also for regions with humid climate.

The use of alternative solutions to the discharge of wastewater in sensitive areas, where advanced tertiary treatment is not affordable, was encouraged. FABY ET AL. (1999) criticize the very strict restrictions which are even in some parts much higher than the WHO (1994) guidelines concerning reuse in agriculture. Nevertheless they found out that the decree of 1994 in France, which provided the basis for water reuse rules, were followed by 16 wastewater irrigation projects worked out during the 1990’s. In the future new projects are expected to be developed as alternative solutions to wastewater discharge in sensitive water bodies.

A study about the industrial sector in Thailand and its willingness to adopt wastewater reuse practices indicates that only 10.5 per cent of the surveyed industries reuse their treated effluent. Furthermore the tendency of the surveyed industries is directed into non-adoption of industrial waste water reuse. (VISVANATHAN AND CIPPE, 2000). Again this shows the need for analysing the costs and benefits in all sectors.

Related to public acceptance and health issues a risk assessment should be part of the planning process. For example a careful assessment of the extent of potential health risks involved in wastewater reuse for irrigation is necessary. The extent of risks then might be weighted against urgency and derived benefits of the water reuse in order to make a sound decision on the project (SHAHALAM et al., 1989).

Last an example of widespread public relation work associated with water reuse or recycling is shown. The “Queensland water recycling strategy” serves as an example (Queensland Government, 2001). This strategy was initiated from the department of Natural Resources (DNR) in Australia and is managed from the EPA to increase the beneficial use of a largely untapped resource. The reports, which range from educational needs, agricultural water recycling, urban water recycling, health effects and legislative considerations were all published (the last in 2001) with the goal to reach all people involved in water management issues, to promote the possibilities of water recycling in all sectors and give governmental support by planning and implementation.

12 Conclusions

This review about wastewater reuse in agriculture shows that an integrated planning approach, considering economic as well as environmental and health issues, related to water reuse is essential to guaranty a success. Furthermore it has been shown that the issue of wastewater reclamation is discussed and implemented all over the world.

Although wastewater has been used already for decades and even back in the ancient Greece in the

Minoan civilization (ca. 3000 – 1000 BC), (ANGELAKIS et al., 1999) the need for adaptations of the guidelines to the specific area of concern is high and still a challenge to all involved disciplines. The adaptation to the local conditions should increase the benefits and decrease the health risk. Furthermore this will result in a higher public acceptance which is crucial for implementation of reuse projects.

Wastewater reuse in agriculture has been shown as one important management issue for sustainable use of the limited freshwater resource, next to demand oriented water allocation and water desalination. Important, because of the potential economic and environmental benefits. It is necessary and worth to initiate and support wastewater reuse projects all over the world, since our population and with that the food demand is growing steadily, whereas water availability will stay the same.

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Contact

Nicole Kretschmer, University of Applied Sciences, Institute for Technology in the Tropics, Betzdorfer Str. 2. 50679 Cologne, Germany; E-mail: Nicole.Kretschmer@dvz.fh-koeln.de

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WASSERRESSOURCENMANAGEMENT IN CHILE

Alexandra Nauditt, Lars Ribbe, Hartmut Gaese

Abstract

This article gives a survey of economical, legal and institutional aspects of water management in Chile.

The Chilean System of water distribution is characterized by a strong participation of the private sector and a pronounced autonomy of the water users in the agricultural sector. The national water policy is currently in a transformation process, with the aim to strengthen governmental influence on the protection of water bodies as well as on water distribution.

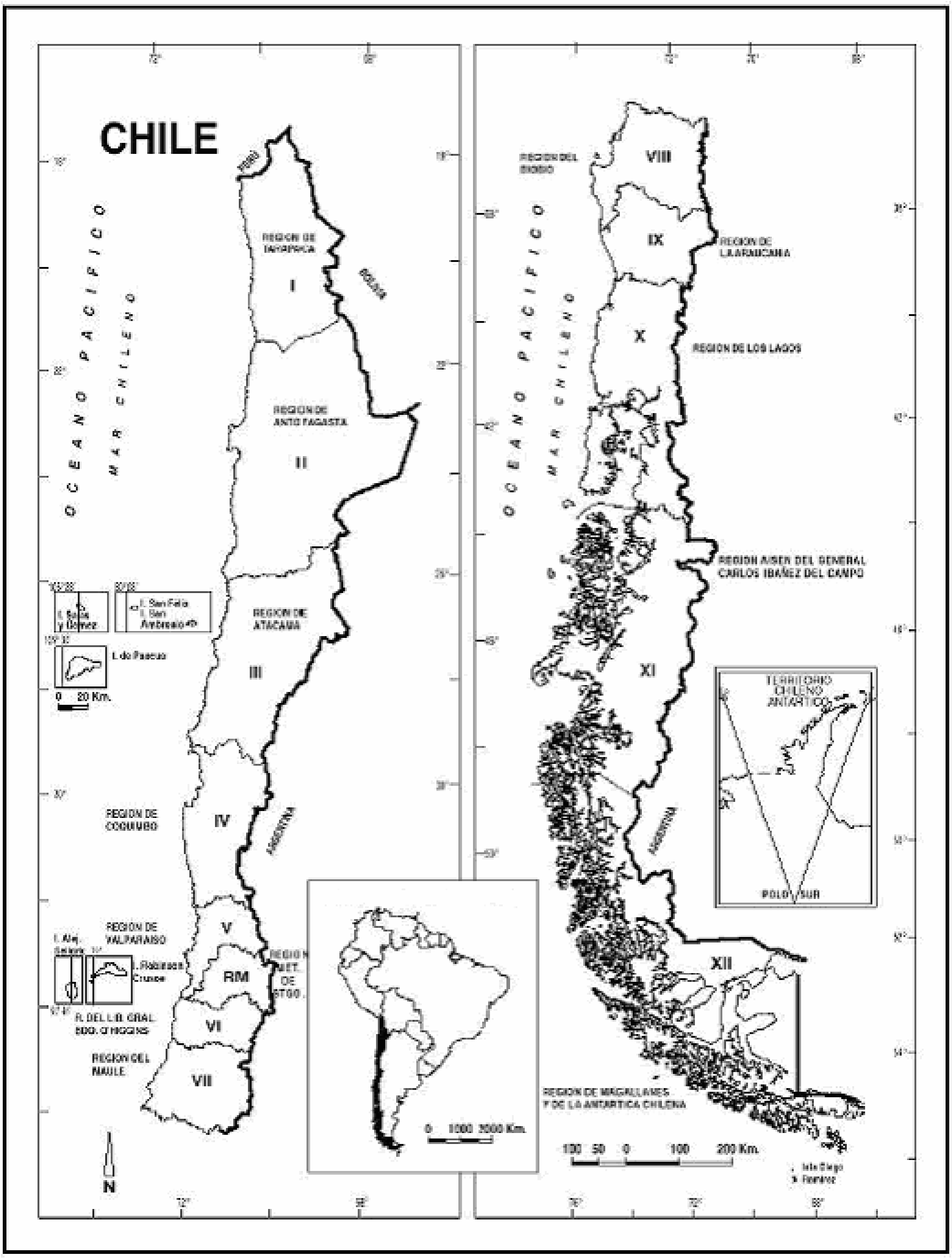
Keywords: Chile, Wassermanagement, Wassergesetzgebung, Wassermarkt, Wasserinstitutionen, Wasserver- und -entsorgung

1 Einführung

Bevölkerungswachstum, ein verbesserter Lebensstandard und die starke wirtschaftliche Entwicklung haben die Anforderungen an die Wasserwirtschaft in Chile wesentlich verändert. Fehlende Marktaktivitäten und ein überholtes Wassermanagement verhindern eine optimale Nutzung und den ökologischen Schutz der Ressource.

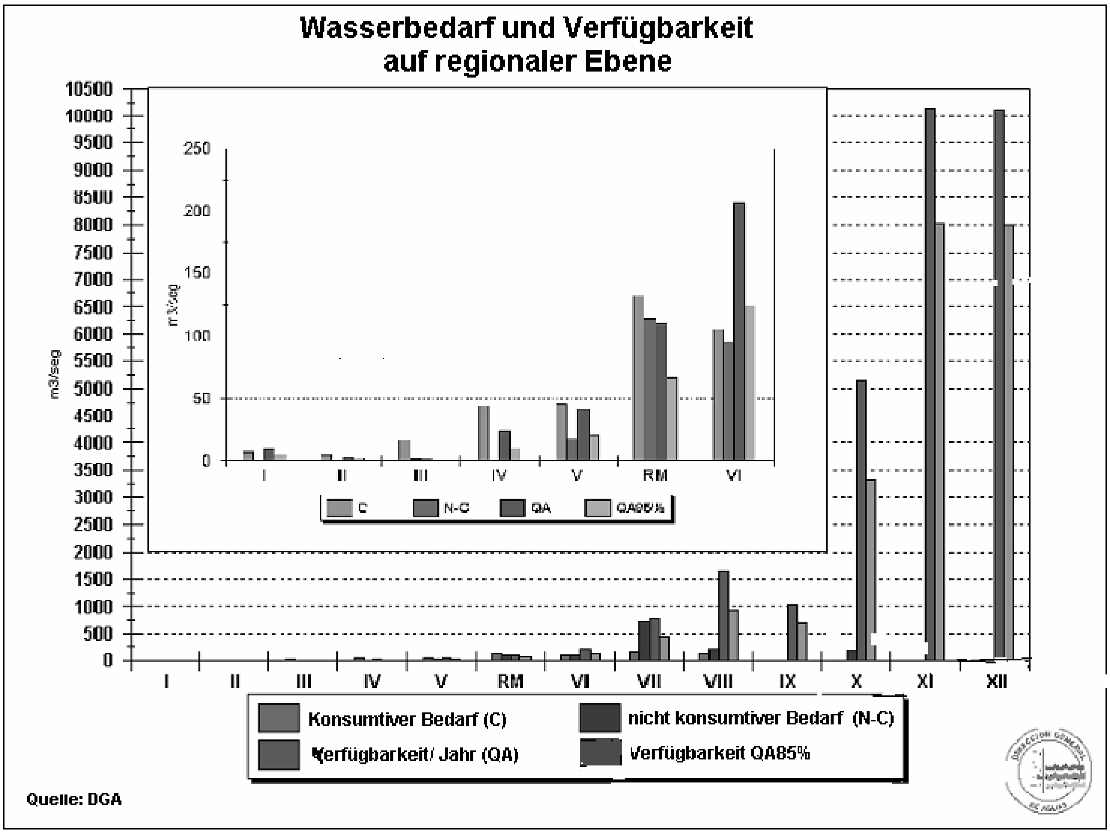
Chile erstreckt sich über einen etwa 180 km breiten und 4.200 km langen Streifen entlang der südamerikanischen Pazifikküste mit einer Gesamtfläche von 757.000 qkm, und birgt enorme klimatische Unterschiede. Mit einem durchschnittlichen jährlichen Niederschlag von 1500 mm und einer durchschnittlichen Verfügbarkeit des für den menschlichen Verbrauch geeigneten Wassers von 70.000 m³/Jahr/Einwohner (weltweit durchschnittlich 9.500 m³/Jahr/Einwohner) liegt die Wasserverfügbarkeit in Chile weit über dem weltweiten Durchschnitt (Peña, 1987).

Das Land ist in die Regionen I – XII und die Región Metropolitana, in der sich die Hauptstadt Santiago befindet, aufgeteilt. Im ariden Norden, den Regionen I-IV beläuft sich der Niederschlag durchschnittlich auf weniger als 50 mm/Jahr, im gemäßigten Süden, den Regionen X – XII, auf bis zu 3200 mm/Jahr, sowohl das Wasserdargebot als auch die Nachfrage unterliegen erheblichen regionalen Schwankungen. Während die Wasserverfügbarkeit in Chile 1992 einen Durchschnitt von 5.475m³/Einwohner/Jahr erreichte, beläuft sich das Dargebot für das nördlich von Santiago gelegene Gebiet auf durchschnittlich weniger als 1.000m³/Einwohner pro Jahr; in einigen Gebieten auf unter 500 m³/Einwohner pro Jahr (Peña 1996, CONAMA, 1999).



Graphik 1: Politische Aufteilung, Regionen I – XII und Región Metropolitana (RM)

Die gesamte Wassernutzung in Chile wird auf 34.21 Milliarden Kubikmeter geschätzt (Ríos, Brehm, 1995), davon werden 32,2 % konsumtiv und 67,8 % nicht-konsumtiv (Hydroenergie) genutzt. 84,5% des konsumtiven Verbrauchs fallen auf die Bewässerung von landesweit ca. 1,3 Mio. Hektar, 4,5 % für Trinkwasser, 6,5 % für Industrie und 4,5 % für den Bergbau (DGA, 1999). Im weltweiten Vergleich ist der konsumtive Wasserverbrauch in Chile sehr hoch und soll DGA - Prognosen zufolge bis zum Jahr 2017 noch erheblich steigen. Hierbei wird geschätzt, dass sich der Wasserbedarf für Industrie, Bergbau und Trinkwasser verdoppeln und für landwirtschaftliches Nutzwasser um 20 % erhöhen wird. Für den nicht-konsumtiven Verbrauch können wegen des Angebots von Erdgas auf dem Energiemarkt keine verlässlichen Prognosen erstellt werden, es ist jedoch durchaus möglich, dass der Bedarf bis auf ein Zehnfaches ansteigen wird (DGA, 1999).



Graphik 2: Wasserbedarf und Verfügbarkeit in den einzelnen Regionen (MOP,DGA 1999)

Die sich verschlechternde Wasserqualität und zunehmende Interessenskonflikte unter den Wassernutzern erfordern eine Überarbeitung der bestehenden Wassergesetzgebung und individuelle Lösungen für jede einzelne Region. In der Praxis ist der staatliche Einfluss auf das Wassermanagement sehr begrenzt, die lokalen Wassernutzerorganisationen führen die landwirtschaftliche Wasserverteilung aus. Sie halten hydraulische Anlagen in Stand, erheben Gebühren und schlichten Konflikte unter den Nutzern. Die Besonderheit des chilenischen Wasserrechts besteht darin, dass Wassernutzungsrechte vom Staat vergeben werden und deren Inhaber wiederum die Möglichkeit haben, diese unter marktwirtschaftlichen Bedingungen weiter zu veräußern. Diese Regelung bringt einige Probleme mit sich; so kann sie beispielsweise nicht gewährleisten, dass einmal auf unbefristete Zeit vergebene Nutzungsrechte auch tatsächlich die sinnvolle, produktive und gerechte Verwendung des Wassers garantieren. Bisher basiert das Wassermanagement auf der Ebene von Flusssektionen -in Anlehnung an die Organisation der Wassernutzerorganisationen- anstelle von gesamten Einzugsgebieten, was eine großräumige Regulierung von Wassermenge und Wasserqualität erheblich erschwert. Obwohl Grundwasser und Oberflächengewässer für gewöhnlich ein integriertes hydrogeologisches System bilden, werden beide separat betrachtet und verwaltet.

Chile verzeichnet als sogenanntes Schwellenland ein kontinuierliches Wirtschaftswachstum, die liberale Wirtschaftpolitik und der einseitige Rohstoffexport haben jedoch ökologische Gesichtspunkte vernachlässigt. So sind z.B. die Oberflächengewässer durch den Kupferbergbau und die intensive Landwirtschaft stark belastet. Die Nutzungsrechte für die Flüsse sind weitestgehend vergeben und die Abflussmengen nehmen ab. Auch die Grundwasserentnahme in den trockenen Regionen I-VI ist vor allem in den 90er Jahren angestiegen. Zwar schreibt die DGA den Nutzungsrechterwerb für

Grundwasser vor, 40-60% der Pumpen werden jedoch ohne offizielle Genehmigung betrieben (Davis 1999b; Hearne and Easter 1995).

2 Wasserrechte und Gesetzliche Rahmenbedingungen

Der Código de Aguas

Die derzeitig gültige chilenische Wassergesetzgebung beruht im wesentlichen auf dem Código de Aguas von 1981. Weitere Gesetze sind das Bewässerungsförderungsgesetz und die im chilenischen Umweltgrundgesetz von 1994 verankerten Wasserqualitätsnormen. Zum einen gibt es demnach die strukturellen Wassergesetze, die die Stabilität und Flexibilität der vergebenen Wasserrechte vorgeben und zum anderen die regulierenden Qualitätsnormen, die die physischen, chemischen und biologischen Kriterien des Wassers kontrollieren sollen.

Die im Código de Aguas festgelegten strukturellen Gesetze haben zum Ziel, private Investitionen in das wirtschaftliche Potential der Ressource zu sichern und räumen den Inhabern der Wasserrechte erhebliche Freiheiten ein. Die vom Staat vergebenen Wassernutzungsrechte sind nicht anfechtbar und durch die in der Verfassung verankerten Besitzrechte zusätzlich untermauert. Der Nutzungsrechtinhaber verfügt über eine nahezu unbegrenzte Freiheit bei der Wassernutzung, so kann er die ihm zugeteilte Wassermenge in jeder Form nutzen oder nicht nutzen, unabhängig vom Bodenrecht an eine andere Stelle transferieren und an einem anderen Ort vermarkten sowie kommerziell nach markttypischen Kriterien veräußern. Andererseits gibt es wenige einschränkende Gesetze. Die Nutzungsrechtinhaber sind nicht verpflichtet, Anlagen zur Wassergewinnung zu bauen, es werden keinerlei Steuern, Tarife oder Gebühren für die Nutzung oder Nichtnutzung erhoben. Weiterhin gibt es bei der Vergabe der Nutzungsrechte keine prioritären Kriterien, ökologische Aspekte spielen keine Rolle.

Der Wasserkodex von 1951 – Grundlage für den heute gültigen Código von 1981 – schuf im Rahmen eines liberalen Gesetzesansatzes eine staatlich administrative Konzession, die stärker auf private als auf öffentlich-rechtliche Bereiche der Wasserverwaltung einging. Wasser wurde kauf- und verkaufbar, der Eintrag in staatliche Titelregister verlieh der Privatperson größeren Rechtsschutz. Der Wasserkodex von 1969 ging einher mit Allendes Wirtschafts- und Sozialpolitik, die mit der Verabschiedung der Agrargesetzgebung (Ley de Reforma Agraria, No. 16.640) von 1967 begann und deren Ziele in einer weitreichenden Bodenreform und der Verstaatlichung von Großgrundbesitz lagen.

Die zentralen Aussagen und Änderungen des Wasserrechts durch die einzelnen Códigos sind in Tabelle 1 zusammengefasst.

Tabelle 1: Wichtige Aussagen der Wassergesetze (Códigos de Agua) von 1951, 1969 und 1981 [Quelle: Gentes (2000), Dourojeanni (2001)]

Código de Aguas 1981	Wasser ist ein nationales Gut, über das sich in bestimmten Fällen ein privates Nutzungsrecht erlangen lässt. Zwischen Land und Wasser findet eine juristische Trennung statt. Die Rolle des Staates als spätere Kontrollinstanz ist sehr eingeschränkt; sie liegt nur in der Kontrolle des korrekten Vergabeverfahrens. Das Konzept der Nichtnutzung wird eingeführt, d.h. eingeschriebene Nutzungsrechte können von Dritten unbehelligt für einen zeitlichen Rahmen benutzt werden. Es gibt keine staatliche Prioritätenliste für die Wassernutzung mehr (vorher wurde der Bergbau bevorzugt).
Código de Aguas 1969	Wasser wurde zu nationalem Eigentum öffentlicher Nutzung. Die früheren Vorzugsrechte fielen weg. Rückführung der Konzentration von Wasserrechtseigentümern in den Besitz weniger Großgrundbesitzer. Minimierung der Kompensationszahlungen für Wasserrechtsenteignungen. Verbot der Abtretung eines Nutzungsrechts. DGA erhält Vollmacht, Nutzungsrechte ganz oder teilweise als hinfällig zu erklären. Einführung von staatlich festgesetzten Quoten für eine rationale und effiziente Nutzung der Ressource (Bewässerung).
Código de Aguas 1951	Stärkung der juristischen Reichweite der Nutzungsrechte durch den juristischen Eintrag in das Wasserregister der DGA und den Eintrag als staatlich geschütztes Eigentumsrecht ins Register nationaler Liegenschaften (Conservador de Bienes Raices). Bildung der DGA; bis 1969 werden ihre Aufgaben allerdings von der staatlichen Bewässerungsbehörde ausgeführt. Einführung einer Spezifizierung des beantragten Wassernutzungsrechts nach Art, Ziel und notwendigen infrastrukturellen Arbeiten. Interessenten und Nutzungsrechtsinhaber vollzogen die Verantwortung über die Kontrolle und Verteilung des Wassers innerhalb dreier Körperschaften: den Kanalgesellschaften (asociacones de canalistas), den Wassergemeinschaften (comunidades de aguas) sowie den Kontrollorganen (juntas de vigilancia). Einführung der Vergabe von provisorischen Rechten. Inhaber eines Wassernutzungsrechts konnten die Form der Nutzung nicht eigenhändig ändern, eine Rückgabe dieser an die Hauptwasserdirektion war notwendig, die dann über die Vergabe der Konzession neu entschied. Die Hauptwasserdirektion wurde berechtigt, Wasserrechte, die über einen Zeitraum von 5 Jahren nicht genutzt wurden, aufzuheben (siehe Art. 280).

Wasserqualitätsnormen

Die Gesetzgebung für die Wasserqualität ist bisher sehr lückenhaft und die Verantwortlichkeiten für ihre Durchführung auf mehrere Institutionen verteilt, so spielen hierbei das MOP/DGA, SISS und die CONAMA eine Rolle. Umgesetzt werden zur Zeit die Ende der 90er Jahre verabschiedeten Normen für Industrieabwasseremissionen und die Kontrolle der Meeresgewässer mittels der im Umweltgesetz verankerten Norm für die Meeresgewässerqualität. Die Norm für den Status der Oberflächengewässer liegt derzeit dem Parlament zur Verabschiedung vor.

Tabelle 2: Normen zur Wasserqualität

Norm	Jahr	Zuständige Institution
Wasserqualitätsnorm zum Schutz der Oberflächengewässer noch nicht in Kraft	2002	DGA CONAMA
Ley 19.821 ergänzt Ley 18.902 von 1990 (Industrieabwässer SISS), führt Sanktionen gegen Industriebetriebe ein, die die Normen nicht erfüllen und setzt Fristen, in der die Normen erfüllt werden müssen	2002	MOP SISS
D.S. SEGPRES N° 90 Wasserqualitätsnorm für jede Form der Einleitung in das Meerwasser und in Seen	2000	CONAMA
Res. SISS N° 2327 Wasserqualitätsnorm zur Industrieabwassereinleitung in Oberflächengewässer	2000	SISS
D.S. MOP N° 3529 Löst D.S. MOP N° 609 ab, Industrieabwassernorm zur Einleitung in die Kanalisation	2000	MOP SISS
D.S. MOP N° 609 Industrieabwassernorm zur Einleitung in die Kanalisation, abgelöst durch D.S. MOP N° 3529	1998	MOP SISS
Ley 19.300 Ley Marco del Medio Ambiente, Chilenisches Umweltrahmengesetz, Einführung des UVP-Systems SEIA	1994	CONAMA
Ley 18.902 Gründet SISS und überträgt ihr die Aufgabe, Industrieabwässer zu kontrollieren	1990	MOP Chilenische Verfassung
Norma Chilena NCh 409 Chilenische Trinkwassernorm	1978	Chilenische Verfassung
NCh 1.333 Wasserqualitätsnorm zur Nutzung von Trinkwasser für Vieh, Bewässerungswasser, etc.	1978	MOP
NCh 777. Decreto Nº996 Wasserqualitätsnorm für Wasserversorgungsquellen	1971	MOP

Probleme der Wassergesetzgebung

Die wesentlichen Elemente und Kritikpunkte der derzeitigen Wassergesetzgebung lassen sich wie folgt darstellen:

- der Kodex räumt den privaten Wassernutzern eine sehr große Autonomie ein, sie verfügen über Entscheidungsfreiheit bei der Verwaltung und Weiterverteilung des Wassers sowie bei der Durchführung von wasserbaulichen Maßnahmen; einmal Inhaber von Wasserrechten, ist es fast unmöglich dieses Recht wieder zu verlieren
- geringe staatliche Einflussnahme auf den ökologischen Schutz der Gewässer und ungenügende Kontrolle der Wasserqualität
- keine integrierte Betrachtung der Oberflächengewässer und des Grundwassers sowie der Ober- und Unteranrainer
- die Inhaber der Wasserrechte sind nicht verpflichtet, das gesamte ihnen zugeteilte Wasser zu nutzen
- schlechte Ausgewogenheit zwischen den zu vergebenden Wasserrechten und der tatsächlichen verfügbaren Wassermenge in manchen Einzugsgebieten
- sie räumt den Nutzungsinhabern die Möglichkeit ein, eine Modifizierung des Wasserkodex zu verzögern

Reform der Wassergesetzgebung

Seit 1992 läuft das Gesetzesprojekt zur Modifizierung des jetzigen Wasserkodex. Anfang 2002 wurde der entsprechende Entwurf dem Parlament vorgelegt und muss noch vom Senat verabschiedet werden. Zentrale Anliegen der Reform sind unter anderem:

- Erweiterung der juristischen Möglichkeiten der DGA mit dem Ziel einer stärkeren Einflussnahme auf Bereiche wie Transfer, Aufrechterhaltung und Verwaltung der Ressource,
- Einführung einer Gebühr für erteilte aber nicht genutzte Wassernutzungsrechte,
- Verpflichtung der Wassernutzungsrechtinhaber, ihr Kontingent in einem bestimmten Zeitraum zu nutzen oder zurückzugeben ,
- Sicherung eines ökologischen Mindestabflusses (caudal ecológico),
- Einrichtung einer nationalen Wasserkommission, die mit der Ausführung der nationalen Wasserpolitik betraut werden soll,
- Schaffung von Einzugsgebietskomitees,
- Vollständige Implementierung der im Umweltrahmengesetz von 1994 enthaltenen Wassernormen in das Wasserrecht,
- Berücksichtigung der Konflikte, die Dritte betreffen (Ober-/Unterlaufkonflikte, Wasserverschmutzung) mit Hilfe eines Managements auf Flusseinzugsgebietsebene.

