Integrated Concepts for Reuse of Upgraded Wastewater

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Work package 7

Deliverable D17

Water treatment options in reuse systems

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WORK PACKAGE 7
WATER TREATMENT OPTIONS

DELIVERABLE D17
WATER TREATMENT OPTIONS IN REUSE SYSTEMS

DELIVERABLE RESPONSIBLE

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SUMMARY

Europe has a long history in water management in general and more specifically in the “small water cycle”; the treatment and distribution of drinking water and the collection and treatment of wastewater are well developed practices. However, the recycling of treated wastewater has not been widely applied in most European countries. But due to the increasing need for protection of water resources, the growing environmental awareness and the public inclination to sustainability the pressure on water recycling is gradually increasing.

Therefore, in 2003 the Aquarec project sponsored by the European Commission under the Fifth Framework Programme was started. The general target of the Aquarec project is the development of ‘integrated concepts for reuse of upgraded wastewater’; with special focus on the European Countries. To reach this target the project was divided in 8 workpackages; 3 on the strategic level (WP1-3), 3 on the management level (WP4-6) and 2 on the technological level (WP 7&8). In this report the research in WP7 is published. The objective of WP7 is the definition of wastewater treatment options in reuse systems, with focus on reuse of municipal wastewater.

Treatment matrix

One of the key elements in the Aquarec project is the development of a water treatment matrix in which wastewater treatment process schemes are categorized as a function of the raw wastewater quality and the reuse application. Starting point for building a water treatment matrix is the definition of thinkable reuse applications; municipal wastewater can be reused for an industrial, a domestic (household/irrigation), a natural, and an agricultural purpose. These reuse options require different kind of water qualities. The different water qualities can be reached by using of specific levels of treatment. Next step in the development of the treatment matrix is the construction of treatment trains or schemes. With the different primary, secondary and tertiary unit process operations numerous different treatment trains can be constructed.

To limit the number of treatment trains in the matrix, a selection has to be made. From basic considerations a set of logical limitations can be deducted.

- Primary treatment level
    - Many processes can lead to comparable process results; so not all primary processes should be evaluated further.
    - Processes based on the solubilization of constituents have to be followed by biological secondary processes.
    - Total removal of particles can be realised by (a combination of) primary processes.
- Secondary treatment level
    - Biological processes can handle effectively the dissolved organic constituents