3 Organisatorische Struktur des Wassersektors

Staatliche Institutionen

Die Hauptverantwortlichkeiten für Wassermanagement und die Umsetzung des Código de Aguas liegen bei der DGA (Dirección General de Aguas), die dem MOPTT, ehemals MOP, (Ministerio de Obras

Públicas, Transporte y Telecomunicación), dem Infrastrukturministerium unterstellt ist. Ihre Aufgaben sind vor allem die Erarbeitung von Wassermanagementstrategien, Vergabe von Nutzungsrechten, Forschung und Datenerhebung, Überwachung der natürlichen Gewässer, Kontrolle der im Wasserkodex vorgegebenen Organisation der Nutzergruppen und das Eingreifen bei Konflikten unter den Nutzern. Weiterhin arbeitet die DGA mit der **CONAMA** im Bereich des UVP-Systems SEIA (Sistema de Evaluación de Impacto Ambiental) zusammen.

Die seit 1969 wirkende DGA ist vom privaten Wassersektor unabhängig und führt keine Aufträge für wasserbauliche Maßnahmen aus. So kann sie unparteiisch ihre Funktion als kontrollierende und gesetzgebende Instanz erfüllen, ohne die ökologische und ökonomisch effiziente Nachhaltigkeit aus den Augen zu verlieren. Andererseits ist die Durchführung einer nationalen Wasserpolitik in der Praxis eher schwierig, bei der Schlichtung von Konflikten unter den Wassernutzern spielt die DGA in der Regel kaum eine Rolle und kann beim Weiterverkauf der Nutzungsrechte nicht eingreifen. Was die Wasserqualitätskontrolle angeht, ist die Zuständigkeit auf viele Institutionen verteilt und sehr lückenhaft.

Die 1994 eingerichtete nationale Umweltbehörde **CONAMA** (Comisión Nacional de Medio Ambiente) ist neben des Verfassens und der Umsetzung der Umweltgesetzgebung für die Evaluierung und Koordinierung von nationalen Umweltprojekten zuständig. Ihr Direktorium setzt sich aus 13 Ministern zusammen. Die regionalen Vertretungen der CONAMA, die **COREMAS**, überwachen die lokale Umsetzung der Umweltprojekte und der gesetzlich geforderten UVPs.

Als weitere öffentliche Einrichtung ist die Wasserbaudirektion **DOH** (Dirección de Obras Hidráulicas) für die Entwicklung größerer Wasserbauten, Planung, Ausschreibung, Bauüberwachung und Instandhaltung der Bewässerungsinfrastruktur zuständig. Auch sie ist dem **MOP** unterstellt und nimmt im Sinne der neuen Wasserpolitik und eines integrierten Einzugsgebietsmanagements aktiv an der Planung zu einer effizienten Nutzung der Wasserressourcen teil, indem sie die gesamten hydraulischen Anlagen in einem Einzugsgebiet entwirft, baut und instandhält. Hierzu zählen Be- und Entwässerungssysteme (Primärinfrastruktur, Staudammbauten, Regenwasserkollektoren, Flussbettregulierung, Uferbefestigungen, größere Grundwasserentnahmebauwerke, Hochwasserkontrolle sowie Projekte zur Trinkwasserversorgung von ländlichen Gegenden. Außer einigen kürzlich durchgeführten größeren Maßnahmen, hat es in den letzten 15 Jahren keine staatlichen Subventionen in große Bewässerungsprojekte gegeben.

Die Comisión Nacional de Riego (**CNR**) ist ein interministerielles Komitee, das dem Wirtschaftministerium, dem Finanzministerium, dem Ministerium für öffentliche Arbeiten, dem Ministerium für Landwirtschaft und dem Planungsministerium untersteht. Die CNR ist für die Bewässerungspolitik verantwortlich.

Als Abwasserkontrollbehörde wurde 1990 die **SISS** (Superintendencia de Servicios Sanitarios) gegründet, die zwar auch an das **MOP** angegliedert ist, jedoch als unabhängige Institution fungiert. Bislang verfügt diese Einrichtung nur über geringfügige Mittel und wenig Personal, so werden im Augenblick nur die Abwässer von etwa einem Drittel der vorhanden Industriebetriebe kontrolliert.

Tabelle 3: Staatliche Institutionen im chilenischen Wassersektor:

Institution	**Zuständigkeit**
DGA Nationale Wasserbehörde Untersteht MOP	Vergabe der Nutzungsrechte Planung und Erarbeitung von Strategien zum Wassermanagement und der Wassernutzung Forschung und Datenerhebung Überwachung der Qualität und Quantität der natürlichen Wasserressourcen, die öffentlich genutzt werden Kontrolle der vorgegebenen Organisation von Nutzergruppen
DOH Untersteht MOP	Planung und Entwicklung größerer Wasserbauten Planung, Bauüberwachung und die Instandhaltung der Bewässerungsinfrastruktur
CNR Nationale Bewässerungsbehörde	Verantwortlich für Bewässerungspolitik Vergabe von Fördermitteln zur Verbesserung der Effizienz in der Bewässerung
CONAMA Nationale Umweltbehörde	Planung der Umweltpolitik Umweltgesetzgebung Evaluierung von Förderanträgen Durchführung des UVP-Systems (SEIA)
CONAF - Nationale Forstbehörde Untersteht MINAGRI	Erarbeitung eines nationalen Programms für Flusseinzugsgebietsmanagement und Bodenschutz Schnittstelle Land-Wasser-Vegetation Programme zur nachhaltigen Nutzung der Waldökosysteme
SAG Land- und Viehwirtschaftsbehörde Untersteht MINAGRI	Beteiligt an der Besteuerung von Wasserbaumaßnahmen Umweltmonitoring (Wasser, Boden) Erarbeitet Politik zur Wiederverwendung von Abwässern in der Landwirtschaft
SISS Staatliche Abwasserkontrollbehörde	Festlegung der Trink- und Abwassergebühren Überwachung der Abwässer der Industrieunternehmen Erarbeitet mit der CONAMA die Emissionsrichtlinien Überwachung der regelmäßigen Emissionsberichte der Wasserversorgungsunternehmen Bereitstellung von Daten zur Wasserqualität und Emissionen
Servicio de Salud Pública, Ministerio de Salud Pública	Überwachung der Wasserqualität von Trinkwasserquellen und öffentlichen Badegewässern

Wassernutzerorganisationen

Ist ein Wassernutzungsrecht einmal vergeben, wird die Verteilung des Wassers und die Infrastruktur von den Inhabern selbst verwaltet, die sich meist in Nutzerorganisationen zusammenfassen.

Die Struktur dieser Organisationen ist im Código de Aguas festgelegt (Código de Aguas 1981, S. 59ff):

Juntas de Vigilancia, Wassernutzerorganisationen mit juristischer Eigenständigkeit für ein gemeinsam genutztes natürliches Oberflächengewässer oder einen Flussabschnitt. Die Wasserentnahmebauten werden gemeinsam betrieben und instand gehalten. Die Zuteilung des Wassers wird entsprechend der Wasserrechte gewährleistet und kontrolliert.

Asociaciones de Canalistas, Wassernutzerorganisationen mit juristischer Eigenständigkeit für Kanäle und Stauseen sowie Grundwasserentnahmestationen, verteilen das Wasser der Hauptkanäle und der Reservoirs an die einzelnen Nutzer, verwalten die Primärinfrastruktur.

Comunidades de Agua, Nutzergruppen ohne juristische Eigenständigkeit, verwalten eine gemeinsame Wasserquelle jeglicher Art, Nebenkanäle bzw. Verteilerkanäle.

Comunidades de Obras de Drenaje, Nutzergruppen ohne juristische Eigenständigkeit, die gemeinsam Entwässerungsbauten betreiben und instandhalten. Diese Organisationsform wird jedoch in der Praxis nicht umgesetzt.

In vielen Einzugsgebieten existiert jedoch keine dieser ordentlich registrierten Organisationen. Unter den legal funktionierenden Nutzerorganisationen ist die Beteiligung eher gering, d.h. etwa die Hälfte der Nutzer verwalten das Wasser ohne formelle Organisation (DGA, 1999).

4 Wassermarkt

Der durch den Código de Aguas von 1981 geschaffene Wassermarkt basiert auf der Übertragbarkeit von Wassernutzungsrechten. Diese von der DGA vergebenen Wasserrechte sind unabhängig von Landbesitz und Bodennutzung und somit nicht an den Verkauf von Land gebunden.

Es gibt zwei Möglichkeiten für die Weitergabe von Wasser: der Besitzer eines oder mehrerer Wasserrechte kann eine gewisse Menge Wasser für einen bestimmten Zeitraum „vermieten“, hierbei handelt es sich um eine unkomplizierte Kaufaktion, meist für den Zeitraum einer Bewässerungsperiode, manchmal nur für wenige Stunden eines Bewässerungsvorgangs. Für die längerfristige Weitergabe eines bestimmten Wasservolumens ist ein offizieller Verkauf des Wasserrechts erforderlich. Dieser Transfer erfolgt im allgemeinen über einen unbefristeten Zeitraum, mindestens jedoch für eine Bewässerungsperiode. Der Käufer übernimmt dann die Verantwortung für die rechtgemäße Verwendung des Wassers (Hearne and Easter, 1995).

Es können folgende vorteilhafte Aspekte eines freien Wassermarktes beobachtet werden (Gentes 2000, Peña 1996):

- Wasser als wirtschaftliches Gut führt zu einem achtsameren, ökologisch nachhaltigeren Umgang mit der Ressource und einer effizienteren Nutzung, da es Anreiz für den Inhaber bietet, das Wasser lukrativer und effizienter einzusetzen
- Flexible Handhabung der Wasservergabe ohne bürokratische Umwege
- Vermeidung von aus öffentlichen Geldern bezahlten, kaum bzw. schlecht genutzten Infrastrukturmaßnahmen (Gazmuri, 1994)
- Vermeidung einer Wasserpreisverzerrung

- Wassermangel und Auswirkungen von Dürreperioden können mit Hilfe eines kurzfristigen Wassermarkts und einer vorübergehenden Übertragung von Wasserrechten ausgeglichen, wirtschaftlich intensive Wassersektoren (Fruchtanbau, Wein etc.) schnell und unbürokratisch versorgt werden.

Es wird dann mit Wasser gehandelt, wenn die Einnahmen durch den Weiterverkauf die Transaktionskosten übersteigen. Die Transaktionskosten bestehen aus folgenden Komponenten (Hearne and Easter, 1995):

- Kosten für Infrastrukturmaßnahmen, die für den Wassertransfer und das Messen der Abflussmenge erforderlich sind. Hierbei müssen auch die Filtrations- und Verdunstungsverluste bei der Übertragung berücksichtigt werden
- Kosten für die Vermittlung von Käufern bzw. Verkäufern
- Kosten für die Registrierung des rechtmäßigen Besitzes eines Wassernutzungsrechts, Beglaubigung des Vertrages, Vertragsprovisionen, sowie der Erwerb von notwendigen Erlaubnissen der für Wasser zuständigen Verwaltungseinrichtungen.

Diese Kosten sind häufig zu hoch und verhindern den Transfer.

Der ökonomische Wert von Wasser hängt im wesentlichen von der Wasserverfügbarkeit ab, aber auch von der Bereitschaft der Nutzer, für Wasser zu zahlen. So sind beispielsweise die Preise für Wasserrechte in der Atacama-Wüste aufgrund der hohen Nachfrage aus den dortigen Minenprojekten extrem hoch.

Der durch den Código de Aguas geschaffene Wassermarkt hat in der Praxis zwar Investitionen in die Erschließung der Wasserressourcen für die Trinkwasserversorgung und die Wasserkraft gefördert und entsprechende Infrastrukturmaßnahmen vorangetrieben, die Wassernutzung in der Landwirtschaft jedoch wurde nicht wesentlich verbessert. Die Landwirtschaft ist mit 87% der weit wichtigste Wassernutzer, die Effizienz in der Bewässerung liegt aufgrund der fehlenden modernen Bewässerungstechnologien jedoch nur bei etwa 30% (Chile Sustentable,1998).

Der Wassermarkt sollte u.a. private Investitionen in die Bewässerungsinfrastruktur vorantreiben. Diese Erwartung wurden jedoch nicht erfüllt, zum einen aufgrund der niedrigen Marktbewegung – in den meisten Regionen ist ausreichend Wasser vorhanden – zum anderen wegen der hohen Kosten der Infrastrukturmaßnahmen. Erst durch ein staatliches Subventionsprogramm in den 90er Jahren „PROMM : Programa de Rehabilitación y Mejoramiento de Proyectos medianos y menores de Riego“, das insgesamt die Bewirtschaftung von etwa 300.000 ha ermöglichte, konnte die Bewässerungsinfrastruktur modernisiert und eine Verbesserung der landwirtschaftlichen Erträge erzielt werden, während der Markt nur unwesentlich hierzu beigetragen hat (Cepal 1999; MOP, 2001).

5 Wasserver- und -entsorgung

Chile verfügt im Verhältnis zu anderen lateinamerikanischen Ländern schon sehr lange über ein gut funktionierendes flächendeckendes Wasserver- und Entsorgungsnetz. Laut Daten der SISS wurden 1998 99,3 % der Bevölkerung in dicht besiedelten städtischen und ländlichen Gebieten mit Trinkwasser versorgt, 92 % waren an das Entsorgungsnetz angeschlossen. Allerdings wurden nur 16,7 % der Abwässer behandelt (Brown et al, 2000).

Folgende staatliche Institutionen und Ministerien spielen für den Ver- und -entsorgungssektor eine Rolle: SISS (Wasserqualitätskontrolle und -normen), das MOP (Vergabe der Wassernutzungsrechte durch die DGA), das Gesundheitsministerium (Wasserqualitätskontrolle) und seine regionalen

Zweigstellen „Servicios Regionales de Salud Pública", die CONAMA (koordinierende Rolle bei der Bestimmung der Wasserqualitätsnormen) und die Gemeinden und Städte selbst. CORFO, ein staatliches Institut zur Förderung und Entwicklung von Produktion und Technologie (GmbH), geführt von Vertretern der einzelnen Ministerien, verwaltet den staatlichen Teil der städtischen Wasserver- und -entsorgungsunternehmen. CORFO ist im Sektor das für die Planung und Entwicklung zuständige staatliche Organ und für das Vorhandensein eines funktionierenden Wasserversorgungsnetzes verantwortlich. Mit zunehmender Privatisierung hat es jedoch an Einfluss verloren.

Das MOP hat die DOH mit der Durchführung des Programms „Agua Potable Rural" – Trinkwasser für Ländliche Gegenden – beauftragt. Weiterhin gibt es ein von den Gemeinden und Städte ausgehendes Programm, das die Trinkwasserver- und -entsorgung für Haushalte mit Niedrigeinkommen subventionieren soll.

Der Wasserver- und -entsorgungssektor wurde in Chile Ende der 80er Jahre reformiert. Die Reform zielte auf eine Trennung der regulierenden Behörden von den Wasserver- und -entsorgungs-Unternehmen ab. Als staatliche Regulierungs- und Kontrollbehörde wurde 1990 die SISS (Superintendencia de Servicios Sanitarios) gegründet. Auch die CONAMA spielt mit ihrem UVP-System SEIA eine Rolle bei der Kontrolle von Emissionen und Wasserqualität.

1990 wurde SENDOS, das zentralistisch wirkende nationale Ver- und -Entsorgungsunternehmen, in zunächst 11 autonome, regionale Wasserver- und -entsorgungsunternehmen, die größten unter ihnen EMOS (Santiago), ESSBIO (BíoBío) und ESVAL (Valparaíso), aufgeteilt. Diese unabhängigen Wasserunternehmen sind rechtlich verpflichtet, ihr gesamtes zugeteiltes Gebiet mit Wasser zu ver- und entsorgen. Die Wassergebühren basieren auf den Versorgungskosten und werden alle fünf Jahre von der SISS kontrolliert.

Die Versorgungsunternehmen haben ihre Wassernutzungsrechte "geerbt", die ursprünglich in der Hand der die Bevölkerung mit Wasser versorgenden Gemeinden lagen und später der SENDOS übertragen wurden. Manche dieser Rechte werden als prioritär angesehen und deshalb werden umfangreichere Wasserentnahmen proportional nicht gekürzt, wenn das Wasser knapp ist, wie es z.B. bei der landwirtschaftlichen Wassernutzung der Fall ist.

Die Privatisierung der später 13 großen chilenischen Wasserver- und -entsorgungsunternehmen wurde Mitte der 90er Jahre eingeleitet. Die zunehmende Notwendigkeit, die Ver- und Entsorgungsnetze zu sanieren und zu erweitern, bewog die Regierung, private Investitionen in die Infrastruktur und vor allem in Kläranlagen voranzutreiben. Die Einbindung des privaten Kapitals sollte schrittweise erfolgen, so wurden 1998 ENERSIS und ESVAL mit (Anglian Water Services Ltd, UK) , 1999 EMOS, 2000 ESSEL, ESSAL und ESSBIO mit Thames Water teilprivatisiert (Dourejeanni et al, 2001).

Tabelle 4: Verteilung der Zuständigkeiten für die Wasserver- und –entsorgung 1999

Zuständig für Wasserver- und Entsorgung Dez. 1999	Anteile in städtischen Gebieten Dez. 1999
CORFO	36,9 %
Privatunternehmen	58,1 %
Gemeinden	4,5 %
Andere	0,5 %

Quelle: SISS 1999

Für das Jahr 2000 lag die Zuständigkeit für die Trinkwasserversorgung zu 6,4 % bei privaten, zu 55,9% bei halbstaatlichen und zu 33,2 % bei rein staatlichen Versorgungsunternehmen. Hierbei werden die halbstaatlichen Unternehmen von den privaten Inhabern verwaltet (Brown et al, 2000); die staatlichen Anteile werden vom staatlichen Institut zur Förderung von Produktion und Industrie CORFO verwaltet. Die Regierung schreibt vor, dass mindestens 35% der Anteile an Versorgungsunternehmen staatlich bleiben müssen. 44,2 % der Anteile von Aguas Andinas (ehemals EMOS), dem für die Región Metropolitana (Santiago) zuständigen Versorgungsunternehmen, liegen noch in staatlicher Hand, bei ESSEL sind es 44,2%.

Tabelle 5: Wasserver- und –entsorgungsunternehmen, Anschlußgrad

Nr	Region	Unternehmen	Einwohner	Trinkwasser		Kanalisation	
				Versorgte Bevölkerung (Einw.)	Ab-deckung (%)	Abwasser-entsorgte Bevölkerung (Einw.)	Ab-deckung (%)
1	I	ESSAT S.A.	402.366	401.963	99,9	393.039	97,7
2	II	ESSAN S.A.	446.716	446.479	99,9	434.060	97,2
3	III	EMSSAT S.A.	236.962	234.731	99,1	219.971	92,8
4	IV	ESSCO S.A.	510.890	510.158	99,9	481.269	94,2
5	V	ESVAL S.A.	1.402.117	1.387.772	99,0	1.256.826	89,6
6	V	COOPAGUA S.A.	3.294	3.294	100,0	680	20,7
7	M	AGUAS ANDINAS S.A.	5.387.565	5.387.565	100,0	5.275.601	97,9
8	M	AGUAS CORDILLERA	398.883	398.883	100,0	391.130	98,1
9	M	AGUAS LOS DOMINICOS S.A.	13.400	13.390	99,9	12.885	96,2
10	M	AGUAS MAN-QUEHUE S.A.	16.452	16.452	100,0	15.516	94,3

Fortsetzung Tabelle 5

11	M	SERVICOMUNAL S.A.	68.044	66.744	98,1	57.944	85,2
12	M	SMAPA MAIPU	570.964	570.964	100,0	570.330	99,9
13	VI	ESSEL S.A. (Thames Water)	522.022	517.687	99,2	418.462	80,2
14	VII	ESSAM S.A. Aguas Nuevo Sur Maule	603.945	601.235	99,6	565.001	93,6
15	VIII	ESSBIO S.A.	1.564.726	1.554.179	99,3	1.358.948	86,8
16	IX	ESSAR S.A.	568.263	567.821	99,9	511.742	90,1
17	X	ESSAL S.A.	520.531	520.527	100,0	453.456	87,1
18	X	AGUAS DECIMA S.A.	125.562	125.562	100,0	113.949	90,8
19	XI	EMSSA S.A.	67.926	67.881	99,9	61.640	90,7
20	XII	ESMAG S.A.	145.742	145.658	99,9	144.113	98,9
		Insgesamt	13.576.370	13.538.945	99,7	12.736.562	93,8
	Kleinere Versorgungs-Unternehmen	Insgesamt	48.623	45.967	94,5	11.497	23,6
		Insgesamt Städte	13.624.993	13.584.912	99,7	12.748.059	93,6

Quelle: SISS 2001; M = Region Metropolitana (Santiago)

6 Schlussbemerkungen

Die Durchsetzung der Reform des chilenischen Wassermanagements ist auf dem Weg, geht jedoch sehr schleppend voran. Die Interessen der einflussreichen Wassernutzer sind nicht mit einer Umverteilung der Wasserrechte vereinbar, so verfügen beispielsweise die großen Betreiber der Wasserenergie über nicht genutzte Wasserrechte zum nicht-konsumtiven Gebrauch, die sie weder nutzen noch weitergeben bzw. verkaufen, um sich die Möglichkeit offen zu halten, in unbestimmter Zukunft weitere Wasserkraftanlagen zu bauen. Drei Viertel seines Strombedarfs deckt Chile durch die Wasserenergie.

Der Konflikt zwischen Inhabern konsumtiver und nichtkonsumtiver Wasserrechte beruht unter anderem auf der Tatsache, dass bei der nichtkonsumtiven Nutzung die Wassermenge zwar nicht abnimmt, das Abflussregime jedoch wesentlich verändert wird. Hinzu kommt, dass das Wasser an einer anderen Stelle wieder eingeleitet als es entzogen wurde. Da die Rechte für konsumtive und nichtkonsumtive Nutzung als zwei unterschiedliche Güter untereinander nicht austauschbar sind, wird der bestmögliche Markt für diese Ressource unmöglich gemacht.

Studien, Workshops und internationale Symposien sollten in den letzten Jahren dazu beitragen, eine neue Wasserpolitik zu formulieren. Als ein Ergebnis wurde im Dezember 1999 von der nationalen Wasserbehörde (DGA) die „Política Nacional de Recursos Hídricos“, ein Leitfaden zur nationalen Wasserpolitik, erstellt. Hier wurden die Schwerpunkte „Wasserbedarf“, „Umwelt und Wasserverschmutzung“ und „Klimaveränderungen“ berücksichtigt. Neben Vorschlägen zur Modifizierung des Wasserkodex von 1981, die u.a. die Veränderung der Nutzungsrechtvergabe und eine verstärkte Einbindung der Umweltanforderungen vorsehen, wird das Prinzip eines integrierten Einzugsgebietsmanagements befürwortet. Stärkung des Umweltbewusstseins in der Bevölkerung, um einen sorgsameren Umgang mit der Ressource Wasser zu bewirken.

Das im Jahr 2001vom Ministerium für Öffentliche Bauten (MOP) für 6 Jahre entworfene Programm für ein Wassermanagement auf der Ebene von Flusseinzugsgebieten „PMRH“ soll Strategien für ein integriertes, dezentrales Einzugsgebietsmanagement entwickeln und durchführen, unter Beteiligung aller öffentlichen und privaten Organisationen, die für die Nutzung, Gewinnung und den Schutz der Ressource zuständig sind. Für das Programm ist bei der Weltbank ein Kredit von 180 Mio. US $ beantragt worden. Ein Zuschuss von 10 Mio US $ wurde bereits durch das GEF bereitgestellt.

Ein weiteres Ziel der neuen Wasserpolitik ist eine Stärkung des Umweltbewusstseins in der Bevölkerung, um einen sorgsameren Umgang mit der Ressource Wasser zu bewirken.

Die Organisation der Einzugsgebiete basiert auf Leitplänen (Planes Directores) zum regionalen Wassermanagement, die von hierfür gegründeten Einzugsgebietskomitees (Comité de Desarrollo de la Cuenca Hidrográfica a Nivel Local) bestehend aus Mitgliedern der regionalen Regierungen und anderen öffentlichen und privaten Wassereinrichtungen, ausgeführt werden sollen.

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8 Abkürzungen

CEPAL Comisión Económica para América Latina – UN-Wirtschaftskommission für Lateinamerika

CNR Comisión Nacional de Riego - Chilenische Bewässerungskommission

CONAMA Comisión Nacional de Medio Ambiente - Nationale Umweltbehörde

COREMA Comisión Regional de Medio Ambiente - Regionale Umweltbehörde

CORFO Corporación de Fomento de la Producción

DGA Dirección General de Aguas – Staatliche Wasserbehörde

DOH Dirección de Obras Hidráulicas, Behörde für Wasserbauten

MOPTT Ministerio de Obras Públicas, Transporte y Telecomunicaciones, Infrastrukturministerium

Nch Norma Chilena, Chilenisches Gesetz

PMRH Programa de Manejo de Recursos Hídricos a Nivel de Cuencas Hidrográphicas, Programm für ein Wassermanagement auf Flusseinzugsgebietsebene

PROMM Programa de Rehabilitación y Mejoramiento de Proyectos medianos y menores de riego

SAG Servício Agrícola Ganadero, Landwirtschaftsbehörde

SEIA Sistema de Evaluación de Impacto Ambiental, Umweltverträglichkeitsprüfung der CONAMA

SISS Superintendencia de Servicios Sanitarios, Staatliche Abwasserkontrollbehörde

UVP Umweltverträglichkeitsprüfung

SACHVERSTÄNDIGENRAT FÜR UMWELTFRAGEN (1998):
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WATER MANAGEMENT ISSUES OF THE ACONCAGUA WATERSHED, CHILE

Lars Ribbe and Hartmut Gaese

Abstract

This paper gives an overview of the Aconcagua basin and its water resources issues. The Aconcagua is one of the major basins in Chile, facing problems in terms of water resources availability, water use conflicts, pollution and allocation. In addition, general information on population, economy and geography will be given.

The outline on the watershed presented in this article serves as the basis for an applied research project on the design of watershed information systems currently under way at the ITT taking the Aconcagua as one example.

Keywords: Aconcagua river, water resources management, watershed management, Water Allocation, water quality .

1 Introduction

While the south of Chile is in general rich in water, the central and northern regions of the country face water scarcity and in general a growing pressure on water resources utilization. Chile's economy, especially the agricultural sector, strongly depends on reliable water supply. In the country 1,2 Mill. ha or 55 % of total cropland are irrigated contributing to 7,5 % of national GDP (World Bank 2000).

In the 5th region, where the Aconcagua is by far the biggest river, average water availability per capita is around 1000 m³/a. The largest fraction of Chile's population is located in the central part of the country[1] with growing tendency. Today 11 of a total of 15 Million (74 %) live here on 88,000 km² or 11,7 % of the total area of continental Chile (compare Tab.1). Chile's total population is estimated to grow to 18.7 Million until 2020 and to 22.2 Million until 2050 (CELADE 2002). In this context it is obvious that the already strong pressure on natural resources and thus conflicts between different water users will increase which could mean significant losses for the national and regional economy.

[1] The regions Valparaíso (V), Liberardor Gen. B. O'Higgens (VI), Maule (VII), Bio Bio (VIII), and 'Metropolitana'

Tab. 1 Per capita water availability and total population in Chile;

Region	Water Availability m³/capita in 1999; (1)	Total population in 2002; (2)
I	750	426,351
II	250	492,846
III	300	252,353
IV	1,600	600,363
V	1,000	1,542,492
RM	600	6,038,974
VI	9,000	773,950
VII	29,000	904,104
VIII	29,500	1,853,678
IX	41,000	864.929
X	169,500	1,061,735
XI	No data	86,697
XII	No data	151,869
Total	-	15,050,341

RM: Metropolitan Region Source: (1) DGA 1999, (2) INE 2002

2 The Aconcagua Watershed

Rio Aconcagua basin is located roughly 50 km north of the national capital Santiago (Fig. 1). It has an extension of about 140 km from East to West and 70 km from North to South with a total area of 7.550 km² representing 46 % of the area of the fifth region. The course of the river has a total length of about 214 km flowing from east to west from the spring of Juncal river to the mouth at Concón. However, the river is called 'Aconcagua' from the confluence of the rivers Blanco and Juncal (Fig. 3). It is characterized through a relatively steep slope (average 8 ‰), high sediment load due to lack of vegetation leading to high erosion rates in the upper watershed. In the middle and lower part the river has typically a meandering bed (see Photo 1a). There are only smaller constructions to control the river course so far.

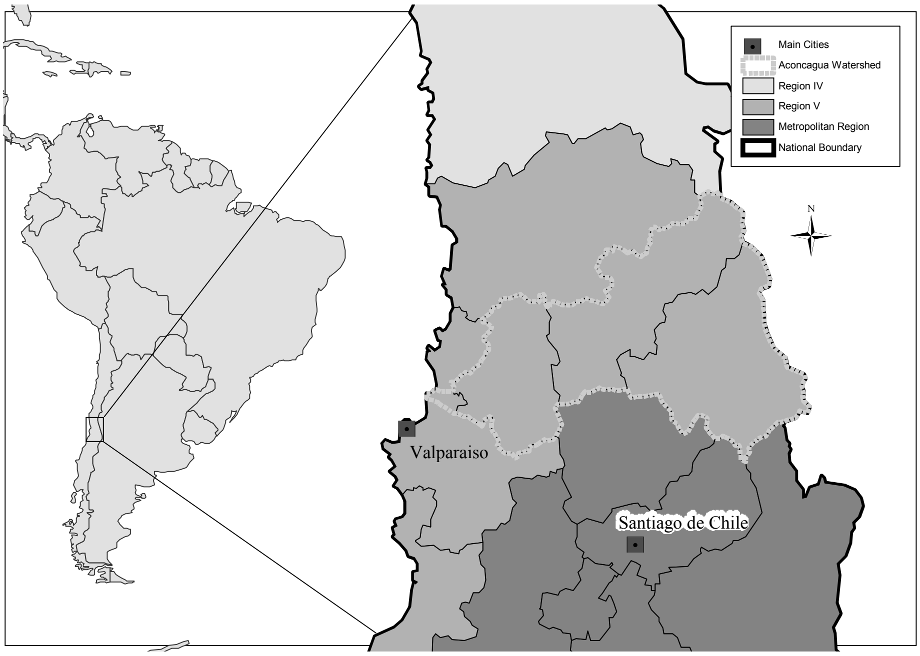
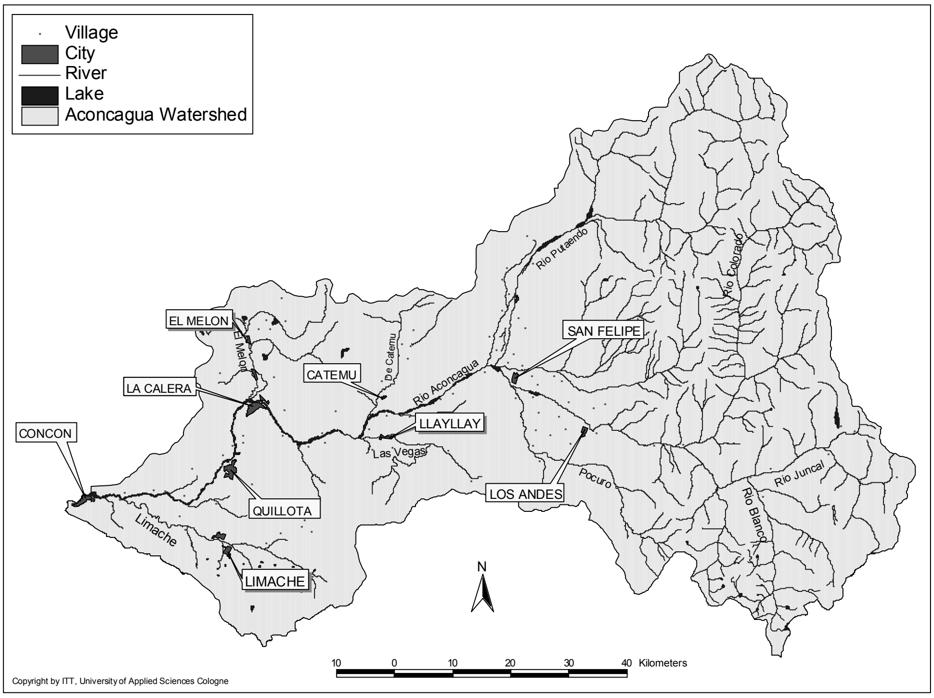


Fig. 1: Location of the Aconcagua Watershed in Chile



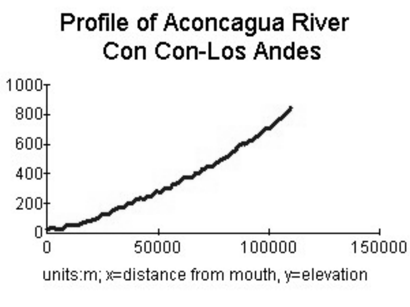


Fig. 2: Area map with hydrological network and profile of the Aconcagua Watershed, Chile

Photo 1a

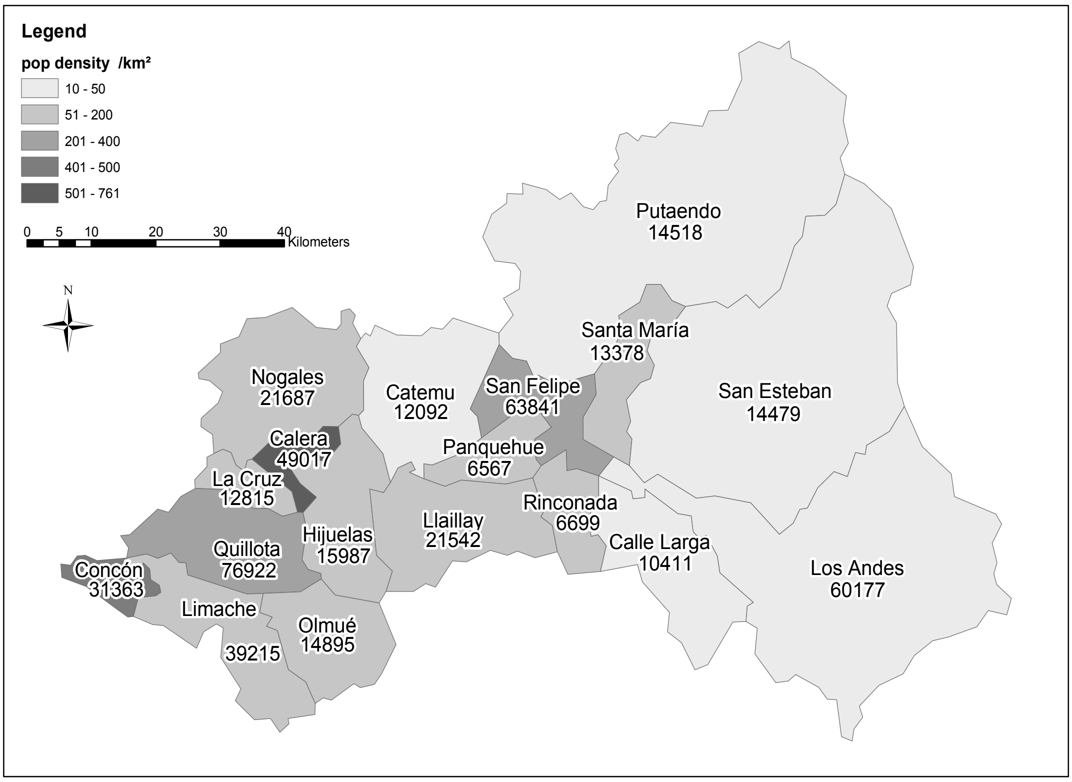
Photo 1b

Photo 1: Aconcagua river at Romeral (1a) and San Felipe (1b)

3 Socio-economic background

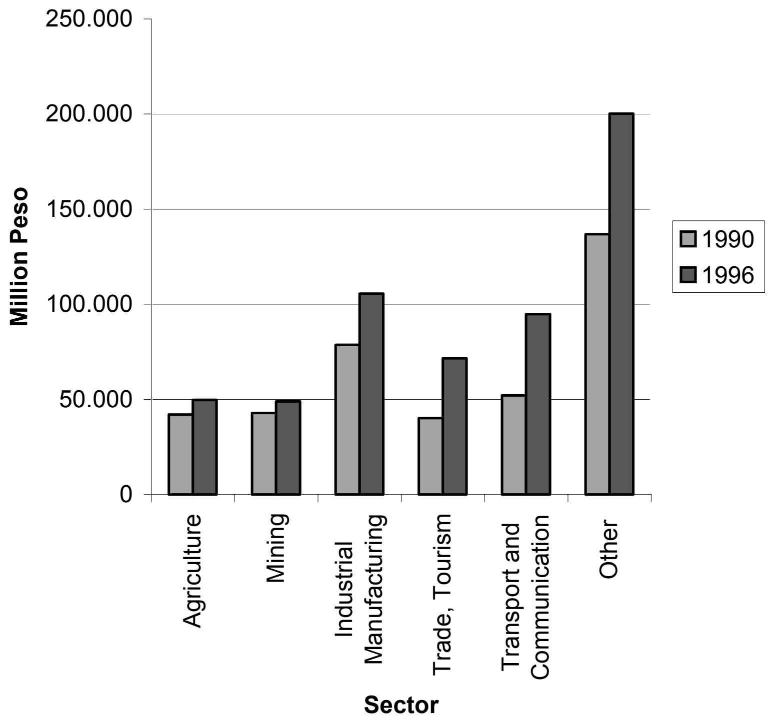
The total population of the watershed is 485.614 (INE 2002) (see Fig. 3). The main urban centre of the 5th region, Valparaíso/Viña del Mar, with a total population of around 650,000 is located 20-30 km south of the river mouth outside the catchment area. It is significant in the sense that around 43 Million m³/a water from the watershed is transferred to these cities to meet a significant part of their water demand. On the other hand they are an important market for the products of the intensive agricultural production within the watershed. In addition farmers produce for the international market (mainly USA and to a lesser extend Europe) taking advantage of the opposite growing season. Around 25 % of the population (>15 years of age) is working in the primary sector, 48 % in the tertiary sector and 17 % in the secondary (INE 2001). The Gross Domestic Product (GDP as PPP) in the fifth region is similar to that of the whole country around 8,700 US$ per capita in 1998 (to compare: 1988: 4280 US$/cap., 1978: 1940 US$/cap. (World Bank 2000); A GINI Index[2] of 0.58 in 1996 shows that income is distributed extremely unequal (UNDP 2002). In Fig. 4 you can see the contribution of the main economic sectors to regional GDP.

[2] The GINI index of income or resource inequality is a measure of the degree to which a population shares that resource unequally. The index is scaled to vary from a minimum of zero to a maximum of one, zero representing no inequality and one representing a maximum possible degree of inequality.



Data source: INE 2002; below each community the total number of inhabitants is indicated

Fig. 3: Population and population density of communities within the Aconcagua watershed



Data source: Central Bank of Chile (1998)

Fig. 4: GDP In the 5th Region of Chile by sectors

4 Land use and vegetation

The upper watershed is a mountainous area with several peaks above 5000 m asl. One of them, the Aconcagua is the highest mountain of the Americas (6960 m asl). Vegetation in the upper part is very sparse. Between 1500 and 2500 m it is limited to occasional bushes and cactuses (compare photo 2 a,b). Trees can be found up to 1500 m asl. Uses of economic significance in the upper watershed are limited to mining. The main mine here is "Andina" of the national Mining company CODELCO in the Rio Blanco subcatchment and "El Soldado" in Nogales, Fundicion Chagres in Catemu (company DISPUTADA DE LAS CONDES). Recreation, e.g. skiing at El Portillo area or hiking in the nature reserve "La Compania" is an additional economic activity in the area. On both sides of the river, starting from the confluence of the rivers Juncal and Blanco (1400 m asl) vegetation is richer since water is the crucial limiting factor to plant growth (photo 2b).

Photo 2a

Photo 2b

Photo 2: Typical vegetation in the upper watershed; 2a: sub-catchment Colorado river at 1700 masl, 2b: the Aconcagua river at Chacabuquito, 1030 masl.

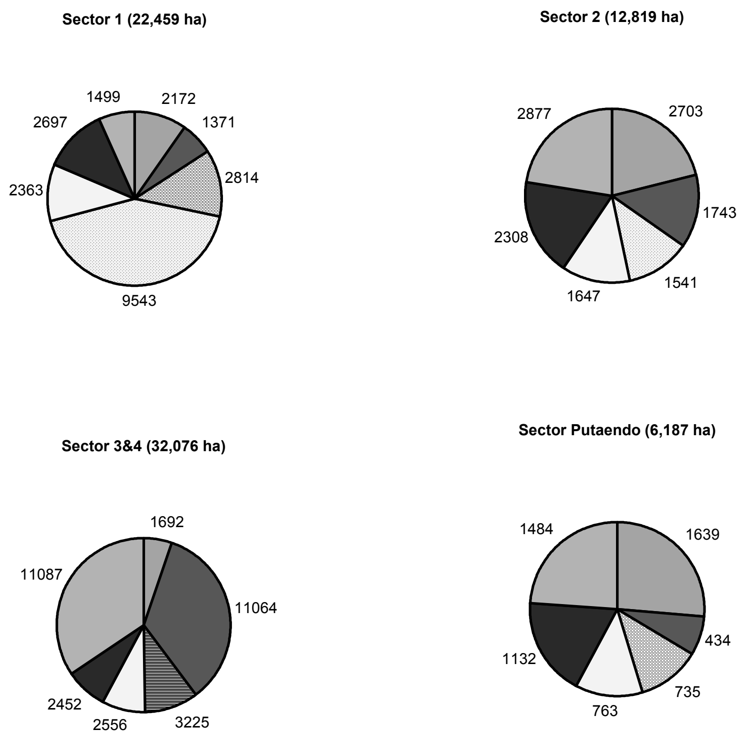
Significant agricultural activities start 10 km downstream of Chacabuquito where the first alluvial plain is fanning out forming the first irrigation sector. Since summers are very dry, agriculture almost entirely depends on irrigation. Regarding irrigation water use the catchment is divided into four independent sectors, whose land use overview is given in Fig. 5. It shows that pastures and fruit (mainly grape, avocado, stone fruit) are the most important agricultural crops. Main annual crops are wheat, corn, potato, beans; main vegetables are onion, tomato and artichoke, distributed along the river according to their climatic adaptations.

Total irrigated area in the catchment was 68,588 ha in 1993 representing 84 % of the total irrigated area of the 5th Region (81,809 ha; DGA 1996).

More and more agricultural land is converted to residential areas mainly for outskirt or country residences. By law a property in the country side can not be smaller than 5000 m².

Erosion due to lack of significant vegetation is another known problem; A study of IREN (1979) estimates that 280,000 ha in the fifth region are ´very severely´ or ´severely´ affected by erosion. However, recent information on the extent of erosion in the Aconcagua watershed is not available.

The extraction of sediments of the river bed in the lower part of the river is considered as a further environmental issue affecting the stability of river morphology and ecological integrity.



Legend

- annual crops
- vegetables
- stone fruit
- table grapes
- avocado
- other fruit
- irrigated pastures
- partially irrigated pastures

Data source: EDIC (1994)

Fig. 5: Agricultural land use in the main irrigation sectors in 1993

In terms of water use the River is divided into four sectors (compare Fig. 11):
sector IV is very small and usually considered together with sector III.

Sector I: Chacabuquito to San Felipe ("Puente San Felipe")

Sector II: San Felipe to Romeral

Sector III: Romeral to Puente Lo Venecia

Sector IV: Puente Lo Venecia as far as the river mouth.

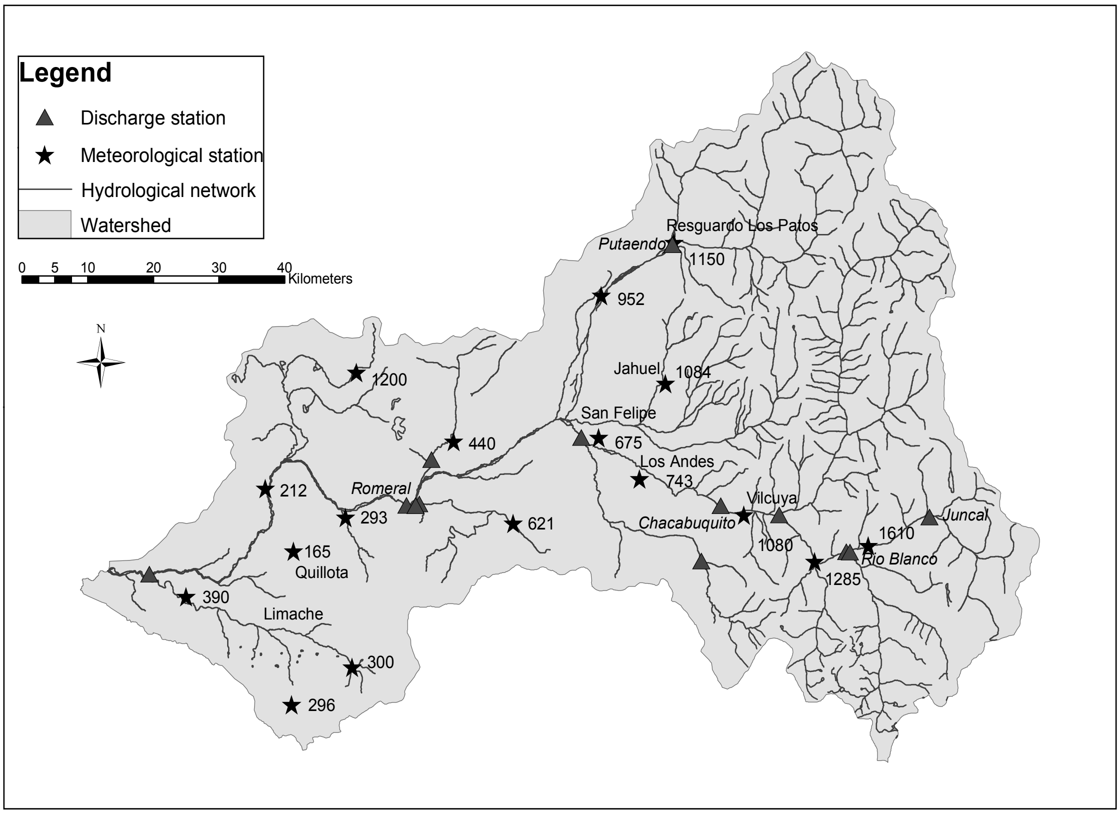
Putaendo: Rio Putaendo between Resguardo los Patos and El Baden

5 Water Availability and Water Use

Climatically the area is characterized as Mediterranean type climate (Csb according to Koeppen´s classification) with wet, cold winter and warm, dry summers lasting from October to March. During fall and winter south-eastern winds are dominating, sometimes of polar origin. During spring and summer, north-western directions prevail. In the interior (Los Andes and San Felipe Provinces) summers are drier and warmer and winters are slightly colder than at the coast.

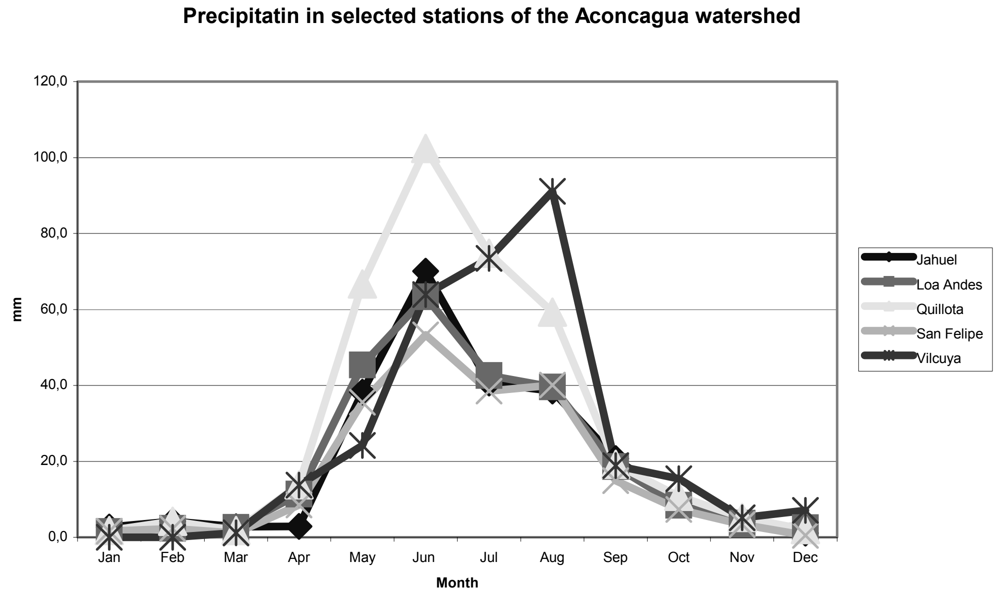
Water Availability

Precipitation is characterized by a typical annual pattern with very limited rainfall during summer, totalling to less than 20 mm between October and March, and high precipitation during winter with 90 – 95 % of annual rainfall occurring between May and September. Fig. 6 shows the location of meteorological and discharge stations of the DGA, Fig. 7 shows the general pattern of precipitation at five stations within the watershed and Fig. 8 shows the long term variability of precipitation.



Data source: DGA

Fig. 6: Location and altitude of meteorological and discharge stations in the watershed



Source: DGA 1996, location of stations: Fig. 6

Fig. 7: Annual pattern of precipitation at selected stations (mean values 1950-1993)

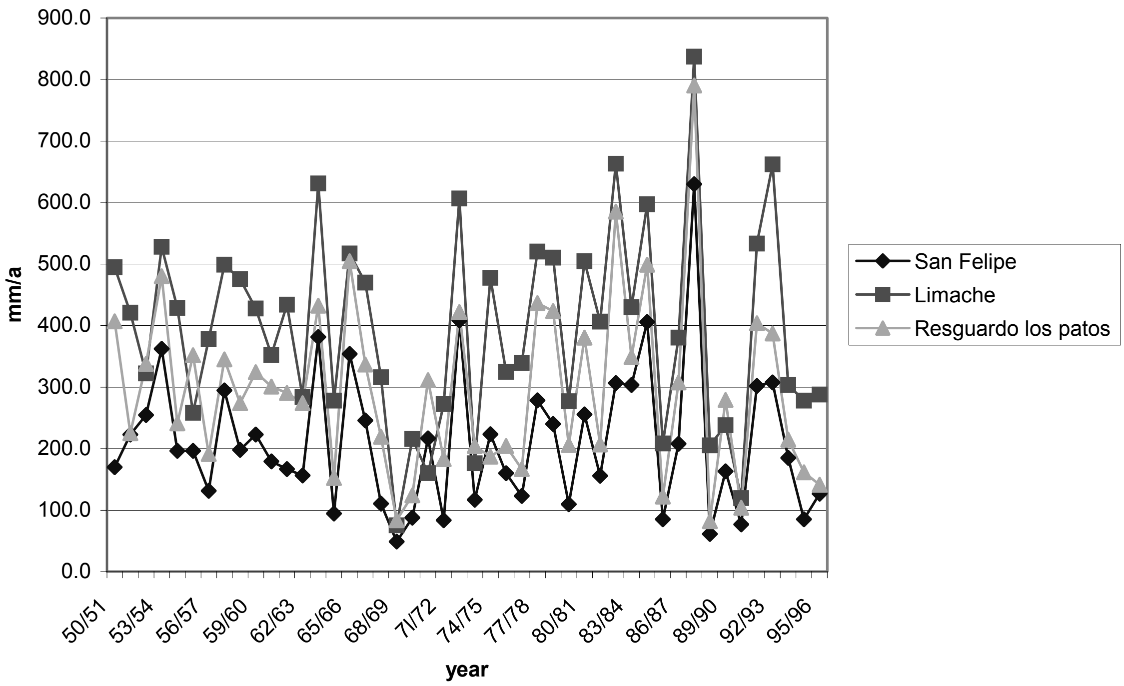
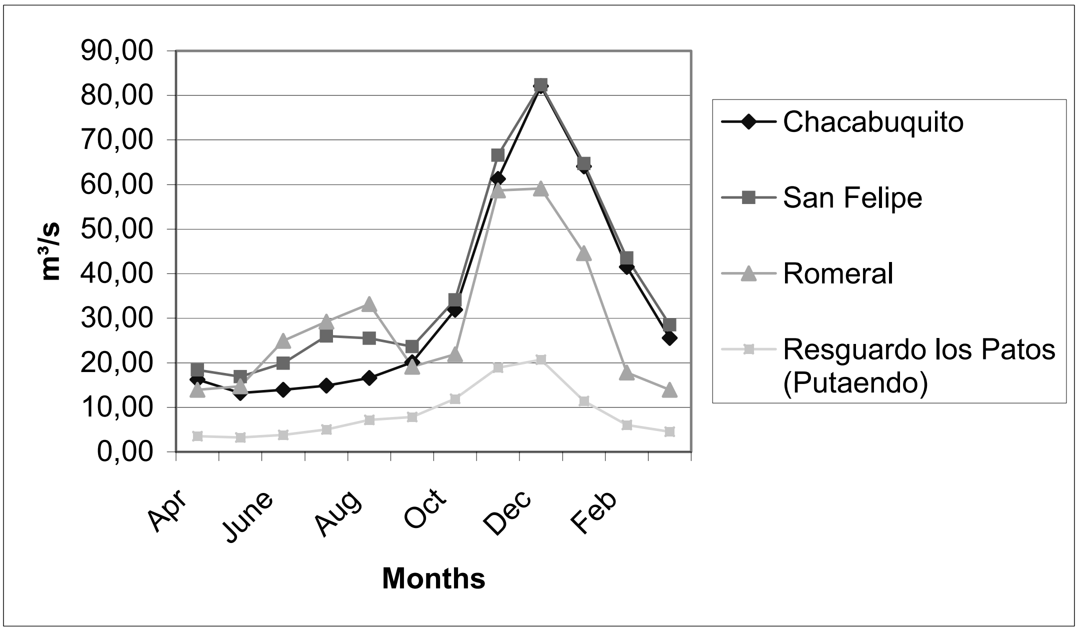


Fig. 8: long term variability of precipitation at three selected stations (1950-1996)

Data source: EDIC 1994, location of stations: Fig. 6. Note: years of maximum precipitation (53/54, 63/64,72/73,78/79, 82/83, 87/88 and 92/93) are El Niño years, with a multivariate ENSO index < -1 (NOAA, 2002)

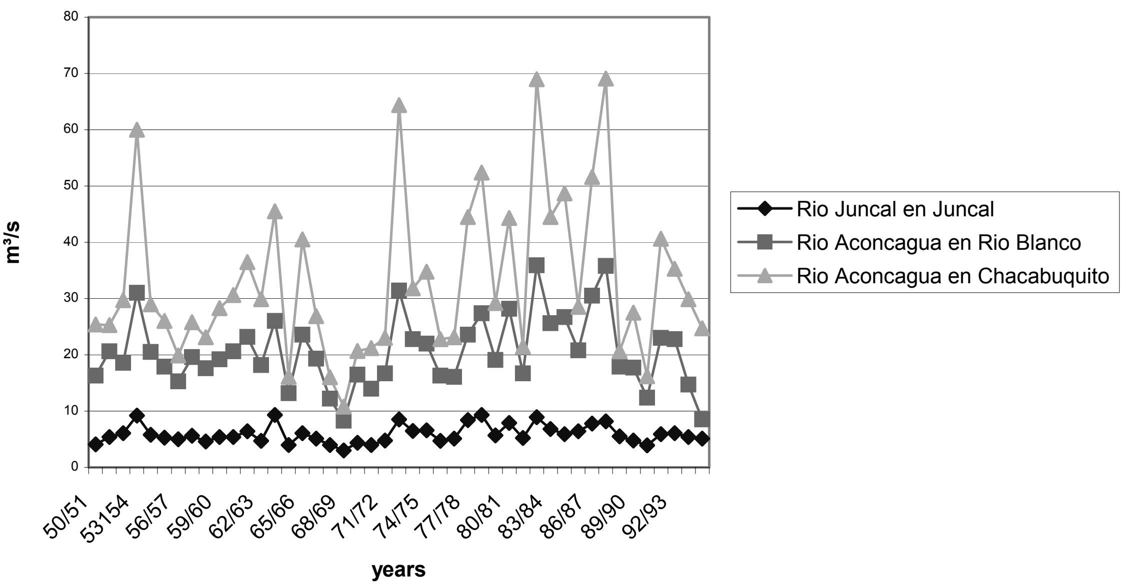
Since in the upper watershed precipitation occurs in form of snow, the discharge of almost all tributaries and the main river are showing peak discharge during snow melt between October and February (nival regime; see stations Chacabuquito and Resguardo los Patos in Fig. 9). The middle and lower part of the river is of mixed (nivo-pluvial) regime with rainfall during winter months (peaks in

June and July) being the second determining factor of river discharge. Stations San Felipe and Romeral in Fig. 9 give an example. An additional important feature of water availability is the long term variability. In Chacabuquito where the long term average discharge is 31 m^3/s levels of between 10 and 70 m^3/s as annual averages can be observed (Fig. 10). It should be noted that the seasonal Q is strongly influenced by human impacts.



Data source: DGA 1996; values are monthly averages (1950 – 1993); location of the stations: Fig. 6

Fig. 9: Annual variability of discharge at selected stations in the Aconcagua watershed



Data source: EDIC 1994.

Fig. 10: Long term variability of discharge in the upper watershed (1950 – 1993)

Water Use

Total water use in the watershed amounts to 1766 x 10^6 m³/a. 552 x 10^6 m³/a are non-consumptive uses (mainly used for energy production). Of the consumptive uses, irrigation is by far the largest sector accounting for 1025 x 10^6 m³/a (80 % of total consumptive uses), followed by industry and mining with 98 x 10^6 m³/a and domestic water use with 91 x 10^6 m³/a (DGA 1996).

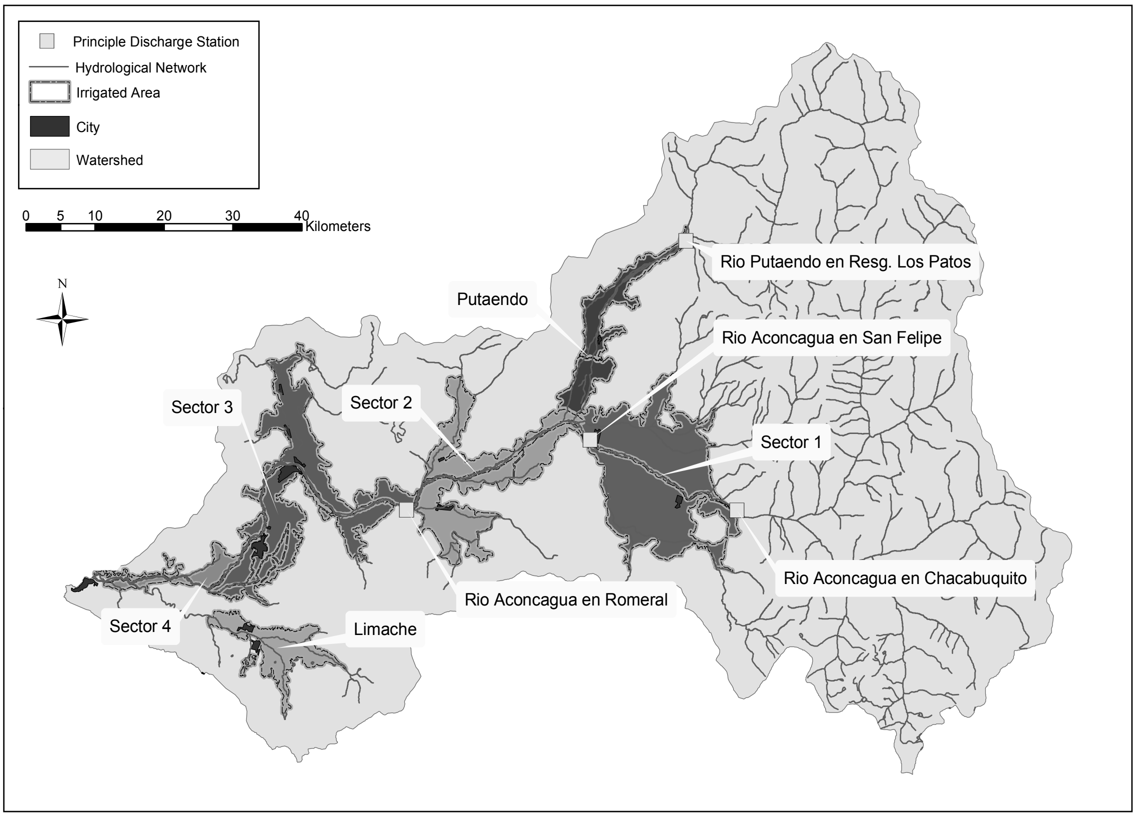
Currently the construction of a dam to alleviate the water scarcity problem is under intensive discussion. The favourite solution at the moment is to built a dam upstream of Chacabuquito. A discussion of the pros and cons regarding a possible dam is beyond the scope of this paper. Since currently less than 50 % of all available water resources are used mainly due to strong seasonal differences it seems probable that through the construction of a dam significantly more water will be available for irrigation.

With Chile being a newly industrializing country, having an economic growth of typically above 7 % in recent years (average 1988-98 = 7,6 %) and a population growth of around 1,5 %, an increasing pressure on water use is likely. A prediction of the DGA for the year 2025 estimates that total water demand in the watershed will amount to 2350 x 10^6 m³/a which is 30 % more than the present use - assuming introduction of modern irrigation technology and no expansion of irrigated area (see Tab. 2). Consumptive uses in the same period are estimated to increase by 14% to 1388 x 10^6 m³/a.

Tab. 2: Water supply and demands in the five major irrigation sectors (in 10^6 m³/a)

	Sector 1		Sector 2		Sector 3 & 4		Putaendo	
Year	1995	2025	1995	2025	1995	2025	1995	2025
Water availability (mean)	1055		1182		922		273	
Agricultural demand	365	381	228	247	324	314	108	102
Domestic demand	9,8	18,9	0,3	0,5	81	144	0,3	1
Industrial demand	15	29	1,2	2,3	64	121	0	0
Mining	13	19	0,7	1,1	4	6	0,2	0,2
Total demand	403	448	230	251	474	586	109	103

Data source: DGA 1996 (original data was monthly data in m³/s, location of sectors: Fig. 11)



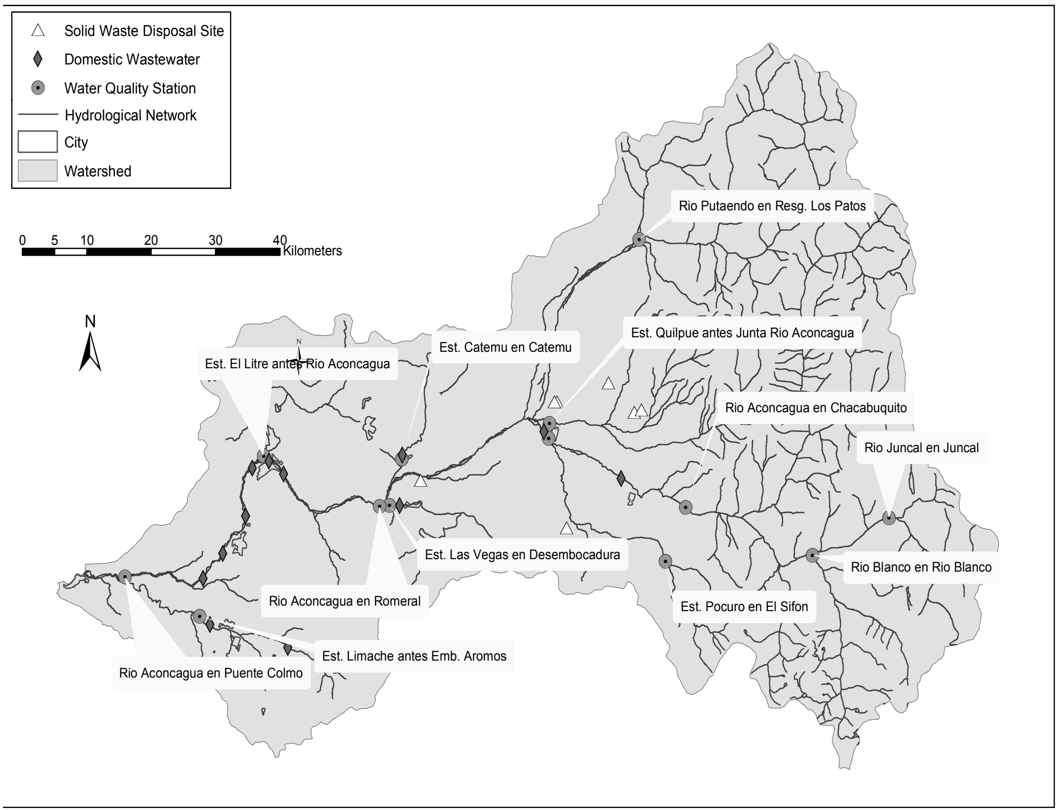
Data source: DGA 1996

Fig. 11 Main irrigation sectors and corresponding discharge stations

6 Water Quality Issues

Main issues of concern within the watershed are contamination due to domestic wastewater, mining effluents due to accidental spills and the influence of intensive agriculture on the ground as well as the surface water quality.

Monitoring of water quality has been limited to the basic program of the DGA which is measuring water quality in all main sectors of the river and several tributaries (Fig. 12). Within this program samples are taken four times a year. The measurements are limited to the basic physico-chemical parameters, and heavy metals. Nutrients as well as BOD and COD where recently included in the program. Currently a project of the “Universidad Mayor” is under way with the aim to analyse the ecological conditions in the entire watershed including bio-toxicological testing of surface and groundwater at selected stations. Results are expected in late 2003.



Source: DGA/Departamento de Proteccion y Calidad de Agua

Fig. 12: Location of water quality monitoring stations

The sources of pollution are not sufficiently monitored. The national Emissions Control Authority (SISS) keeps only part of those industries discharging to the river under surveillance. Apart from that it is controlling the wastewater treatment plants operated by ESVAL, the regional water supply and sanitation company. ESVAL in turn controls those industries discharging to the sanitation network. The legal basis in this sector is defined by the decree 609/1998 (emissions of industrial wastes to sewers, MOP) and the decree 90/2000 (norm for the discharge of liquid wastes to marine and surface waters, CONAMA).

It seems crucial to conduct a survey of main sources of pollution of water resources. The following paragraph gives an overview.

Sources of Pollution

Domestic effluents

At several points untreated sewage is entering the Aconcagua river. Tab. 3 summarises the main wastewater discharges. It should be noted that these waters enter the river without any or only rudimentary treatment. Currently, however, the construction of wastewater treatment plants is under way with the aim to treat wastewater of the main urban centers (Quillota, La Calera, San Felipe, Los Andes, Limache). They are due to start functioning until end 2002.

Tab. 3: Domestic wastewater discharge to the Aconcagua river – main urban centers

Point of discharge	Discharge (l/s) two measurements	Characteristics		
		BOD (mg/l)	BOD[3] (mg/l)	F.Coli (MPN*10^6)
Los Andes	73,7/80,5	153,0	120,5	6,4
San Felipe	151,2/169,2	106,6	46,5	4,8
La Calera	165,9/172,3	38,9	69,2	1,8
Quillota	100,4/105,4	123,3	119,2	3,3

Data source: Kristal, 1997. Discharge was measured twice : F.Colif = Feacal Coliform; 2: second campaign

Industry and Mining

Several industries along the river discharge their effluent directly to surface water (Tab. 4). 23 industries discharge to the sewage network.

Location/recipient	Name	Type of Industry	Main Water Quality Issues
Rio Blanco	Andina (Codelco)	Mining	Copper
Catemu	Soldado (Disputada)	Mining	Copper
San Felipe	Pentzke	Canning	Organic
San Felipe	Corpora	Canning	Organic
La Calera	Algas Marinas “Algamar”	Fish processing	Organic
La Calera	Sociedad Industrial La Calera	Chemical	Organic load, Dissolved solids
La Calera	Cemento Melón	Cement	Dissolved solids, sulphates
Concón	BASF	Chemical	Organic, nitrogen, sulphates
Concón	Refinería de Petroleo Concon	Refinery	Carbohydrates
Estero Quilpué	Matadero Santa María	Slaughterhouse	Suspended solids, fat and grease
Estero Catemu	Agricola Catemu	Meat Processing	Suspended solids, fat and grease
Estero Los Loros	INDUCORN	Food processing	Organic
Esterlo el Melón	Sobraval Ltda.	Meat processing	Suspended solids, fat and grease

Source: Kristal 1996

Tab. 4: Industrial discharges to surface waters

[3] ESVAL, “Mejoramiento del Alcantarillado del Rio Aconcagua. Secciones 1,2,3”

Diffuse pollution

Agriculture is the typical diffuse source of water quality impairments. Within the watershed there are several areas of intensive agriculture with a high potential of affecting water quality a) through discharge of drainage water into the river and b) through infiltration of contaminants to groundwater.

So far no systematic study is available on the impact of agriculture on groundwater pollution within the watershed. Since all the irrigated agriculture in the Aconcagua valley is intensive in the sense of fertilizer and pesticide use, one can assume that in the long run water resources are under threat especially in those areas where the aquifers are highly vulnerable, i.e. in zones with shallow groundwater and high permeability of the soil.

Status of Water Quality in the Watershed

The following is a selection of just a few data on water quality. It is entirely based on results of the monitoring program of the DGA.

Fig. 13 gives an example for copper pollution in the Rio Blanco sub-catchment. The total concentration of copper (dissolved and suspended) shows very high variations. Five times during the observed period, during summer when the snow melt occurs, concentrations were above 10 mg/l. Even in downstream stations, where water is directly used for irrigation, concentrations of 6,5 mg/l (San Felipe, Nov.1993) and 2,6 mg/l (Romeral, Dec. 1995) were reported. Copper like other heavy metals has the potential to be accumulated in the soil. In addition high copper concentrations will impair the ecological status of the river as it shows eco-toxicological effects. In Germany recommendations for copper concentrations (dissolved) are 0,05 mg/l for water used for irrigation and 0,004 mg/l in order to guarantee no effect on aquatic communities (BMU 2001).

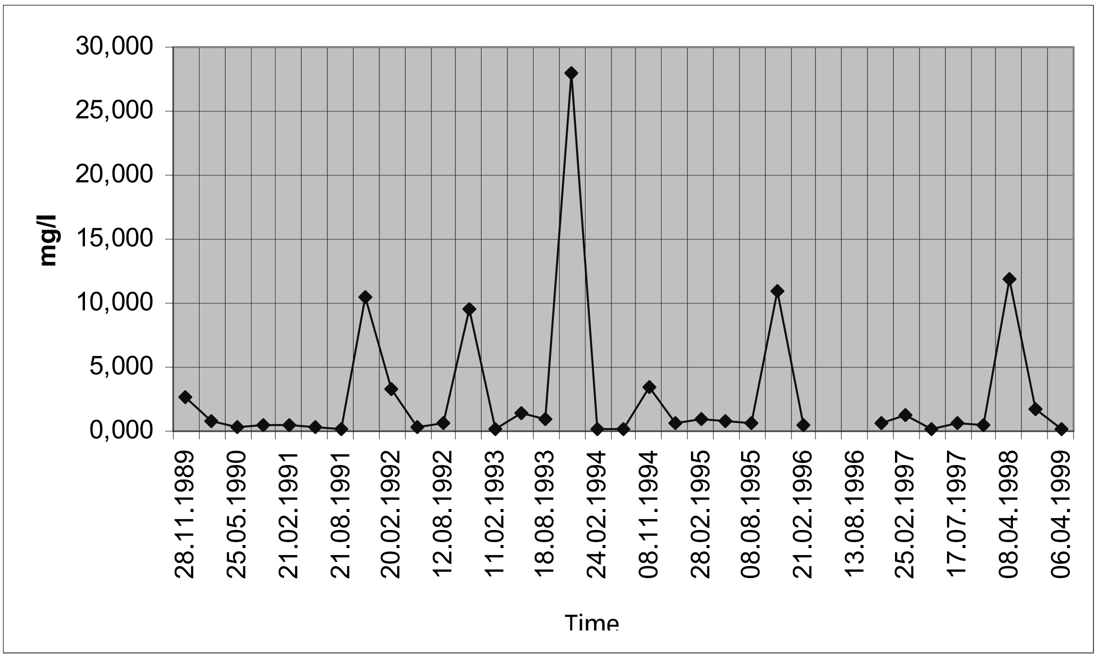


Fig. 13: Copper concentration in the Blanco River between 1989 and 1999

Fig. 15 shows recent values of nitrate and phosphate at eleven stations within the watershed. The values are arranged according to quarters of the year (Jan. – March = Q1). At almost all stations nitrate as well as phosphate values are elevated showing the influence of anthropogenic activities. Average values at the background station, Juncal (St.1), Resguardo los Patos (St. 9), Estero Pocuro (St. 16) are typically below 0,02 mg/l for phosphate and below 0,3 mg/l for nitrate. Some phosphate levels are above 0,3 mg/l and nitrate values above 5 mg/l. Even though these levels are not alarming they should be taken serious since they may impair aquatic communities, lead to algal blooms in the river among other effects.

Station	Name
2	Rio Blanco
5	Chacabuquito
4	San Felipe
9	Risguardo los Patos
11	Estero Las Vegas
12	Romeral
13	Estero Catemu
14	Estero Litre
15	Puente Colmo
16	Estero Procuro
17	Estero Limache

Key to stations in Fig. 15 (location: Fig. 6)

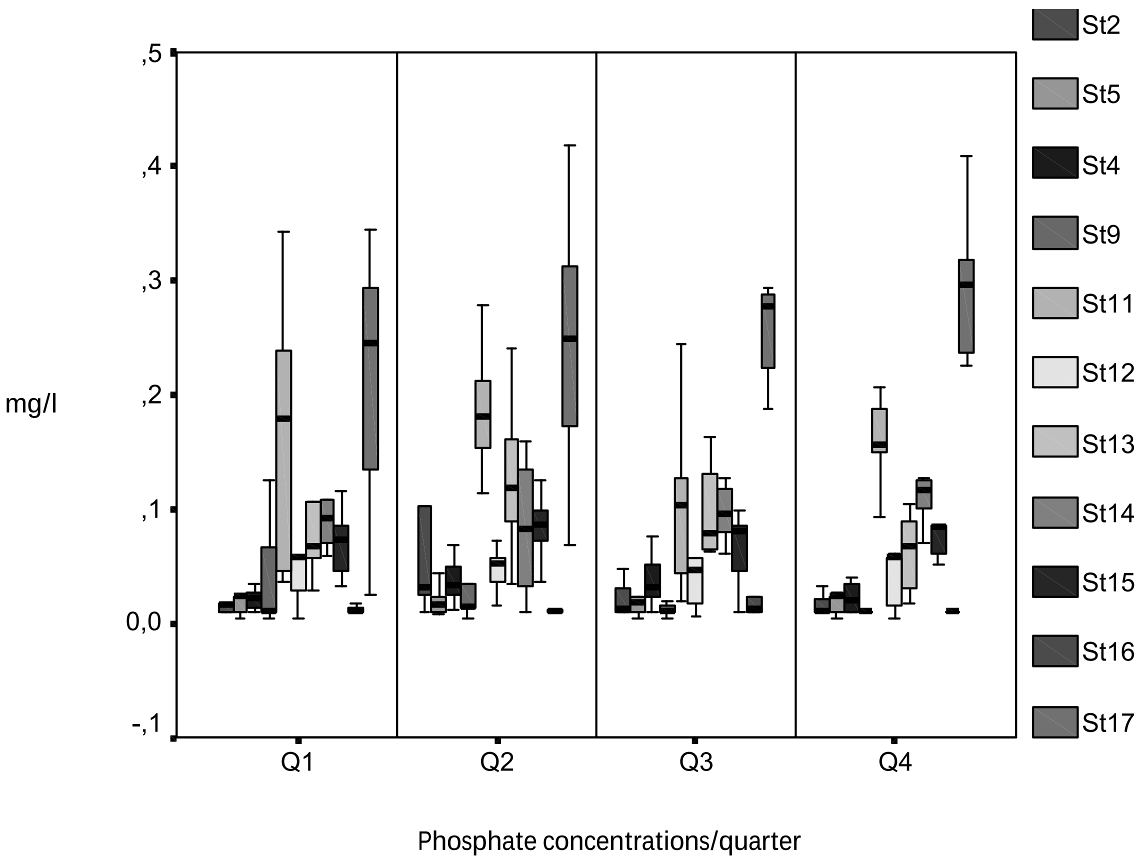
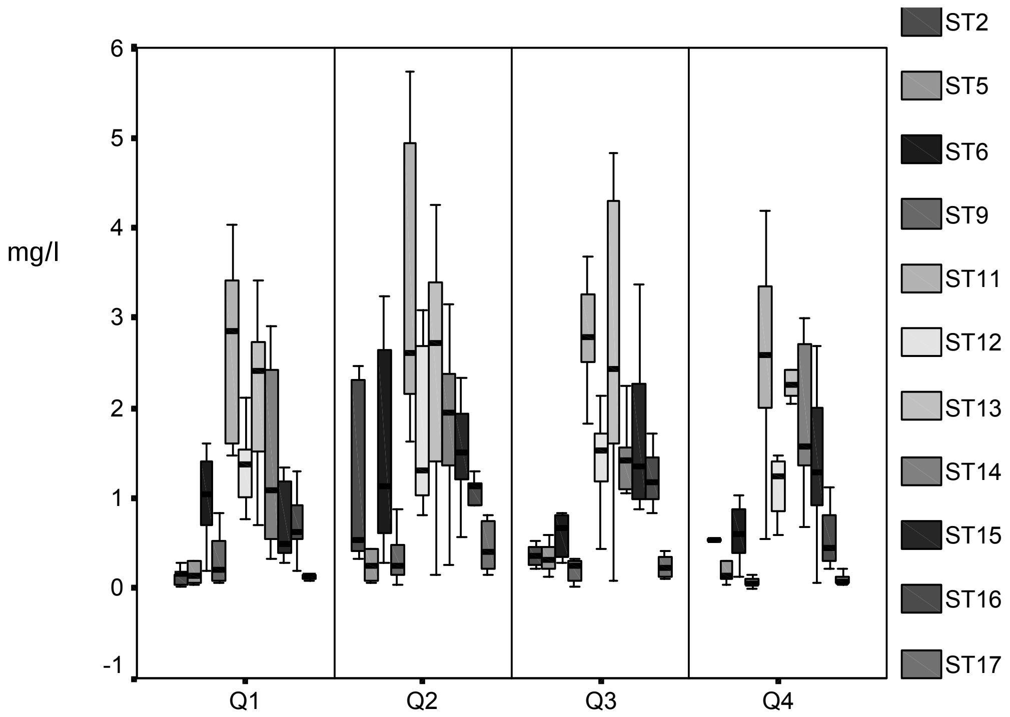


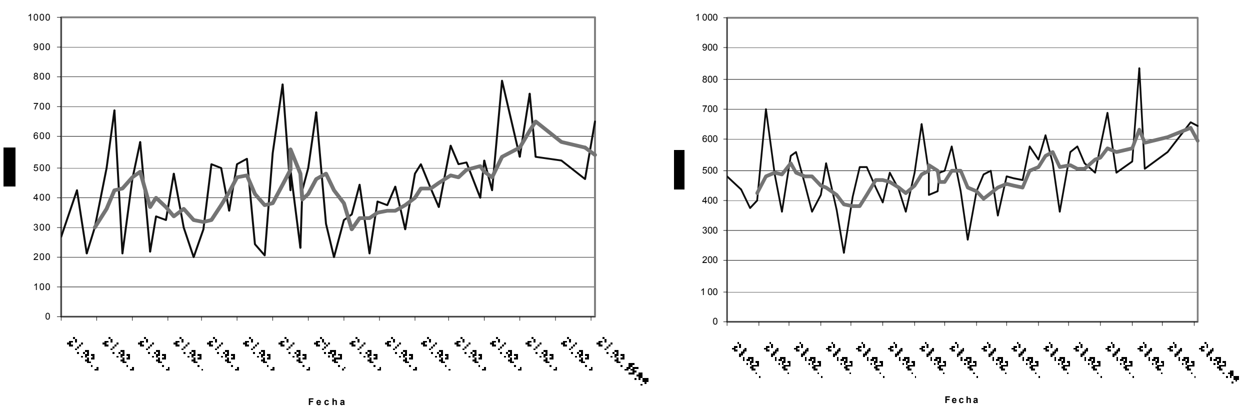
Fig. 14a: Box plots showing total phosphorus concentration at major stations for each quarter of the year (first quarter = Jan.-March)



Nitrate concentration/quarter

Fig. 15b: Box plots showing nitrate concentration at major stations for each quarter of the year (first quarter = Jan.-March)

Fig. 16 shows the trend (green line is the moving average) of electric conductivity (EC) within the last two decades for two stations. An increasing trend between 1990 and 1999 can be recognized even though statistically not very relevant. Since EC is an indirect measurement for total dissolved solids (TDS) it can be assumed that there are certain processes leading to an increased concentration of major Ions. In general a more intense use of water resources can lead to this effect. It should be noted though that still no alarming values have been reached so far; the observed values are at no time above 1000 µS /cm and even at this level only for very sensitive crops a salinity hazard exists.



Left: San Felipe, right: Romeral. Values in *µS/cm*

Fig. 16: Trend of conductivity at San Felipe and Romeral stations between 1984 and 1999.

7 Central Issues of Water management

Reform of the water sector

In Chile a reform of the basic water law of 1981 (*Codigo de aguas*) is under way. Main topics are a reform of water user associations, introduction of a system to control water pollution and other environmental issues like environmental water demand, legal status of not used water rights, as well as the general structure of Chiles water sector and the introduction of water resources management on the basis of hydrological catchment areas.

The norms and regulations in the water sector are being expanded recently introducing new norms on water quality criteria for discharges to surface waters and sewerage systems. In preparation are norms for the water quality of natural surface waters and for groundwater protection.

With the "**Water Resources Management Program**" the Chilean government aims at implementing developing principles for the future water resources strategy. The program is aimed to receive a credit from the World Bank of 180 Million US$, half of the total project cost (MOP 2001).

Overview of current pressures on water resources

The following is just a short list of the most important water management issues in order to present an overview:

- The water resources of the Aconcagua watershed are almost completely used for agricultural, domestic, industrial or other uses. Consequently there is a quite strong competition for water use with a potential for future conflicts.
- The international highway No. 60 is the most important connection of Chile to Argentina. Accidents of trucks transporting dangerous substances would have detrimental effects on the water quality since the highway runs for over 100 km at the bank of the river.
- Hydropower production is the fastest growing sector related to water consumption. Even though it is a non-consumptive use there are impacts, for example the diversion of large quantities of water from one sub-catchment to another and the storage of water over short periods.
- Extension of agriculture to slopes. In recent years the agricultural area, traditionally limited to the valleys, expanded to the foothills of the mountains at both sides of the river. The danger of erosion here is very high. Former agricultural areas within the valley are increasingly used for housing.
- Extraction of river sediments for construction. The sediments are often taken directly from the river bed causing significant contamination with suspended sediments. At the same time the morphological structure of the river is affected.
- Minimum ecological flow. During summer the flow of some stretches of the river is extremely low. There will be a discussion on how much flow is necessary to sustain aquatic communities and recreational attractiveness.
- Conjunctive use of surface and groundwater. Renewable groundwater resources in the watershed are not completely quantified. The general notion is that additional water resources are available. In recent years the number of licenses for the use of ground water increased. However, so far there is no sound scientific basis for the quantitative relationship between ground and surface water.

- Construction of a multi-purpose dam in the upper watershed. At the current state of discussion a construction of a dam just above Chacabuquito is favoured. With this dam an additional 50.000 ha could be irrigated.

8 Conclusions

This article presents the basic available data regarding water resources management in the Aconcagua Watershed, Chile.

Even though overall water availability is significantly higher than actual water use, there is still a considerable pressure on water resources stemming from large annual and long term variability of precipitation, conflicts between upper and lower riparian water users and the growing industrialization and population which will lead to a steady increase of water demands within the next decades.

As a further problem water pollution is mentioned. There is not enough data available which would permit a final assessment of the status of water quality in the Aconcagua watershed. However, some issues can be singled out: more intense agriculture is likely to have an impact on ground and surface water quality. A first signal could be seen in the high concentration of phosphorous and nitrogen compounds in the tributaries of the Aconcagua. Regarding pesticide pollution no recent studies are available. Another water quality issue is heavy metal pollution due to mining. At several sampling points in the upper and middle part of the Aconcagua, copper concentration of above 1 mg/l were reported. These concentrations are far above any international norm or recommendation and pose a potential threat to aquatic life and irrigated agriculture.

The issues described in this article demand a coherent approach to water management in order to prevent deterioration of water resources in the watershed. It seems obvious that an integrated planning taking the entire watershed as a basis is necessary. The planning should address the topic of upper and lower riparian water users and should emphasise a stringent control of water quality. Both aspects are addressed in the concept for a new water policy of Chile (DGA 1999). However, up to this point it is not clear whether this policy reform will have success.

With the ongoing research project of the ITT together with the Catholic University of Valparaíso, the University of Chile and the DGA a further step towards sustainable management of water resources will hopefully be achieved.

Acknowledgement

This study was conducted within the project “Water cycle for food production” with support of the Ministry of Education, Science and Research of the state of North-Rhine-Westphalia, Germany (MSWF-NRW). In addition support was granted through BMBF/IB and DAAD which permitted the exchange of scientists and students with relation to the project. In Chile the following institutions provided helpful data on the Aconcagua Watershed: DGA, ESVAL, Junta de Vigilancia (III). We would like to express our special thanks!

9 Abbreviations

DGA	Direccion General de Aguas; National Water Service of Chile
m asl	meters above sea level
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
CONAMA	Comision Nacional de Medio Ambiente
SISS	Superintendencia de Servicios Sanitarios (Emissions Control Authority)
ESVAL	Empresa de Obras Sanitarias de Valparaíso (Domestic Water Works Company of Valparaíso)
MOP	Ministerio de Obras Publicas (Ministry of Public Works)
PPP	Purchasing Power Parity

Contact

Lars Ribbe, University of Applied Sciences, Institute for Technology in the Tropics, Betzdorfer Str. 2. 50679 Cologne, Germany; e-mail: lars.ribbe@fh-koeln.de

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WATER USE AND WASTEWATER REUSE IN INDUSTRY AND AGRICULTURE IN CHILE

An analysis concerning the use of partially treated or untreated wastewater from agro industrial production in agriculture

Dan Etschmann

Abstract

This paper focuses upon the applicability of using water in a cyclic manner seen from the viewpoint of agro industrial production, where the ultimate goal of this approach is aimed at saving water resources. The concept includes measures intended to optimize the water use while taking into account the production process and the changing legal situation in Chile concerning wastewater output. The simulation tool developed in order to evaluate the feasibility of the concept and its implementation will also be described.

Keywords: water, wastewater, wastewater reuse, pollution, agro industrial production, agriculture, Chile, simulation

1 Introduction

Using water and thus producing wastewater has been an imminent part of human society for as long as human society has existed. Apart from being a life giving substance, of which according to the WHO, each human being would need at least 20 liters per day it is also put to use in many other areas, such as energy supply, production industry including mining, agriculture and others [Damrath, Cord-Landwehr, 1998].

Fresh water resources however are limited. From the 1360 million cubic kilometers water that exists on the globe, only 2.7 percent or 37 million cubic kilometers contains little salt. 77.2 percent of this fresh water is bound in form of snow and ice; further 22.4 percent are groundwater of which two thirds lie below 750 meters under the ground. Lakes and swamps contain 0.35 of fresh water; rivers carry 0.01 percent and 0.04 percent of fresh water is in the atmosphere. Thus only half a percent of all the existing water can be reached and is available as fresh water [Opitz, 1995].

Growing populations, growing agricultural activity, growing industrialization, and thus growing water needs have led to such high use and contamination of naturally available fresh water, that the need to act in order to spare this precious resource has become imperative. The worldwide water consumption per capita has risen from 400 cubic meters in 1940 to 800 cubic meters today. This water is consumed in irrigation, industrial production, growing demands on behalf of the population and luxury consume. Additionally, the worldwide consumption of water is ill divided over the globe: a US-citizen consumes about 547 liters of water per day, whereas a farmer on the southern edge of the Arabian Peninsula consumes 20 liters of water.

[Opitz, 1995]. The step towards improving the system of water use and reuse in agriculture is to be considered by suggesting that wastewater handed on to agriculture is applied to the ground. This technique is also referred to "reclaiming water" [Page, 1996]. While some components that constitute the contamination could be potential nourishment for agricultural production, the entire contamination would need to be removed from the wastewater through the ground. If this can be achieved, the ground would act as a large filter, decomposing the contamination carried in the wastewater.

Reuse of sewage water has been practiced for a long time in various parts of the world. Parts of the Mezquital Valley in Mexico have been irrigated with sewage water since 1886 while land disposal of waste water has been practiced in India for up to 160 years [Rowe, 1995]. In recent years many more projects that apply wastewater for various needs have been implemented.

2 Objectives

Aim of this work was to analyze an agro industrial production system - embedded in a larger social, legal and economical environment - in order to evaluate the feasibility of a concept focusing on the reuse of wastewater generated in the production process. The evaluation was to be carried out using modern simulation techniques. In addition, a general simulation model that can be quickly adapted to other agro industrial production systems was to be developed and tested.

3 Analysis

Water cycles

The concept of reclaiming water reduces the paths that water covers within the natural water cycles that take place. Water once contaminated by industry follows its path over agriculture onto the surface and eventually into the ground. The water that has been led back into the ground can then be used once more in industry and does not need to be treated, thus reducing the amount of water that the water treatment utility needs to deal with.

Furthermore, the contamination of agro industry contains many substances that are readily biodegradable or originate from agricultural production. Thus the cycle of substances needed in agriculture is also reduced, as substances that would be removed from the water at the utilities water treatment is now directly applied in agriculture.Thus the benefits of reclaiming wastewater are that the water itself is put to use without having to be treated, while the contaminating components in the wastewater are put to use productively and do not need to be disposed of.

However, great care must be taken to avoid problems with approach described above. The main threat evoked by the approach mentioned above is that various forms of wastewater contamination are spread in the environment without control through a central body rather than being removed from the wastewater in a controlled surrounding, such as a wastewater treatment system.

In the past, problems have been encountered when using domestic wastewater for irrigation. Infectious disease transmission through irrigating food crops with untreated domestic sewage or treated wastewater with questionable quality has been registered in several cases. Other pollutants such as cadmium have been observed to accumulate in the kidneys and livers of animals who were fed upon domestic wastewater sludge-amended pastures [Page, 1996].

Nation

Continental Chile stretches out along a narrow strip of territory with an average width of 180 kilometers located between the Andes Mountains and the Pacific Ocean in the southern cone of South

America. Its area totals 757,000 m^2 and is 4,200 kilometers long. More than 200 small basins that drain the west slopes of the Andes, featuring a hydraulic regime with an important snowmelt component, are located in the national territory.

The availability of water resources in Chile is characterized by an extraordinary heterogeneity in spatial distribution, with extremely low values in the north and very high ones in the south. Owing to this, the water balance in Chile shows an average flow at a national level of 30,000 m^3/s, of which 21 m^3/s correspond to the northernmost regions whereas 20 m^3/s correspond to the southernmost regions of the country. In the northern half of the country, the average water availability lies below 1,000 m^3/inhabitant and year, in some of the northern regions, this figure lies at only 500 m^3/inhabitant and year. In the southern half of the country, the water availability exceeds 10,000 m^3 /inhabitant and year [Peña T., 1997].

Among consumptive uses, irrigation stands for 84,5 % of the total water use, with an average flow of 546 m^3/s, which is used to irrigate approximately 2 million hectares, located to the north of 39° southern latitude, which corresponds approximately to the IX Region. This activity shows an important development at a national level owing to the particularly favorable climate and soil conditions, in addition to the availability of water resources during the spring and summer periods which originate from the thawing of the snow in the Andes Mountains [Cerda G., 1999].

The use of water for domestic purposes in the country is equivalent to 4.4% of the consumptive use and supplies 98% of the urban population and approximately 80% of the rural population. Mining and industrial use accounts 11% of the entire consumptive use. The mining demand is particularly important in the northern area of Santiago, whereas the industrial demand is concentrated around the urban centers of Santiago, Valparaiso and Concepción.

Economic and social framework

Over the last decades Chile has undergone rapid economical growth, so that the country has often been called the "Tiger of Latin America". However, social problems (poverty, insufficient housing, lacking health care), lacking security in competitiveness, over-exploitation of natural resources and lacking care of the environment have been reason for discussion [Gaese, 1999].

The growth in GDP per capita at constant prices has risen in the 70's, fell from 1980 to 1985 and has risen sharply from 1985 to 1990. In the first years of the 90's the GDP has risen not quite as strongly as in the years before. The poverty rate however has risen from 17% in the 70's to 34% at the beginning of the 90's and had risen to even 38% in the time-period of 1980-1985. Unemployment has equally grown from 4.1% in the 70's to 6.0% in 1990 and had been at 11.7% in the time-period of 1980-1985 [CEPAL, 1991].

In the area under study there are important urban settlements, such as the cities of Los Andes, San Felipe, Llay Llay, La Calera, Quillota, Limache, Con Con, La Ligua, Cabildo, Petorca among others. According to the 1996 census, the total population of the area included 530,000 people, 80% distributed in urban areas and 20% living in rural areas [Cerda G., 1999].

Legal and institutional framework

Until 1999 no effective regulations existed aiming to limit the contamination values of wastewater from industrial organizations. This led to great damages in many of the rivers all over the country, which in turn damaged agricultural production among many others.

An important change in the legal landscape is to be seen in the new legislative norms concerning wastewater disposal. According to the currently applying laws, especially Norm 609 of the Water Code, wastewater disposed of into surface waters must comply with maximal concentration regulations. In response to this, the water supply utilities have obliged companies with industrial production (companies with contamination values greater than the contamination equivalent to 100 inhabitants) to abide by a maximal contamination as of 20th of August 1999. An extract of maximal contamination values that apply for wastewater fed into the sewer system of ESVAL are listed in the following table:

Table 1: max. limits for the concentration of wastewater fed into the sewer system

Contamination	Unit	Maximally permitted concentration for waters disposed of into surface water
pH		5,5-9,0
Temperature	°C	35
Total Solids	mg / L	300
BOD_5	mg / L	300
Fats and Oils	mg / L	150
Ammoniac	mg / L	80

In addition to the above-mentioned concerning legal limits for wastewater issuing into the sewer, Chile has developed over the past years its mechanisms concerning the rights to use surface and ground water. The existing legal framework is designed to make use of market mechanisms, specifically in the case of the use of water; it is designed to favor the reallocation of resources through setting up a market of usage rights [Peña T., 1996].

According to the legislation, the waters are national goods of public use and granted to private individuals by legally entitling them to use such rights. However, the right of water usage is conceived as a real property, which the holder can use and dispose of freely. Thus it is also a tradable right, regardless of the aims for which the waters are to be used for [Peña T., 1996].

As the tradition of water rights has already existed in Chile for over a century and incentives are currently undertaken to optimize market mechanisms towards a more efficient use of water, it seems feasible that wastewater can also be seen as a tradable good as long as the quality of this water is in accordance with the intended use.

Outline of company analyzed

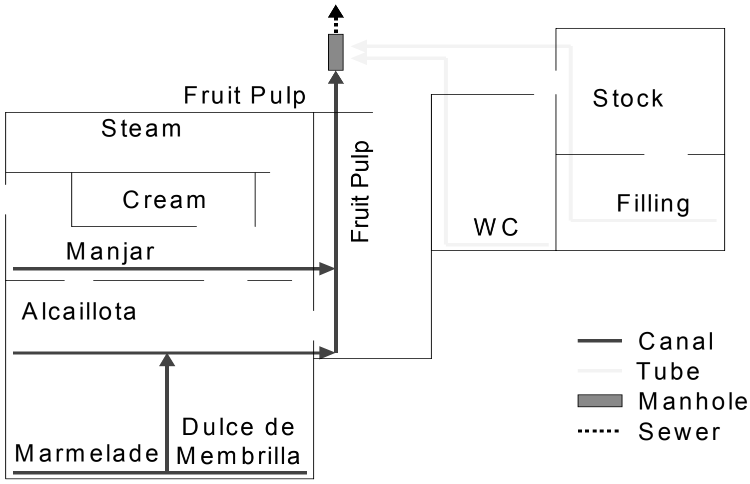
Eckart Empresas S.A. employs a few more than 40 people and is thus a small-sized company. The company produces 4 different products: marmalade, manjar (similar to fudge), quince cheese and cream. In order to produce marmalade and quince cheese, the intermediate product fruit pulp is also produced at place.

The following amounts are produced:

Marmalade: 230 t/month

Quince cheese: 120 t/month

Manjar: 100 t/month



Picture 1: Layout plan of Eckart S.A.

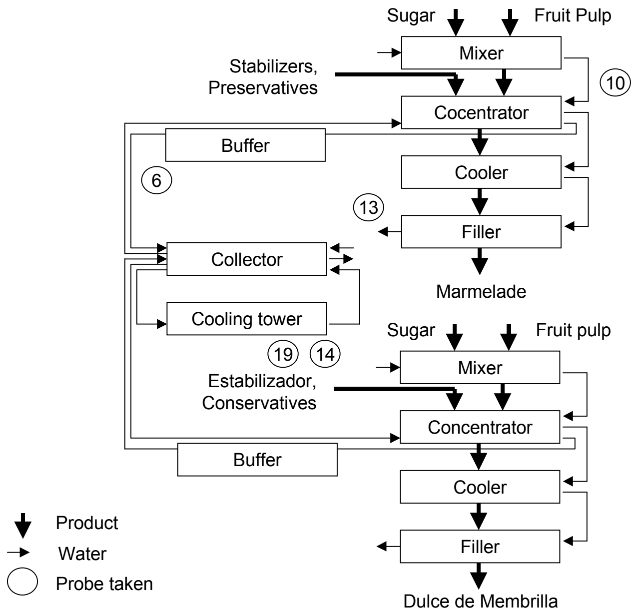
Quince cheese, or "dulce de membrilla", is quince pulp that has been concentrated through cooking. After having been cooked, the quince pulp hardens to a soft mass while cooling down. As it turns into a cheese-like substance it is referred to as quince cheese.

Manjar is a mixture of milk and sugar that is heated, and as a result turns to a light brown color. In other parts of Latin America it is also called "dulce de leche", however manjar is claimed to have a higher content of milk fat than dulce de leche. English fudge is similar to manjar but much harder.

A layout plan of the production site of Eckart can be seen in Picture 1. It must be stated that the layout at its current state has evolved over the past years, without an overall plan existing for the logistics in production. This leads to the fact that for the production of marmalade, fruit pulp is brought from the stock and transported through the fruit pulp region to the concentrators. Once the marmalade has been produced, it is transported back through the fruit pulp region and the stock to the filling region at the far right hand side.

The production of manjar and cream is coupled, for the manjar is produced with skimmed milk that is centrifuged on site. The cream originating from this centrifuging process is concentrated in order to produce further cream.

The water consumption varies every month. This is due to the fact that production activities vary over the year. Production of pulp only takes place from January to February, for in this time fresh fruit is available. In these months a water consumption of 65 m^3/ day can be registered, which is the highest value of the entire year. Between March and June the fruit pulp is processed into marmalade or quince cheese at a higher rate than the rest of the year. Thus the water consumption is up to 45 m^3/ day within these months. The rest of the year the water consumption amounts to 25 m^3/ day.



Picture 2: Production system for marmalade and "dulce de membrilla"

Most of the company's water comes from an on-site well and is not used for direct consumption, but for cleaning production installations. Drinking water supplied by ESVAL is used for the bathrooms, kitchens and for the steam producer.

The owners of the company have a plot of land situated close to the production sites. This plot of land is 25.000 m^2 large and is used as an orchard. The owners have already considered using the wastewater of their company for watering a part of the plot.

The production systems of Eckart S.A. were analyzed and documented as shown in **Picture 2**. The rectangles represent production machines; the wide arrows show a flow of product and the slim arrows a flow of water. The numbers in the circles show the identification number of the probes taken.

4 Methods

Factors to be varied

Based on the observations made at Eckart S.A., there are various factors that can be varied in order to reduce the production costs and at the same time save the amount of water used for production. These factors need to be analyzed closer in order to estimate the impact that these factors have on the production as well as on the environment. These are:

- Saving water
- Altering the production program
- Using detergents more suitable for reusing water in agriculture

- Balancing wastewater over one day
- Separating wastewater
- Treating wastewater.

Evaluation of alterations

Varying the factors mentioned above will have an impact upon the economical performance of the company considered. As this impact cannot be estimated directly, a closer analysis of the proposed changes needs to be undertaken. The impact-analysis of proposed changes can be carried out using conventional economical calculation methods or can be dealt with using a simulation model. The aspect of generating a simulation model and evaluating the results will be dealt as followed.

Evaluation of proposed changes

Using conventional economical methods and applying simulation techniques evaluated the proposed changes. These simulation techniques are now described more closely.

Simulation model

Granted that the problem under consideration is a highly complex one and that the different influences have a high interdependency, it is difficult to anticipate the influence on the general outcome using conventional methods. Additionally the calculation effort using conventional methods for analyzing even small examples is very high.

Thus simulation techniques, which describe a problem as closely as necessary and attempt to find an optimal solution to the described problem, can be used successfully. However it must be stated that the results of a simulation model can only be as good as the model describes the problem and must thus be viewed critically.

Techniques

According to VDI simulation is “representation of a system with its dynamical processes in an experimental model in order to attain results that can be extrapolated into reality”.

An evaluation using simulation techniques must thus start with setting up a simulation model in which the relevant factors can be altered in order to be able to estimate the behavior of the entire system analyzed. Further the effects of changes of relevant factors need to be studied. The results achieved through the simulation need then to be interpreted in how far the simulated results correspond to reality.

Linear programming

In various fields of economical planning, the method of linear programming has become a popular way of dealing with problems that contain many more variables than equations and have at least one variable that needs to be maximized or minimized.

The basic model of linear programming is a production oriented problem concerning n products P1, P2, .., Pn being produced with m stations F1, F2, .., Fm and each station having the capacity b1, b2, .., bm [Corsten, 1998, pp. 238-239]. Further the following presumptions apply:

- Amount of products produced equals the amount of products marketed
- Price and variable costs per unit are constant
- The production coefficients (time of a product at a certain station) are constant

- Capacities are constant and known over the time frame to be planned
- There are no substitutional or complementary effects between the products
- Preparation costs and time for machines are not accounted for
- The variables to be optimized are one dimensional (scalars)
- Factor prices (ground, work, capital) are constant

The approach toward solving the problem stated above is:

$$Z = \sum_{j=1}^{n} cj \cdot xj \rightarrow Max!$$

While adhering to the following secondary conditions:

$$\sum_{J=1}^{n} tij \cdot xj \leq bm$$

And the non-negative conditions:

$$xj \geq 0$$

Where:

Z is the value that is to be optimized, also called the objective value

x_j is the amount of product j (j=1,2,..,n)

F_i are the production stations (i=1,2,..,m)

c_j are the economical values to be maximized and

t_{ij} are the production times (production coefficients) of product j on station i

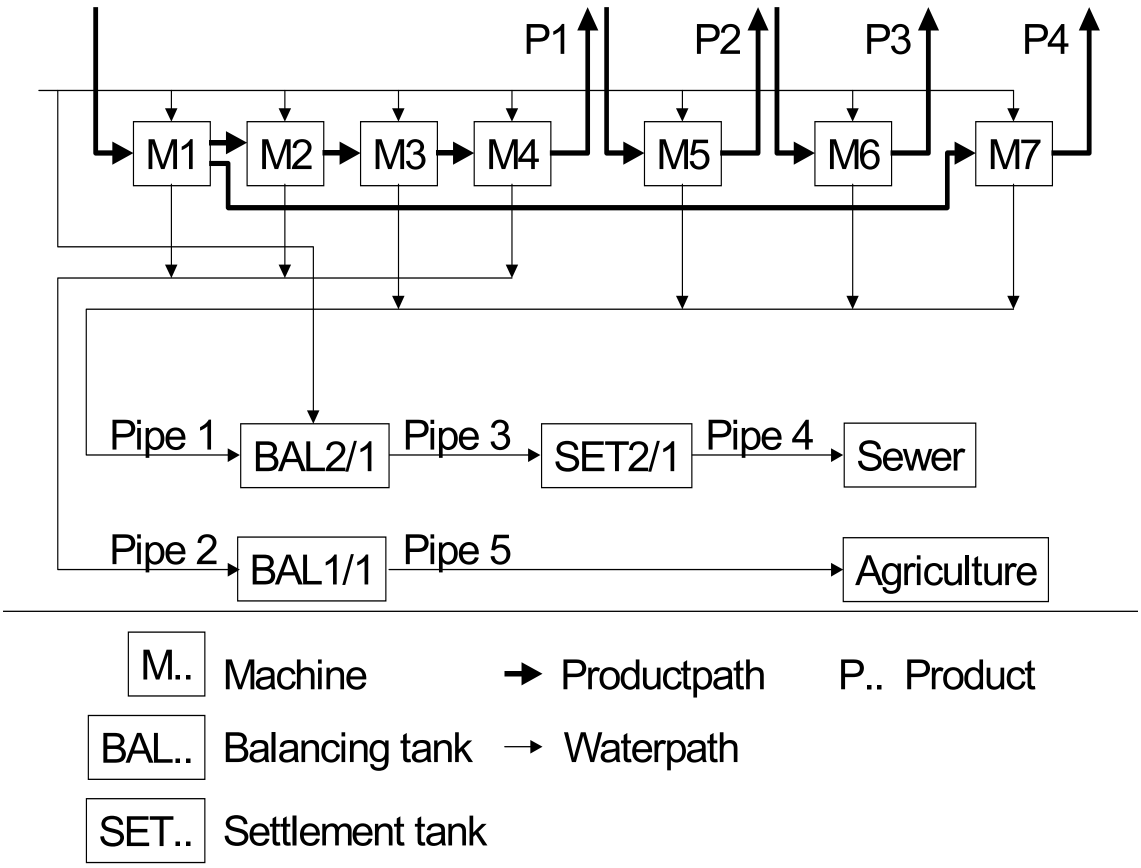
For large problems, the simplex-algorithm is used to solve the problem stated above. The simplex-algorithm follows an iterative pattern that steps through the solution area in an attempt to find the optimal combination of variables. In order to do this, the inequations are turned into equations by introducing slip variables (y).

Outline of the simulation model generated

Introduction

From the stated above it was established, that a way of using the wastewater from Eckart in an agricultural application might be achieved by separating out wastewater that can be used in agriculture, balancing wastewater over one day and partially treating the wastewater - by settlement - that will be disposed of into the sewer. In order to be able to estimate the quantitative aspects of the entire system a simulation and optimization model was created. The proposed system of wastewater separation with balancing wastewater over one day and partial wastewater treatment for using the separated wastewater in agriculture while issuing the treated wastewater into the sewer was modeled and analyzed and will be described in the following.

As can be seen in **Picture 3**, the machines produce the products P1 to P4, while also creating wastewater that initially runs through Pipe1 and Pipe2. The wastewater is first piped into balancing tanks, after which one string runs through a settlement tank and eventually issues into the sewer system. In the second string, the wastewater is transported to its agricultural application after having been balanced over one day.



Picture 3: System model

The overall aim of the simulation model is to maximize the value added achieved through processing agricultural products. This aim needs to be considered in connection with all other related such as water use or environmental impact.

In order to do this, the parameters that have influence on the considered problem need to be determined, after which their interdependency needs to be analyzed. Once these factors have been established, the problem under consideration can be formulated and implemented.

Parameters considered

At the starting point of designing a water treatment system for an agro industrial production there is the production with its water use contamination of water. These factors are influenced by the amount of processed goods. Factors concerning the existing production can be divided into factors concerning the production machines, the products and global parameters. These are:

- Production machines:
- Processing speed
- Amount of water used
- Contamination induced
- Costs of machines: investment, energy consumption

Products:

- Amount produced
- Cost of raw goods
- Cost for storage
- Revenues
- Market demand

Global parameters:

- Costs of fresh water
- Costs of energy
- Limits for contamination of effluents discharged into the sewer system.

There are certain interdependencies within the parameters mentioned above. One example is the revenues and the market demand, which is interrelated, but will be, treated as separate exogenous parameters within this model.

The next sets of parameters that can be varied are the type of water treatment systems and their capacities. As the water treatment systems bring about high investments, they have an imminent impact on the value added. These parameters can be divided into treatment specific parameters and global parameters. These are:

- Capacities of treatment tanks
- Reduction of contamination in each treatment tank
- Interconnection of treatment tanks
- Costs for treatment tanks and operation costs.

A further step envisaged within the project mentioned above is considering the further application of effluents in agriculture. For this, limitations for the anticipated application need to be considered. These too can have an impact on the value added, as water used in agriculture can be seen as an economical good that can be sold. In order to comply with the systematization introduced above these parameters will be included into the set of global parameters.

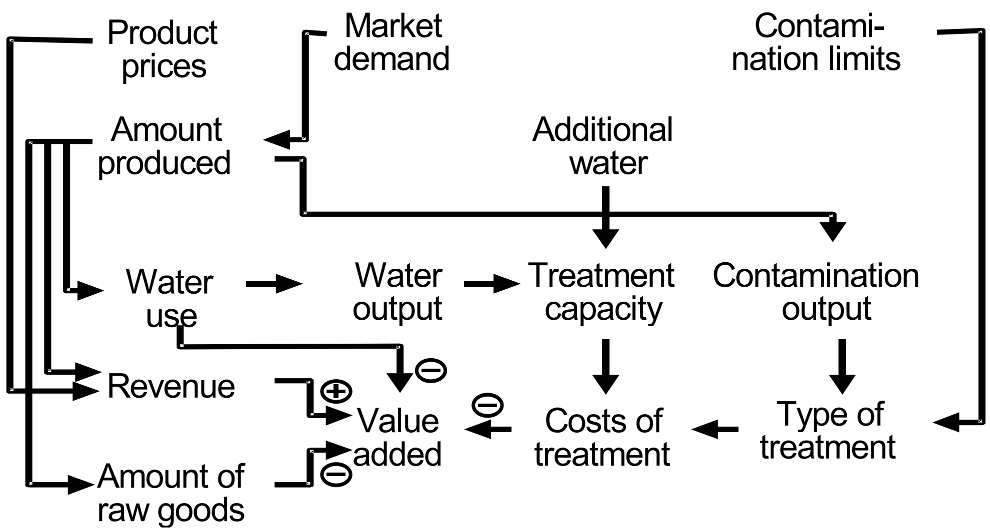
Global parameters:

- Limits for contamination of effluents used in agriculture
- Revenues from selling effluents to agriculture.

The parameters mentioned above can be divided into parameters that are given and cannot be changed and parameters that can be varied in order to improve the results of the production and ultimately the value added. An overview over fixed and variable parameters is shown in the following table:

Table 2: Variable and fix parameters

Variable parameters	Fixed parameters
Amount produced	Processing speed
Type of treatment	Amount of water used per machine
Capacity of treatment tanks	Contamination induced per machine
Interconnections between treatment tanks	Costs of machine
	Costs of raw goods
	Costs for storage
	Revenues from products
	Market demand
	Costs of fresh water
	Costs of energy
	Contamination limits for effluents to sewer and to agriculture



Picture 4: Parameters and their interdependencies

Interdependency of parameters and governing equations

From the perspective of the agro industrial production, there exist various interdependencies between the parameters mentioned above. Some parameters have direct influence on the value added, while others have indirect influence on the value added. **Picture 4** schematically shows the interdependencies of the different parameters.

The central part of the diagram is the value added and the factors that have a direct influence on the value added. These are the revenue, the amount of raw goods required, the amount of water required, the costs for water treatment and the costs for additional water that can be used to dilute the contamination.

As can also be seen in the diagram, the amount produced has a large impact upon the water used, the revenue, the amount of raw goods required and the water output. The amount of contaminated water in turn has an influence on the required treatment capacity, which further has and influence on the costs for treatment.

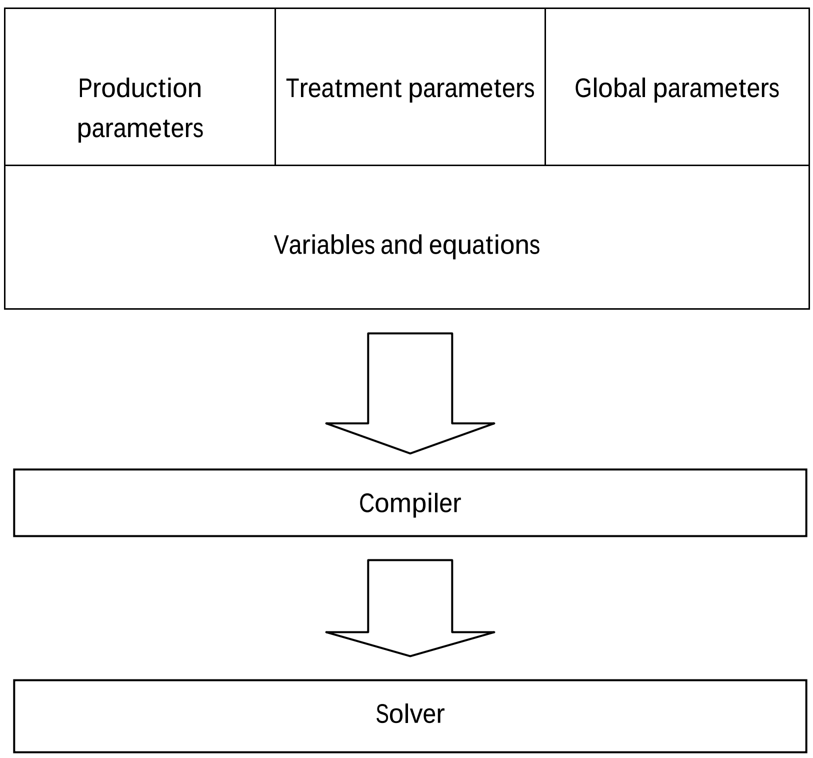
The revenue has an additive influence on the value added, whereas all other factors have a diminishing influence on the value added. This is indicated through the "+" and "-"symbols in the diagram.

The governing equations that describe the problem under consideration are directly derived from Picture 4.

General Model

In addition to the company specific model a general model was generated with the aim of being able to adapt the model quickly to new production systems to be analyzed.The general model is structured first into a company specific part and a general part. The company specific part needs to be adapted to the company currently analyzed. It contains only static data, i.e. numeric values. The general part defines the interdependencies of the input data and the values to be optimized. Since the relationship between input data and values to be optimized are not straightforward, the general model also includes calculation of various diagnostic values, which can be used as debugging aids.

Picture 5 shows the basic structure of the entire general model and the processing and solving steps described above. The company specific part of the model, or company specific sub model, is further divided into the categories: production, treatment and global.



Picture 5: Structure of the general model

The category “Production” describes the production of the company currently under analysis; this includes the production machines, the logistical structure within the production and the products. The category “Treatment” describes the wastewater treatment. The category “Global” contains all data that globally applies to the company. This includes water prices, energy prices, and maximal contamination for water reused in an agricultural way and maximal contamination for water disposed of into the sewer system.

The general part describes the problem using equations. These equations start with defining the kernel equation of the simulation model: calculating the value added through production. In order to evaluate this, the output of products and contamination from the machines is calculated, after which the treatment of contaminated waters from each sector is calculated while considering the maximal contamination that the output to agriculture or the sewer system. The amount of water output to each sector in turn defines the required capacity of each treatment tank.

In the following the sub model “Variables and equations” will be described, after which will follow a description of the output to the file “Results.dat”. After that the categories “Production”, “Treatment” and “Global” will be described.

Variation of parameters and sensitivity analysis

The aim of varying some input parameters is to establish how certain endogenous variables react to changes in the exogenous variables. In order to do this, some variables of interest where chosen to be varied. The changing input data was written into the respective files and a simulation run documented using the output functions implemented with the model. The output files were then transferred to Excel in order to be able to analyze the data using graphical representation.

The exogenous variables varied are:

- Demand of Product 2 (marmalade)
- Price for fruit pulp for Product 2
- Price for fruit pulp for Product 3 (“dulce de membrilla”)
- Additional variable costs for Product 2
- Additional variable costs for Product 3
- Retail prices for Product 2
- Legal limits for amount of solids in water issuing into the sewer system

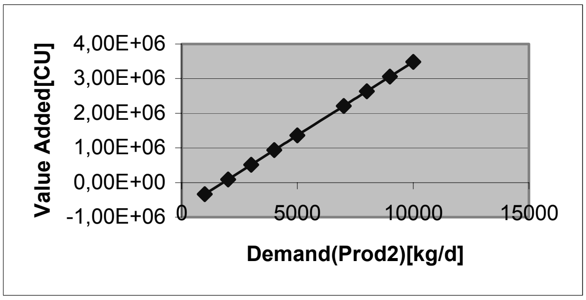
The results gathered from the analysis of the output data are to be discussed in the following.

Demand

The first variation of input data was undertaken to establish the dependency between the demand of a product and the value added that could be achieved with changing demand. The result shown in Picture 6 is a linear dependency of the value added upon the demand of a product.

Purchasing prices

The dependency of the value added and the amount produced upon the purchasing prices shows a typical characteristic encountered with linear programming: In order to optimize the objective variable, some remaining variables are changed gradually, where others are kept constant for as long as the objective value can be altered towards the desired goal. If altering the gradually changed variables cannot achieve the optimal goal, at least one variable is changed immediately to the other limit. This creates unsteady points within the function of the objective value. This phenomenon can be seen in **Picture 7**, where the amount of Product 2 that is produced is kept at the level of 5000 kg (the maximum demand of the market) for as long as the purchasing price is below 600 CU. As soon as the purchasing price for the raw goods of Product 2 lies above 600 CU, the production of Product 2 is stopped completely. This causes an unsteady change in the value added at 600 CU and creates a bilinear dependency of the value added upon the purchasing price.

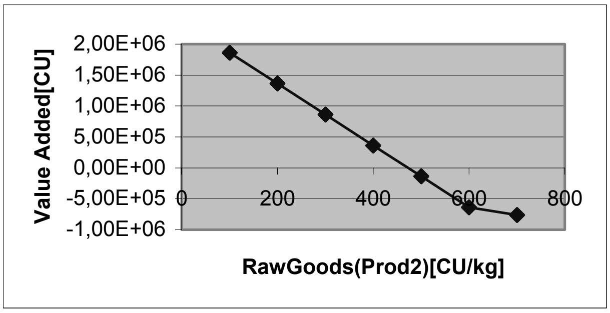


Picture 6: Demand of Product 2 and Value added

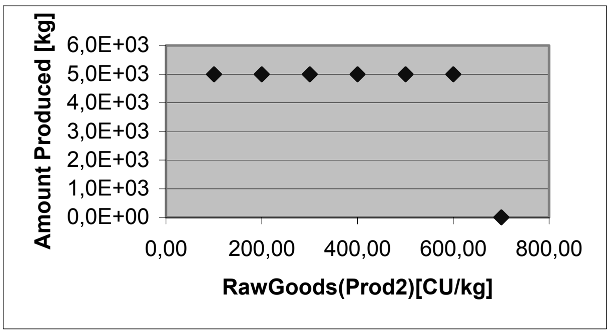
Additional variable costs

The next parameter varied is the additional variable costs for the products 2 and 3. Theses costs take into consideration additional costs that occur proportionally to the amount produced. Typical examples are costs for administration, stock and energy that have not been taken into consideration in the model (i.e. energy consumed in the administrative building). It is presumed, that the variable costs are proportional to the amount produced, and not over-, or underproportional.

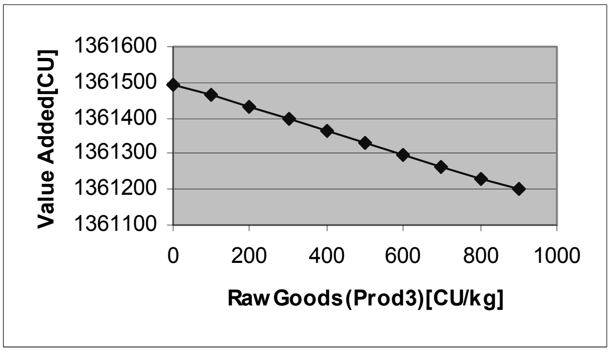
The value added as a function of the additional variable costs for Product 2 and Product 3 is linear and can be seen in **Picture 7**, **Picture 8** and **Picture 9**.



Picture 7: Purchasing prices for Product 2 and Value Added



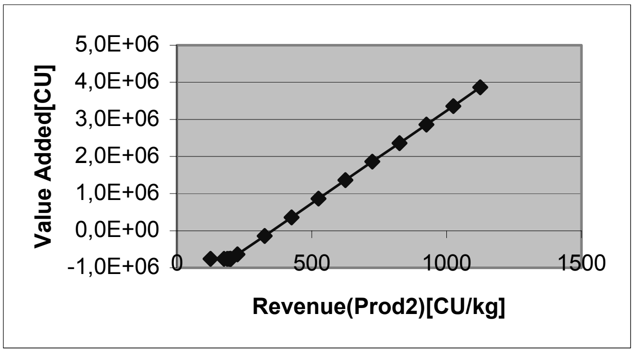
Picture 8: Purchasing prices for Product 2 and Amount Produced



Picture 9: Purchasing prices for Product 3 and Value added

The Value added as a function of the purchasing prices for Product 3 contains only one linear arm, due to the fact the critical value of purchasing prices for Product 3 had not been reached within the frame depicted. The value added as a function of purchasing prices for Product 3l shows a bilinear form as soon as this critical value will be analyzed.

Retail prices



Picture 10: Retail prices of Product 2 and Value added

The influence of the retail prices, prices that the product is sold for on the market, was the next parameter of interest. The results can be seen in **Picture 10**. Here also the value added as a function of the retail prices shows the characteristic discussed above. However, the value added remains constant as long as the Product 2 to is not being produced. As soon as Product 2 is produced, the value added rises linearly. The data points close to the bend in the function demonstrate the behavior of the linear programming system: the strategy of producing no Product 2 to producing the maximal amount of Product 2 does not change gradually, but at one certain point.

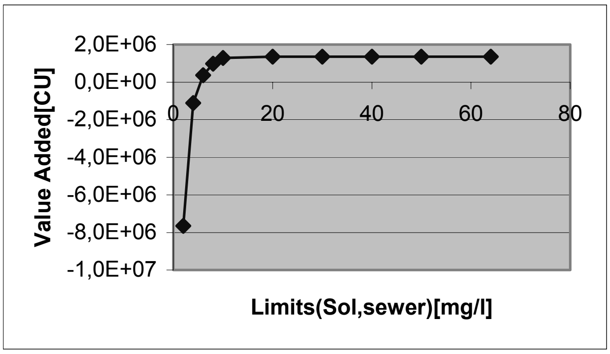
Limits of wastewater contamination

The further set of parameters analyzed are the legal limits that apply to the wastewater that issues into the sewer system. Considering that the current limit values are rather lax in comparison with many other states, it must be taken into consideration, that theses limits will be lowered in the future. Thus it is of grave importance to be able to estimate the influence these values have upon the entire system.

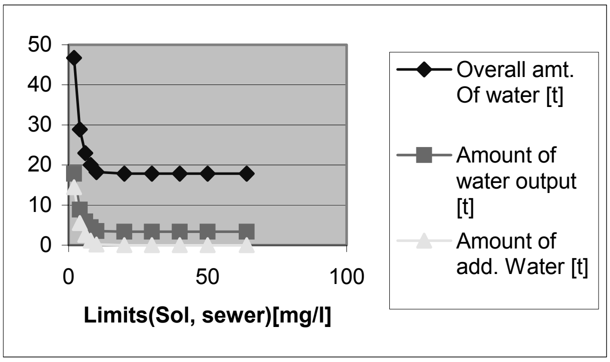
The amount of solids in the wastewater was the parameter that was chosen to be varied. The current legal limit was assumed the maximal value that will be of interest in the future, the smallest value analyzed was 2 mg/l. The results can be seen in **Picture 11**.

Additionally, the amount of water consumed was analyzed and graphed as shown in the following data:

- Overall amount of water used: the amount of water that is used by the entire system in one day
- Amount of water output: the amount of wastewater that originates directly from the production process
- Amount of additional water: the amount of water that flows without directly being put to use, that however has the function of diluting the contamination in the wastewater originating directly from the production process
- The resulting graph can be seen in Picture 12.



Picture 11: Legal limit of solids in wastewater and Value Added



Picture 12: Legal limits of solids in wastewater and amount of water consumed

5 Results

The picture above shows that a model can be created for the rather complex system of water use and wastewater treatment in agro industrial production. Further, certain dependencies were focused upon and showed to have a linear or bilinear character. These are: the value added as a function of market demand, purchasing prices for raw goods, additional variable costs and the revenue for products sold.

The dependency of the value added upon the legal limits of solid concentration in the wastewater shows a non-linear behavior, where low allowed concentrations of about 5.5 mg/l and less lead to a negative value added. The function of the amount of water used depending upon the allowed concentrations also shows non-linear behavior.

6 Conclusion

Several solutions for the given problem of dealing with wastewater originating from food production were developed and analyzed. The basic thought for the solutions developed was applying the wastewater in agriculture with as little additional effort as possible. Furthermore, an economical evaluation of steps to be taken was developed. Considering that the amount of factors that play a role in the whole system of food production and dealing with the wastewater, a simulation model was developed in order to be able to assess the influence certain factors have.

Two steps towards improving the system and at the same time dealing with the changed legal landscape were suggested. These are:

separating some of the wastewater and balancing both paths of wastewater over one day, thus reducing the contamination of water disposed of into the sewer and

applying the collected wastewater to life-stock, that are abundant in the region thus putting the water to further use and finding a way of dealing with the contamination without having to treat it.

Additionally, the developed simulation model needs to be applied in other companies in order to validate it further and to refine it in order to be able to formulate a larger spectrum of problems.

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DEGRADATION FACTORS IN A RISK PRONE AREA: THE SEMI-ARID NORTHEAST OF BRAZIL

Hartmut Gaese

Abstract

The Portuguese settlement of Northeast Brazil of the 17th century was initially restricted to the favorable locations along the coastal area (zona mata) and to the neighboring sub-humid hilly region (zona agreste). Later the settlement extended to the limited spots of favorable conditions located within the area of the semi-arid savanna, the "Sertão" ("brejos" and the humid "serras"). Droughts of varying duration and intensity have severely and repeatedly affected the interior of Northeast Brazil – the "draught polygon", ever since the first settlement of the Portuguese. The consequences of droughts are damages in the agricultural production and shortage in the supply of water to men and animals. Cropping systems are affected by delays of the rainfalls, dry spells in the initial phase of the cropping cycle or even a total lack of rainfall for one or several years.

During the most destructive drought of the 19th century in Ceará half a million people (at that time half of the population of Ceará) and almost all animals died.

Keywords: semi-arid-ecosystem, degradation, agricultural production risk, Brazil

1 Aspects from settlement history

It is difficult to explain why such an unfavorable area as the interior of Northeast Brazil had been settled at all. Throughout the old world such climatic zones where traditionally dominated by regionally flexible nomadic systems. Concerning the land use systems in Northeast Brazil in pre-colonial times little is known apart from few exemptions. It is most likely that locally fixed agriculture has exclusively been practiced along rivers, e.g. at the Rio São Francisco. These agricultural activities are assumed to have been limited to provide the supplementary food to fishery and chasing activities (BOLAND 1997, 40 ff.). The Indians passed through the Sertão only sporadically during there chasing and collecting endeavors and settled at the "oasis" of favorable conditions. They applied gentle extensive methods as a slash-and-burn method covering wide areas and preserving soil fertility. A population pressure which leads to unsustainable slash-and-burn practices was not yet prevailing. Looking further into the past considering the climatic change, 10 000 years ago the conditions in the region where semi-humid or even humid.

According to DICKERSON (quoted in BOLAND 1997, 41) the Portuguese learned the cultivation of a wide range of indigenous annual and perennial crops, e.g. the cultivation and processing of cassava, cashew, nuts, palm trees, corn and further tree crops. The Portuguese also adopted the slash-and-burn practice, though without considering the conditions for sustainability, i.e. maintaining an appropriate relation of cropping in fallow periods to allow the regeneration of soil fertility after the land use cycle. Thus commenced a successive degradation of land according to the degree of the sensitivity of the respective ecosystem. Extensive pasture systems evolved as the predominant systems of the Sertão in response to the demand for meat for the labor force of the sugar plantations of the coastal areas and the minors in Minas Gerais. Following the breakdown of the sugar industry at the eastern coast in the 17th century, labor force was released and partly drifted to the interior of the country.

Principally, pasture systems can be adapted to the local conditions of such marginal zones as the Sertão. The sustainability, though, is assessed conversely in literature, similarly to the conception of the climax vegetation. The felling of trees for ship construction and the production of charcoal since the appearance of the Portuguese have equally contributed considerably to the progressive degradation of the region as an inappropriate pasture management. The effects of the degradation appear especially fatal with draught events. Considering that husbandry contributes undeniably to the degradation or even desertification of fragile regions, future research activities should take special account of the various animal production systems playing an important role in small-scale farming as integrated crop-animal production systems as well as in large-scale extensive pasture management.

2 Agricultural constitution

The agricultural constitution, i.e. the property rights and labor constitution, is up to present a further hampering factor for the development of the human ecological system of Northeast Brazil. As a measure for inequality often used in this context, the application of the indicator farm size structure is misleading. While pasture system farms certainly require substantial land resources (up to 30 ha/animal unit or even more), a few hectares of farm land in valleys of perennial rivers can guarantee the livelihood of a family, even without irrigation. Still, the farm size structure can reflect to some degree the extreme land distribution: More than 70 % of all farms operate less than 10 ha, covering a total share of the agricultural land of 5.4 %. On the other side, farms of more than 1 000 ha, which are 0.4 % of all agricultural holdings, cover 32 % of the farmland area. The land distribution gap in Northeast Brazil thus exceeds by far the land distribution inequality of Brazil as a whole (IBGE 1998: Agricultural Census 1995/1996). The agricultural constitution is a major factor for the low income in the agricultural sector and the unequal income distribution. Northeast Brazil is still among the poorest regions of the world: Three quarters of the persons engaged in agriculture do not even achieve the income level defined as the existence minimum. The most disadvantaged quarter of the agricultural labor force disposes of almost zero income, the second quarter must make a living on half of the minimum income or less, the third quarter finally achieves as a maximum the minimum income, which still in the long view is not sufficient to make a living (GAESE 1996).

3 Macro and regional policy

For decades the predominant economic policy of Brazil has been a policy of import substitution and the establishment of industries protected from international competition, resulting in a substantial distortion of factor and product markets. Only since the beginning of the 1990’s this protective policy has been abandoned in favor of a rather market oriented policy. The effects of the long period of distorted products- and factor markets were a continuation for the developments in the Northeast of the regional, technological and economic dualism initiated already in the 19th century. While the Southeast and South of Brazil have been characterized by a boosting economy in both, the urban as well as in the rural areas, the Northeast has been characterized by disparities among rural and urban areas, among the agricultural and the industrial sector and among the social levels. Since technical progress has predominantly been induced, the distortion of the markets has been transferred to the technology development and application (GAESE 1997).

The financing of the development has to a large degree been provided by the primary sector, specifically the agricultural sector. This is also the reason to specially promote the export oriented production systems within the sector. Research and development of technologies concentrates on those products important for the exterior economy such as sugarcane, coffee, soybean and citrus. Success and progress has been impressive for these products, resulting in “technology jumps” as, for instance, achieved for sugarcane benefiting from the alcohol program. Contrarily to the “modern” export products and the secondary sector, the traditional agricultural sector has been disadvantaged. This has resulted in a misallocation of production factors (shift of comparative cost advantages) such as a migration of labor and capital out of the agricultural sector and the rural areas (GAESE 1994).

This dualism related to the difference in returns on the production factors is particularly dominant in Northeast Brazil featured with a prevailing “traditional” agricultural structure and agricultural constitution hampered in development by the risky natural environmental conditions.

4 Droughts, emergency programs and “disaster industry”

The natural production risk in the Northeast is extremely high. Due to climatic variability, agricultural production suffers extreme yield insecurity up to consecutive years of total losses. This insecurity also affects the industry and trade sectors, since the processing of agrarian primary inputs and the production of food play a major role in the economy of Northeastern Brazil. This group of products suffers from disproportionate fluctuation of prices while the price elasticity of demand is low. The degradation of large areas, erosion caused by inappropriate land use (population growth, intensity too high, extension of the agricultural frontier to fragile areas, etc.) leads to an exponential amplification of the effects of drought events. Nowadays, 30 % of the land use area of the drought polygon is estimated to be strongly degraded.

Groundwater resources are said to be statistically speaking sufficient: 4 300 cubic meters per capita have been calculated, which is more than twofold of what is considered sufficient according to UN standards (2 000 m^3/ capita). The repeatedly heard statement that drought problems in Northeast Brazil are merely a problem of distribution is a misinterpretation rooted in simplification of the drought problem. Comparing the Sertão to Israel and California with the result that the Sertão could be turned into a green area with the available groundwater (Der Spiegel, 24/1998) is definitely wrong. Still, drought events are usually linked to unexplained processes and inequalities which have led long ago to the introduction of the term “indústria da seca”, meaning the business around droughts from which landlords, Members of Parliament, mayors and governors make profit by distracting funds meant for the needing population.

A survey by SUDENE (SUDENE 1999, 67 ff.) concerning the drought programs reveals that the drought-affected population, i.e. small-scale farmers, farm workers, day laborers, settlers, etc. is aware of the problems and has commonly experienced inequalities in receiving its assigned benefit. Undoubtedly, the Brazilian government has so far not succeeded in overcoming the revolving drought calamities.

5 Interaction of the factors influencing the agricultural sector and the farming system development

The essential problem in farm development potentials and thus in the development of the agricultural sector is the risk bound to the location which limits the production and income potentials substantially. The adoption of technical progress is hampered and improvement of investments is a gamble. Farmers respond to the environmental conditions by adopting a risk aversion strategy which is only rational under the insecure production circumstances. The rationality of farmers' behavior comprises also that farmers' aversion risk is proportional to the variance of climate and weather conditions. The more difficult it is to generate individual capital stocks and to secure the subsistence production the more dominant is the risk aversion behavior of the farmer. Thus, the objective knowledge of the expected production function (yields in response to production conditions at the time axis) and the probability distribution (variance) is of immense importance for the decision making of the farmer, which actually is soundly based on the experience of farmers.

In the semi-arid regions, the potential extent of field crops is restrained by the available family labor in periods of peak requirements (field preparation, seeding, harvest) as long as no mechanization of time constraint production processes are introduced. Though, small-scale farms do not dispose of the required capital and due to the absence of collateral on these farms (agricultural constitution) this situation is not likely to change.

Additionally, the income generation through farming activities in small units does not allow employing permanent labor. Seasonal employment of labor force is the most common strategy to overcome peak labor requirements, but, with view to the low cash income generated by the large share of farmers in the region, household members themselves might require generating cash income through off-farm employment in seasonal agricultural activities. Thus, farmers neglect their own plantations, resulting in having difficulties to finalize important field activities within the only possible time frame in which weather conditions allow the development of the crops.

On the other hand, actual developments show a trend of population growth within the group of small-scale farmers. In the least advantaged group of farms production conditions tend to be worse than average and alternative income opportunities are too remote to be accessed. Therefore, the available labor force for this group has grown which has led to a reduction of the income per person engaged in the agricultural sector. The risk potentials for further degradation of semi-arid regions are basically located within this group of farms which has no economic alternative to extracting as much as possible from the limited production factors available.

During the recent decades, a substantial extension of the land use area in Northeast Brazil could be observed (1959: about 58.34 million hectares; 1985: about 85.2 million hectares). Simultaneously, the number of farms has tripled, basically among the group of small-scale farms. During this period, yields of the traditional production (beans, corn, cassava, cotton) dominating the small-scale farm sector were reduced, while those crops produced in the large-scale farm sector (cashew, cacao, sugarcane) showed exactly the opposite trend. One reason for this development is that the small-scale farm sector had to abandon part of the favorable production locations in favor of farming enterprises "with development potential". These farmers had to encroach marginal land, leading in total to a reduction of fallow area in relation to the cropping area and a shortening of the field rotation cycles. The result of this development is called "poverty induced degradation". Research has done little yet to counteract these effects, becoming even more severe due to the continuous increase of population pressure in the traditional sector. On the contrary, research and technology development have concentrated on export oriented production (research goals of the national organization for agricultural research EMBRAPA). Thus, the traditional sector is disadvantaged regarding the research progress and the unfavorable economic environmental conditions such as the credit line policy, i.e. low prices for food in favor of the export oriented agricultural production. In summary, the comparative production advantages of the "modern" agricultural sector and those of the Southeast in comparison to the Northeast with respect to the different structure of agricultural products are increasing.

6 Intra-regional locational factors of the Northeast

The introduction of modern technologies, and thus the development of a modern agriculture, is, besides the building-up of the input and output processing sectors, highly depending on the availability of water. This fact limits "modern" agriculture in the semi-arid areas of the Northeast to very few locations, where modern agriculture is almost exclusively found under irrigated conditions. Capital intensive irrigation, up to present predominantly under the regime of national agencies, accounts for high opportunity costs, since they are mostly located in those locations, i.e. river valley (várzeas) where the climate risk is reduced and rain-fed agriculture at a comparatively high intensity level would also be possible. In these locations, irrigation systems have been constructed which yield unsatisfactory levels of output caused by low water use efficiency and inappropriate irrigation management (water use efficiency 30 %, 30 % of the irrigation areas are severely affected by salinization).

Within the Northeast, locational differences are considerable. The Sertão areas will continue to be net-importing areas for food. In response to the low production potentials production costs are comparatively high. Thus, cost advantages are only relevant for local markets, while more favorable areas have high potentials in this respect. The Central North (Meio-Norte), for instance, or the humid coastal areas have a high export potential, exporting not only abroad, but also inter-regionally, for important primary products (rice, beans, corn) but also for a wide range of tropical fruits (perennial bushes and trees as well as annual crops). The Northeast has already achieved a level of self-sufficiency in the production of vegetables. For this product group there is a marketing potential for producing seasonally varying markets in other regions of Brazil or the MERCOSUR. Considering the comparatively high income elasticity of demand in Northeast Brazil, an increase in income can be expected to induce a substantial increase in the demand for food. The capacity of the regions with pronounced Sertão characteristics will remain low, even if land was distributed more equally. A strategy of fixing people in the countryside (fixação do homen no campo) has to be considered as problematic, migration to areas of higher carrying potential more advantageous.

7 Effects of political and economic environment on development

Since the early 1990's, the political and economic environment has undergone notable changes on national level as well as on state level of the Northeast. In the course of continuous liberalization measures, a pressure to adjust has evolved, which has partly been responded to on the level of MERCOSUR. Presently, the effects of liberalization on the agricultural sector in the semi-arid areas of the Northeast are ambivalent.

Concerning the goals for the predominant farming system, the Brazilian government has taken a considerable turn towards sustainable family farms (MINISTÉRIO DO DESENVOLVIMENTO AGRÁRIO, 2000). These goals are rooted in recognizing that family farms – as long as they are equipped with a minimum stock of resources – are much more flexible and thus less depending on cyclical fluctuations of the economy than commercial enterprises. Besides, considering the aspect of welfare distribution, a farm structure dominated by family farms is much more sustainable in social terms.

8 Conclusions for research

To assess the potential of further development of farming systems considering the further development of population pressure, the following crucial questions have to the raised:

- The national government demands an extension of the agricultural frontier to guarantee the supply of food and currency. This raises the question for the existence and location of unused land resources. It must be considered that the high potential land is already under production and that the encroachment of marginal land to produce for distant market locations is linked to enormous transport costs. The intensity levels of production systems follow the infrastructure development and the growth of decentral sub-centers.

- Which would be the consequences for the agro-ecological environment if the spatial expansions were realized in the diverse locations? Which areas will suffer most from “poverty induced degradation” if more and more marginal land will be farmed by the increasing population? An increase of the agricultural production under the condition of land scarcity – as happening in the historical settlement area “Agreste” – must inevitably lead to an increase of the optimum specific intensity through the application of improved technologies which also induces an increase of the farming risk.
- What will be the role of the family farms with growth potentials? How can the new goals of the government be implemented in the agricultural constitution?
- Which will be the role of the presently expensive irrigation technology and which are the required conditions?
- Which are the optimal technologies for which location and which land use systems will be most sustainable (preservation of the carrying capacity of soils, long-term stability of the farms)?

The quantitative assessment of these interactions is very complex. Economic models developed to include ecological restrictions have to be further simplified. Literature in this context (KUTCHER & SCANDIZZO 1981; BNB 1990) supports the recent approach of the Brazilian government to strengthen the family farming sector. Family farms hold by number the largest share of farms in all climatic regions of the Northeast apart from the dry zones which are dominated by extensive pasture systems. In the course of the ongoing structural change in the agricultural sector, the family farming systems can be expected to increase their share related to both the operated land and the production value.

Plausibility considerations thus lead to the conclusion that the goal pursued by the Brazilian government as well as by the state governments in the Northeast (“fixação do homen no campo”) cannot be successful, even if the economic environmental conditions were improved. The continuous migration should rather be considered as a healthy process in reducing the population in the fragile areas of the Northeast. Furthermore, it must be expected that technical progress will release even more labor force in the future. The general economic development leads to a higher return on labor in other sectors and regions which will in the long run increase the opportunity costs for labor in the agricultural sector. The ongoing integration into the framework of the MERCOSUR will provoke additional impulse to adjust the production systems and spatial resource allocation to the competition situation for specific markets (e.g. meat, milk and cereals) in response to shifting comparative cost advantages. Overall, all these factors will lead to accelerate the migration of labor force from the disfavored regions of low production potentials to the preference regions with high development potentials: a large share of the labor force will migrate to the sub-centers and centers, finding employment in the expanding processing and service sectors. For the primary production just the “modern” sector, which can only evolve in the high potential preference locations, is expected to increase the demand for labor.

Concluding from the actual developments of the agricultural sector in Northeast Brazil, demands for research arise especially concerning the development of appropriate system models considering the influence of the economic and spatial development during the past decade

- to analyze economic-ecological trade-offs and
- to analyze a sustainability oriented resource management at diverse locations in Northeast Brazil.

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INFORMATION INTEROPERABILITY FOR RIVER BASIN MANAGEMENT

Jackson Roehrig

Abstract

Many countries are adopting water policies and legislative instruments for water management in conformance to the agenda 21. According to this agenda, the use and protection of surface water and groundwater are coordinated at a river basin level. The success of river basin management systems relies upon coordinated actions, including provision of and access to information as well as the capability to correctly interpret and use this information. This article presents a discussion on the necessity and benefits of information interoperability for river basin management.

Keywords: Infrmation systems, Geographical Information System (GIS), interoperability, OpenGIS, Decision Support System (DSS), Water Resources Management, River Basin Management, water allocation, water quality, water sectors

1 River Basin Management

Water is a fundamental natural resource influencing human health, ecology and economic development. Flood, water scarcity, desertification, insufficient water supply and sanitation in the poorest population segments, water use conflicts among user sectors or countries, land and water quality degradation arising from population and economical growth, pollution of aquatic ecosystems, erosion and salinization caused by overexploitation and inadequate agricultural practices are water related problems affecting specially developing countries.

Water use has been traditionally managed at a sector level, whereas typical sectors are irrigation, drinking and industry water supply, water delivery, hydropower, fishery, navigation, mining, tourism and recreation. The competition for water between sectors due to population growth and economical development, together with a better understanding of ecological systems, resulted in the development of integrated water management practices. Environmental, economical, legal, social and political motivations has led countries to adopt water policies and legislative instruments for water management in conformance to the agenda 21, in which integrated management practices of use and protection of surface water and groundwater are coordinated at a river basin level. The river basin is a natural, geographical water management unity, permitting a better control over the impact of the water user sectors on water bodies. Due to its interdisciplinary nature, the success of river basin management systems relies upon coordinated actions between water users and other stakeholders of the public and private sector. River basin management involves planning and execution of measures to reduce environmental degradation and to ensure sustainable use of water, including water allocation, water user conflicts, monitoring, protection and rehabilitation of ecosystems.

Many models of river basin management exist, with different participation levels for water users, government and public. Usual organization structures for river basin management consist of one competent authority to enforce legal provisions or of both a river basin agency with executive competence and a committee composed of stakeholders of the public and private sector representing their interests.

The importance of information for water management is exemplified in the EU Water Framework Directive, one of the most significant instruments in the field of river basin management. The success of the Directive relies on close cooperation and coherent action at Community, Member State and local level as well as on information, consultation and involvement of stakeholders, including users. To ensure their participation in the establishment and updating of river basin management plans, it is necessary to provide proper information of planned measures and to report on progress with their implementation with a view to the involvement of the general public before final decisions on the necessary measures are adopted. The information should be as far as possible available for introduction into a geographic information system (EUWFD, 2000).

Water related planning and operation activities in the river basin require the access to data from external sources. Construction, operation and maintenance of pipelines, water mains, wastewater canalization, electricity cables, gas distribution and roads, in the public or private sectors may affect one another, requiring usually official authorization and coordination by the governmental administration. The authorization process requires a spatial analysis - in the simplest cases through visual inspection - to determine the influence of a planned activity on other sectors operating in the area of concern.

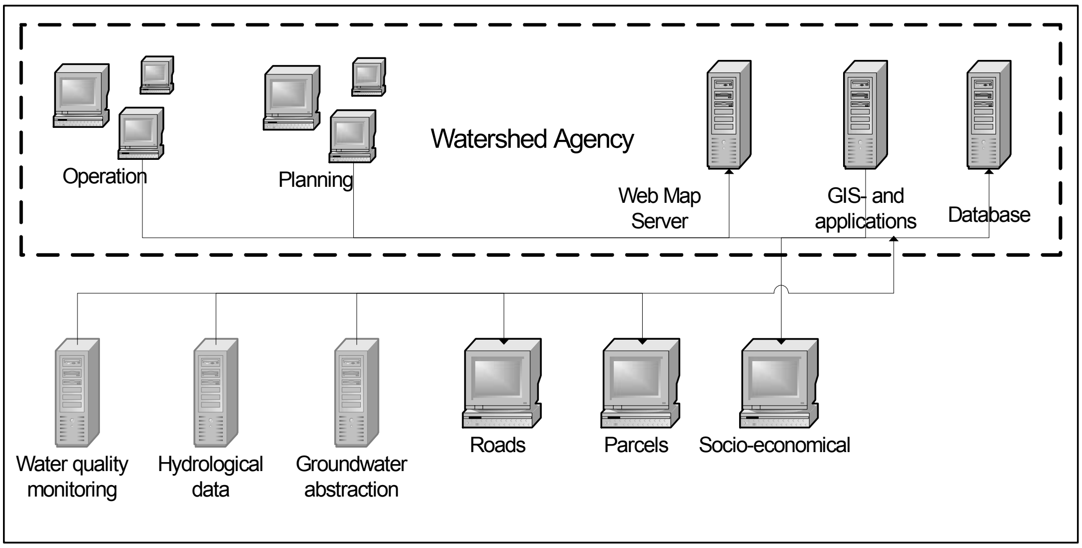
River basin agencies construction, operation and maintenance obligations, like abstraction and impoundment control, control of direct discharge into water bodies, taxation, prevention of flood and accidental pollution, surveillance and monitoring of water quality require a system capable to access and manage information from innumerous sources. Access and provision of information between stakeholders depend on technological and organizational factors, like the capability to interpret the data (semantic interpretation), data quality, scale and time dependence of key processes, network and computer infrastructure and agreement on data use. One of the most significant challenges of integrated water resource management is the information integration.

2 River Basin Information System

The information technology has experienced enormous progress during the last years, being widely applied in the field of water management. The advances in this area bridged the gap between computational scientists and water specialists, permitting the development of more efficient information systems. The object oriented technology and the quasi-standard unified modeling language (UML) enhanced the communication between water and computer experts during the model analysis and design processes, leading to more reliable, extensible and interoperable models and products.

A river basin information system relies upon diverse fields of the information technology like database management systems, geographical information systems, numerical simulation, geostatistics, expert systems, neural networks and decision support systems. A river basin information system supports decision makers and water experts in the planning, operation, evaluation, monitoring and reporting tasks of the river basin management system. Planning tasks requires hydrological, environmental, and socio-economical data, data on water abstraction, release and quality, land use and infrastructure.

Geographical Information Systems (GIS) and database management systems are part of a river basin information system. GIS supports the collection, storage, analysis and presentation of spatial and non-spatial data. It allows multidisciplinary spatial analysis, including socio-economical, ecological and hydrological analysis. Extended data models provide integration of geospatial and temporal data describing surface water hydrology and water infrastructure management. Diverse GIS products are



integrated to commercial database management systems.

Fig. 1: Schematic representation of interoperable water information systems

A further feature of a river basin information systems is the integration of GIS and computer simulation models to solve water specific problems. These include water allocation, groundwater flow and transport, runoff, erosion, reservoir operation, water quality, irrigation and drainage. The single-objective, single-purpose, and single-facility project approach to solve water resources allocation problems that was common in many water planning agencies in the developed countries in the past has gradually been replaced by multi-objective, multipurpose, and multi-facility solutions at the river basin level (McKinney, 1999). The data retrieve for water models and its integration with GIS required for planning (including resource allocation), operation and maintenance may be implemented from lose coupling of ascii files through import and export methods, to tight coupling of databases through the definition of an appropriate data model, to distributed computed platforms like J2EE, COM or CORBA. The results of a simulation model are used as parameter for another model in an integrated environment. The data necessary for simulation –material properties, boundary conditions, initial conditions and constraints are better defined in a geographical information system, based on the properties of the concerned area, then in the numerical models as properties of finite elements or finite volumes. In an integrated modelling environment the user is primary concerned with the description of a physical problem and not with the preparation of a numerical simulation, making modelling more natural, appealing and reliable. Adaptive methods for finite elements, i.e. the optimization of the finite element meshes, retrieve their parameters from the GIS-model in which its embedded (Roehrig, 1998). The attribute enhancement in a GIS model using inverse methods, i.e. an optimization problem to determine material properties starting from numerical solutions, show that data transfer between GIS and numerical simulation is a two-way process.

Decision Support Systems (DSS) are responsible for interoperability, embedding simulation models and GIS to analyse different measures through scenario development. DSS are used in river basin management to predict ecological consequences of water activities and land use changes, as well as an instrument for the development of environmental goals for different ecosystems (Kofalk et al, 2001). Database, interface, and model connection illustrate the major advantages of using a GIS and decision support systems (spatial decision support systems) for river basin management (McKinney, 1999).

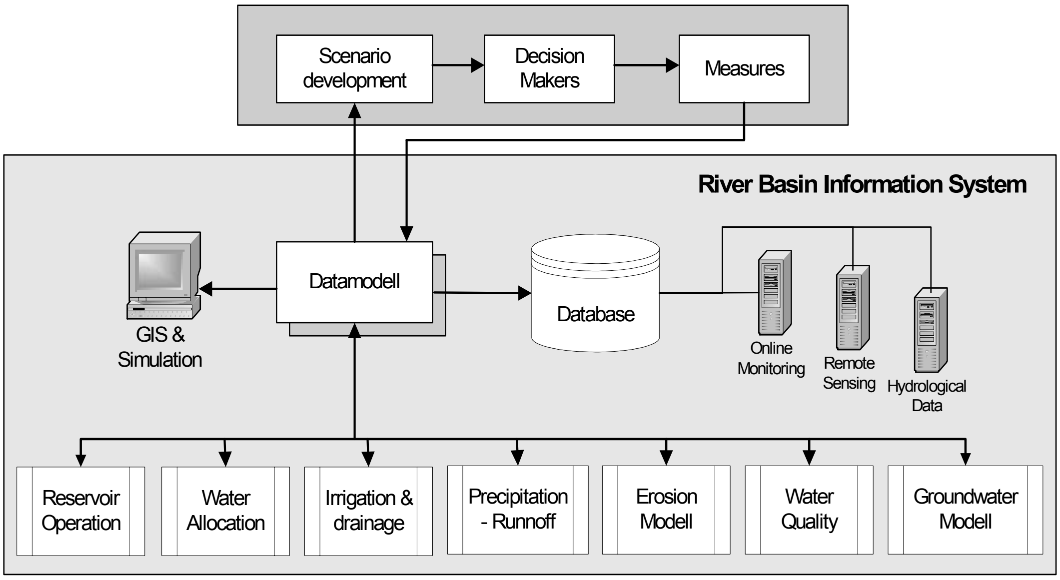


Fig. 2: Schematic representation of model interfaces

3 Interoperability

Information systems require considerable investments to create and maintain spatio-temporal data. Sharing data between users from different institutions helps to return the investments for data providers and to sink the costs for data consumers. Joint projects to share data costs help to improve the data quality and avoid data redundancy. Integration of data and services makes GIS more attractive and facilitates its understanding and usage.

The different proprietary formats of GIS products makes the investment sharing for data acquisition and maintenance difficult. The widely used import and export functions are error-prone and cumbersome due to a small automation grade. Information losses caused by data conversion can occur through geometrical approximations or omission of part of the original data, like topological information or metadata description. Specially the exclusion of metadata compromises the data quality control.

Interoperability enhancement is a response to the benefits of data sharing. It is the capacity to communicate, execute programs, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units (ISO 2382-1). Geographical interoperability is the ability of information systems to a) freely exchange all kinds of spatial information about the earth and about the objects and phenomena on, above, and below its surface, and b) cooperatively run software capable of manipulating information over networks (OGC, 2002).

Diverse initiatives are being conduced to provide geospatial infrastructures, permitting the access and integration of data, like the Open GIS Consortium (OGIS) and the International Organization for Standardization's Technical Committee on Geographic Information/ Geomatics (ISO TC/211). The objective of OGC is the full integration of geospatial data and geoprocessing resources into mainstream computing and the widespread use of interoperable, commercial geoprocessing software throughout the information infrastructure (Buehler and McKee, 1996). An example of geospatial infrastructure on regional level is the GDI (Geospatial Data Infrastructure North Rhine-Westphalia), created in 2000 with the goal of developing the market for geographic information in the German federal state of North Rhine-Westphalia. This will be achieved by connecting the value chains of users, service providers, service enablers, integrators, data producers, and infrastructure providers (Brox, 2000). The operative coordination of GDI is accomplished by CeGI - Center for Geoinformation GmbH (CeGI, 2002), an initiative supported by the German federal state of North Rhine-Westphalia to coordinate actions between the public and private sector, acting as a competence centre to improve the geospatial infrastructures in North Rhine-Westphalia.

The Open GIS Consortium specification *OpenGIS Service Architecture* and the ISO/DIS 19119 provide a framework to develop interoperable systems to access and process geographical information (OGIS, 2002). In this context the service is that functionalities are provided by interfaces. The fundament of this specification is the standardization of interfaces according to the undergoing approaches in the field of information technology, like the *Reference Model of Open Distributed Processing* (ISO/IEC 10746). The Open Distributed Processing is based on message oriented services, service chaining and service metadata (computational viewpoint), mechanisms for distribution, distribution transparencies, supporting services such as security and persistence (engineering viewpoint) and infrastructure that allows the components of a distributed system to interoperate (technology viewpoint).

Interorganizational aspects of data and service sharing have received less attention than technological issues, although considering only technological problems is unlike to permit a successful data and service sharing. The interorganizational context refers to the organizational factors and interdependencies that influence coordination and decisions about joint GIS and database activities (Nedovic-Bodic and Pinto, 1999). Interorganizational systems and databases are manifestations of the interorganizational relationships (Kumar and Dissel, 1996) and model of government (Westin, 1991).

There are many institutional barriers to overcome in order to dispose of the benefits of data and services sharing (Nedovic-Budic and Pinto, 1999; Campbell and Masser, 1995; Citera et al, 1995, Al-Romaithi, 1994). These barriers include a) political acceptance and legal agreement to exploit public data commercially or not, including accessibility of public data by public institutions or the private sector; b) ideological barriers, vertical governmental structures; c) dependence on external data, loss of monopoly, autonomy and control over information; d) different interests and priorities between data providers and users, including access reliability, data quality, level of awareness and spatial data handling skills. Developing countries are in many cases consolidating economies and democracies, where sectors like water are considerably dominated by nepotism and political influence, creating difficulties to the implementation of information access programs. The motivation to share data reflects not only infrastructural and technological advances, but also more transparent and participatory government information politics. Transparency and involvement are also important requirements for river basin management.

Interoperability standards lack specifications related to interorganizational aspects. Interorganizational aspects are concerned with the purpose, scope and policies of an enterprise or business and how they relate to the specified system or service. The interorganizational context has a strong influence on the sharing practices and interoperability requirements. Financial and organizational efforts necessary to the improvement of interoperability can pose insurmountable obstacles, specially for developing countries. Technical problems leading to a limited interoperability include network bandwidth, computing infrastructure, reliable power supply and expertise. The investments necessary to overcome these limitations and to implement river basin information systems based on interoperable information systems may be prohibitive when compared to the budget designated to accomplish the basic measures provided for the river basin management plan.

The interorganizational context of river basin management is usually formalized through law regulations and legitimated through stakeholder participation, contributing to reduce resistances against data sharing and facilitating the establishment of interoperability policies. Solving interorganizational problems of the information interoperability between stakeholders may contribute significantly to consolidate the operation of the river basin agency and to implement the measures provided for river management plans. Information interoperability provides the fundament to coordinate the actions between agency, water users, government and public. This applies specially to new river basin agencies in developing countries. The inherent interorganizational difficulties encountered during the formation of an agency are comparable to those encountered in the development of interoperable river basin information systems, as for example insufficient staff and technical resources, institutional disincentives, historical and ideological barriers, power disparities, differing risk perception (Citera et al, 1995), staff turnover (Sperling, 1995), different priorities between participants, agreement over access to information and leadership (Campbell and Masser, 1995).

Few comprehensive efforts have been attempted to implement geographical interoperability standards for river basin information systems. One successful example of interoperability is the pilot project of the city council of Wuppertal (Germany) and the river basin agency Wupperverband, one of the 11 river basin agencies in North Rhine-Westphalia created at the beginning of the 20th century. The land survey office of the city council provide e.g. parcel data to the river basin association for planning and operation purposes. Wupperverband provides water related GIS-data to the city council for approval requirements also involving other sectors (Sander, 2002). Both institutions use different GIS platforms, and the data sharing technology is based on the OGC standard *Web Map Server (*OGIS, 2000).

4 Conclusions

Information interoperability is part of the river basin interoperability in a broader sense. Overcoming the difficulties to implement information interoperability is a fundamental step forward to consolidate a river basin management system. This involves analysis of information flow, access agreements and restrictions, access directions (one direction or both), data access rights and data provision obligations. The discussion on data transfer offers an opportunity to (re)evaluate the business process of the participants of an integrated river basin management system and to improve underlying data models. Defining information interoperability enhances the stakeholders involvement and formalizes management actions, reducing the complexity of the implementation of the river basin management system.

The scope of the OGIS service architecture can be extended beyond GIS interoperability and comprise other components of a river basin information system in a framework for open distributed processing. Simulation and optimization models are in this context service provisions or combinations of services through service chaining. Interoperability specifications like *OpenGIS Service Architecture, OpenGIS Feature Geometry* (OGIS, 2001), *OpenGIS Web Map Server Interface* (OGIS, 2000) and *OpenGIS Features* (OGIS, 1999) can provide a framework to develop interoperable decision support systems for river basin management.

GIS-interoperability can contribute significantly to implement a river basin management system, helping to overcome institutional barriers and enhancing the legitimating of water agencies through stakeholder involvement.

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URBAN WATER RETENTION BY GREENED ROOFS IN TEMPERATE AND TROPICAL CLIMATE

Manfred Köhler (1), Marco Schmidt (2), Friedrich W. Grimme (3), Michael Laar (3), Fernando Gusmão (4)

e-mail: www.manfred.koehler@fh-nb.de

Institutions

(1) University of Applied Sciences Neubrandenburg, Dep. of Landscape Architecture and Environmental Planning, Germany

(2) Technical University of Berlin, Institute of Landscape Development, Dep. of Applied Hydrology, Germany

(3) University of Applied Sciences Cologne, Institute of Technology in the Tropics, Germany

(4) CEFET, Rio de Janeiro, Brazil

Abstract

The authors of this paper are working on the ecological effects of greened roofs. What are the ecological functions of plants growing on roofs? Are there any benefits for the inhabitants of cities?

Urbanisation is increasing worldwide. As more and more urban areas are paved over, precipitation increasingly runs off directly into surface waters. This does not only change the flow of the waters but also increases the level of nutrients and contaminants led into them. By greening roofs it is possible to reduce such environmental impacts. Green roofs contribute as well to a better microclimate through evapotranspiration, filtering off dust from the air and decreasing temperatures at the rooftop and in the surrounding area.

This team's aim of cooperation is to transfer knowledge of greened roofs of Central Europe to the tropics. This project is supported by DAAD (Germany) and CAPES (Brazil) since 2000. Long-term studies in Germany have pointed out water retention by greened roofs. Nowadays, water retention is one important aspect of modern ecological architecture. Retaining rainwater has a lot of further positive effects in the cities of Central Europe, i.e. to improve the urban climate. The above-mentioned scientific group pointed out some first results based on these European studies for tropical countries.

Keywords: greened roofs, evapotranspiration, Brazil, water retention, ecological architecture

Image 1: Intensively Greened Roof in the City of Rio (MEC), designed by Burle Marx in the 1940s

1 Introduction

Green roofs have a long tradition. The "hanging gardens" of Semiramis are one famous example. One has to distinguish extensively and intensively greened roofs. Intensively greened roofs, also called roof-gardens, can sometimes be found on representative buildings to add additional space (3). The roof-gardens of Roberto Burle Marx are one example. In order to build roof gardens special structural prerequisites are necessary. Roof gardens can then be developed with a high variety in gardening to create a high-quality green space as shown in image 1, the Ministry of Education and Culture (MEC) in Rio de Janeiro.

Extensively greened roofs are different from roof gardens. They have just a thin layer of soil, usually up to approximately 10 cm (~3“), adding an extra weight of water saturated approximately 100 kg/m². Extensively greened roofs only require little maintenance during the first years, after which they develop without additional care. Depending on the regional climate, only dryness-adapted and robust plants can survive. In 1753 the Swedish botanist Carl von Linné already assigned to some plants in his "Species plantarum" the species name "tectorum" as they grow on walls and roofs spontaneously. These species are a good selection to be used on extensively greened roofs. A typical extensively greened roof was created in 1984 on a common apartment house in Berlin, being the reference-object of the authors (14).

Ecologists, landscape architects and technicians have spent more than 20 years developing guidelines for extensively greened roofs regarding ecological, planning and technical aspects. Meanwhile, a number of standards exist in Germany, for example for waterproof roof sealing layers, the selection of substrate, the choice of plants etc. (see www.FLL.de). It is now safe and easy for architects to include green roofs in their design because they can offer the same lifespan as conventional tile roofs. In Germany, companies give a guarantee of 30 years on their green roofs. Nowadays, the extensively greened roof is technically equal to the conventional tile roof while offering ecological advantages.

Essential Advantages of Extensively Greened Roofs

Besides technical advantages, a green roof offers open-space-planning and ecological advantages. An overview of these effects is shown in the following literature (see 7-17). Prerequisites are sufficient building structures. Taking that into consideration, a green roof has the following aesthetic preferences and positive aspects on the protection of species compared to conventional bitumen- or tile roofs:

Longer life and longer maintenance-intervals (19) show that in spite of higher construction costs the green roof will be less expensive after 40 years.

Appealing view from the adjoining houses. This aspect has not been taken into account financially until now.

Additional habitats for birds in the city; in Germany, rare birds can find new habitats on big green roofs that they would otherwise not have in the city.

Rare and specialized plants find refuge on green roofs.

Regarding ecology and water, related further aspects are of importance:

10 cm of substrate showed an evapotranspiration of 90% of the summer precipitation and 75% of the annual precipitation.

The evapotranspiration of precipitation lowers the surface-temperature of the building and improves the microclimate of the open space.

Roof-greening decreases the runoff during storm water periods, reducing the times of sewage system overflow which leads to untreated sewage finding its way directly into the surface waters.

The last points have been research subjects of different working groups all over Germany for approximately two decades. Some essential results regarding water retention are firstly published in this essay. A general overview has already been given by the Association of Landscape Construction (5).

The effect of lowering the surface temperatures of buildings is getting more and more important for regions in warm climates, e.g. in Southern Europe. In tropical regions with higher annual rainfalls and higher evaporation rates this effect might be more important than in Europe. The summer data of water retention in Central Europe is used as a data base in this article.

Urban ecology was developed in Germany as a scientific topic with high priority, especially before the removal of the Berlin wall. Numerous scientific understandings resulted from these works and from the efforts of other research groups. The annual floods of the rivers Rhine, Moselle and Main show that there should be a high priority for decentralized measures to retain rainwater. Nowadays, a charge is raised in many German cities for the diversion of the precipitation into the sewage system. One sealed square meter costs about 1 Euro per year - an important monetary motivation to green roofs as owners can save this charge. Today, 7% of newly constructed flat roofs in Germany are already greened ones.

Green roofs are one element of ecological and sustainable building. Following the Agenda 21-process roof-greening is a simple technology which has however big effects. By combining green roofs with roof-terraces valuable urban space can be gained in the center of our cities with its widely sealed surfaces. The combination of greened roofs with photovoltaic panels, like demonstrated at the UFA-Fabric in Berlin-Tempelhof-Schöneberg (www.ufafabrik.de) leads to a modern system that combines the generation of energy and the protection of the urban environment against the negative effects of sealed surfaces (see image 2).

2 Measurements

Methods

Research on the retention potential of extensively greened roofs was started by the authors in 1985. At first, the weekly runoff was collected from permanent plots of approximately 1 m² each at the project "Englische Straße" in Berlin-Charlottenburg in comparison with the precipitation. This construction showed an annual retention rate of 75% of the entire precipitation as a median value of three years. The results were published in (9, 12). During the summer the retention increased to more than 90%. This value is applied to Berlin with a relation of precipitation to potential evapotranspiration of 550 to 650 mm.

More detailed measurements over 3 minutes take place at the plots of 2 m² each at the Institute of Landscape Development. These investigations are aiming at detecting the water movement in the soil/ substrate to prove positive aspects in the decrease of the runoff-intensity and the runoff-delay.

The latest steps have been measurements on complete roofs, one at the cultural centre "UFA-Fabrik" in Berlin Tempelhof and one at the University of Neubrandenburg of 360 m² each. These examinations show the relation between evapotranspiration and the water content in the soil before a new precipitation. The target is to transfer the measured parameters into a simulation in order to cover long time-periods and to gain a better understanding of the saturated and unsaturated soil water movement in thin substrate layers. The measurements of these installations serve simultaneously as a model for measurements as they were proposed for new locations, i.e. in Rio de Janeiro.

Results

Year	Precipitation	Runoff	Runoff	pot. ETP	measured ETP	Cooling
	[mm]	[mm]	[%]	[mm]	[mm]	[kWh/(m²*a)]
1987	702	179	25.5	641	523	356
1988	595	157	26.4	696	437	298
1989	468	98	20.9	750	370	252

Tab. 1: Precipitation, Runoff, potential and measured Evapotranspiration and Evaporation Cooling of Greened Roofs

Image 2: Extensively Greened Roof in Combination with Photovoltaic Panels, UFA, Berlin

Image 3: Open Runoff System in the City of Rio – Maracana

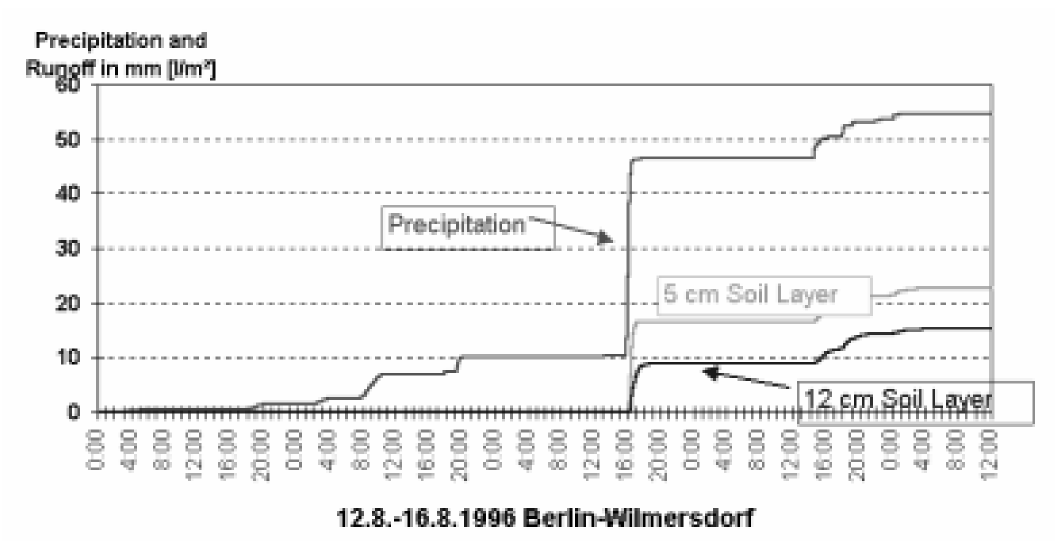

Fig.1: Reduction of Rain Runoff on Extensively Greened Roofs

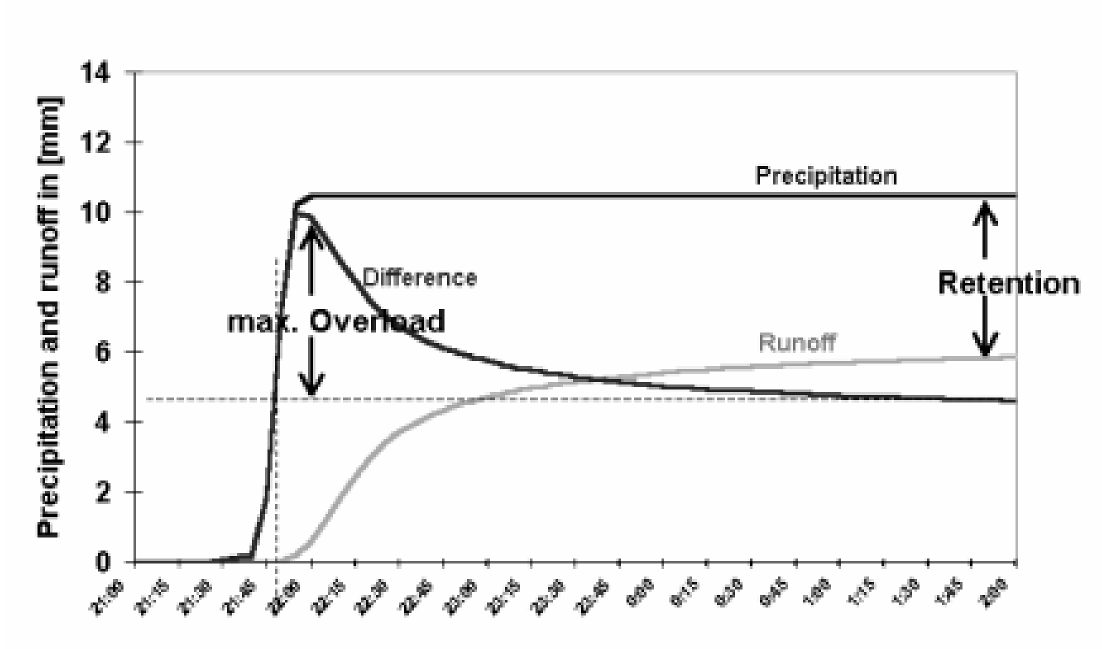

Fig. 2: Water Retention and Drain Delay of Greened Roofs compared with Flat Bitumen Roofs

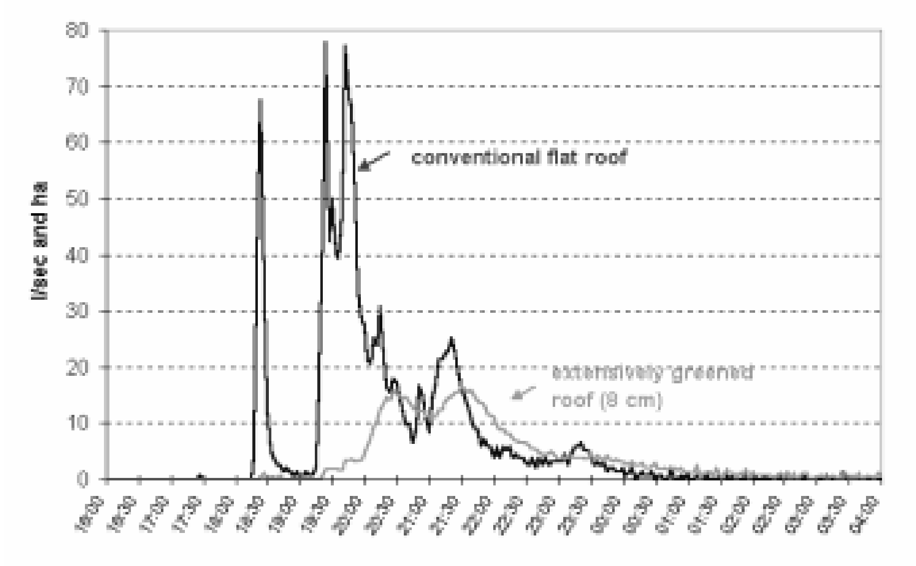

Fig. 3: Measured Precipitation and Runoff 21.5.97, UFA-Fabrik Berlin-Tempelhof (2)

Fig. 1 shows exemplarily the reduction of rain-runoff on extensively greened roofs. The first results, given by the measurements on small greened plots, show an enormous reduction of the runoff due to evapotranspiration of the vegetation and the substrate. The value up to 75% of the annual precipitation is applied to Berlin with a relation of precipitation to potential evaporation with 550 to 650 mm (see Tab. 1 and 2).

The first measurements on small greened plots showed a different retention rate compared to the latest measurements on real greened roofs. Especially during storm water events the big greened roofs have shown a much higher retention rate than expected. The runoff was reduced to 10% of the precipitation intensity (see Fig. 2). This aspect has a high influence on the size of sewage systems.

Storm water, in particular, can overload the mixed sewerage systems, leading to untreated sewage finding its way directly into the surface waters. Separated sewerage systems have a negative environmental impact such as inundations of streets, basements and whole parts of the city.

The reduction of the runoff intensity is applied to the storage capacity of the soil, especially the temporarily storage capacity above the field capacity. In this example the maximum overload as the difference between the precipitation and the runoff was about 6 mm (see Fig. 3). The absolute maximum overload registered in 2 years was 15 mm.

1997	Precipitation [mm]	Runoff [mm]	Precipitation/ Runoff -ratio
Jan	8,1	7,0	0,86
Feb	58,5	55,8	0,95
Mar	22,6	6,4	0,28
Apr	33,1	6,2	0,19
May	75,9	29,8	0,39
Jun	41,6	2,5	0,06
Jul	84,0	38,3	0,46
Aug	37,4	20,0*	0.53*
Sep	8,9	0*	0*
Oct	33,7	1,6	0,05
Nov	18,1	15,0	0.83*
Dec	73,8	58,7	0,80
Sum/ mean	495,7	221.3*	0.49*

1998	Precipitation [mm]	Runoff [mm]	Precipitation/ Runoff -ratio
Jan	54,8	54,5	0,99
Feb	12,9	5,4	0,42
Mrz	62,6	61,0	0,97
Apr	31,8	4,1	0,13
Mai	24,5	0,4	0,02
Jun	91,8	25,4	0,28
Jul	60,5	23,5	0,39
Aug	63,2	17,7	0,28
Sep	53,2	29,4	0,55
Okt	76,1	35,0*	0.46*
Nov	20,2	15,0*	0.74*
Dez	39,9	24,4	0,61
Sum/ mean	591,5	245.8*	0.50*

Tab. 2: Monthly and Annual Rain and Green Roof Drain Values for the Year 1997 and 1998 [2]

3 Conclusions

Until now only a few greened roofs have been investigated scientifically. Further research is necessary concerning the annual change of the precipitation/ runoff-ratio and different types of soil and vegetation. The retention rate differs from the local conditions regarding the relation and distribution between precipitation and potential evaporation.

A second essential parameter for the precipitation/ runoff-ratio is the storage capacity (field capacity) of the soil/ substrate and the vegetation. At the demonstration roofs a field capacity of 10-30% was measured, at 10 cm of substrate the calculated storage capacity is until 30 mm, that means 5% of the annual precipitation.

As long as urbanization continues as in recent years, decentralized strategies and measures will be taken against the environmental impacts of paving. Greening roofs and facades are two possibilities. Other decentralized measures are rainwater-reuse-systems, partly unsealed surfaces and active infiltration systems. The Administration of Berlin, the Senate of City Development, has started projects in cooperation with the Technical University to combine these measures to completely substitute the rainwater sewerage system.

4 Application of Green Roofs in the Hot and Humid Tropics – Case Study Rio de Janeiro

There are some striking differences in the parameters to be observed in the tropics:

a) The storm water events are much more common in the hot and humid tropics compared with temperate climates. What is considered as a hundred-year-event in temperate climates is an annual event in the tropics (see table 3). This has several consequences for its application in the tropics:

- Erosion on freshly implemented green roofs has to be avoided.
- Quicker saturation of the substrate has to be considered.
- Higher temperatures throughout the year, a 12-months vegetation period

b) The gain of biomass is higher (especially when urban air pollutants via rain water fertilize the roof): that might complicate the drainage function of the substrate, but will presumably increase the retention rate of the roof due to the larger surface of the plants.

c) The roof might become a habitat for dangerous animals, principally insects like mosquitoes (dengue, malaria, yellow fever etc.). A careful check of possible plants has to be carried out. Bromelias, for example, should be avoided to open water retention capacity.

- The evaporation rate is higher, evapotranspiration works all year long.

Station	mm/hour	Date	Hour
Campo Grande	116.2	19/03/2000	00:08
Grajaú	90.3	16/02/2000	23:01
Sumaré	81.3	02/04/1998	23:49
Tanque	78.3	09/01/1997	18:42
Tijuca	78.2	17/02/1998	15:15
Vidigal	72.5	15/12/1998	17:43
Cachambi	72.4	28/03/2001	22:17
Tijuca	71.5	07/01/1998	19:00
Anchieta	71.0	28/03/2001	21:23
Madureira	71.0	31/01/1997	19:17

Table 3: The 10 heaviest rainfalls in different parts of Rio de Janeiro/ Brazil from 1997 until March 2001 [4]

At the moment, 5 prototypes of roofs are under construction in Rio de Janeiro. 4 of them are green roofs, 1 is a blank reference roof. The green roofs vary in the thickness and the composition of the substrate. Possible plants are being tested under extensive conditions since October 2000. First results are being published in Brazil during ENCAC 2001 [22].

5 Aspects for City-Planning in the Hot and Humid Tropics

Flooding and water erosion can be especially vehement under hot and humid tropical conditions. In Rio de Janeiro, like in other Brazilian cities, these problems are commonplace, causing death and destruction regularly [4, 5]. There are mainly two reasons for that: first, the frequent and violent storm water events and second, the high soil-sealing rate of urban areas. Even huge sewer and canalization systems are overloaded by the peak storm water load. The average of the 10 biggest storm water events from 1997 to 2001 (see table 3) is 80,3 mm. The green roof can be considered as a very welcomed possibility to cut the peak load: using porous substrate and calculating with a retention rate of at least 0.8, a significant cut of the peak load is to be expected. Regarding results of several German studies [2, 6, 15, 21], the temporarily retention rate during storm water events was always at least 90% of the precipitation intensity. This value applies to the overload of the soil layer (see 2.3), theoretically up to the absolute pore space of the soil with ~75% (at 10 cm of soil layer up to 75 mm).

The annual retention rate for Germany is 50-75% of the total precipitation. This value differs depending on local conditions from the relation and the distribution between precipitation and evaporation (see 2.2). In tropical climates the absolute evapotranspiration of greened roofs is comparatively higher. An annual retention rate of probably 65% (about 900 mm [=l/m²]) of the precipitation is expected for Rio.

The analysis of aerial photography of the Maracanã district in Rio de Janeiro, where the research project is located, shows a sealing rate of approximately 80%. The area has a size of 142 ha [16]. A district of similar density in Berlin has a potential for extensively greened roofs of 20% of the total surface [1]. Considering an annual evapotranspiration of 900 mm one can expect a retention of around 1800 m³/ ha. This value is applied to a cooling of the inner city climates of 6 Mio kWh per ha and year (see table 1).

6 Final Conclusion

Roof-greening means more than just another type of surface of buildings. The scientific work gives a better understanding of the situation and influence of urbanization on the local water and energy cycles and of the change of the habitat function. Also aspects like the retention of pollutants are arguments for the greening of roofs.The research on the effects of greened roofs in temperate climates is far developed and has already found applications in urban relations. Specialized firms in Central Europe already carry out thousands of square meters annually, guaranteeing a quality and longevity comparable or even better than conventional roofs. Research on this topic is only beginning in the tropics. The theoretical considerations show a huge potential for this technology. Now this consideration has to be proved practically. The cooperation project between Germany and Brazil is a first and important step toward it.

7 Biographies

Manfred Köhler, Prof. Dr., Landscape Architect BDLA. Since 1981 several long term studies of urban ecology, especially plants in contact to buildings and their ecological effects. Professor of Landscape Ecology since 1994

Marco Schmidt, Dipl.-Ing., Master in Landscape Planning. Studies on urban water cycles, rainwater management and ecological functions of urban surfaces

Friedrich Wilhelm Grimme, Prof. Dr.-Ing.; Several studies all over the world in the area of bio-climatic architecture

Michael Laar, Dr.-Ing., Architect, M. Eng.; Main topic of work: the bio-climatic architecture in the tropics.

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9 Links

www.FLL.de (State of the art in many topics of landscaping techniques, advice for architects and owners) www.tu-berlin.de/~Wasserhaushalt (further information and links)

www.fh-nb.de/lu/manfred.koehler.html (homepage with further information and links)

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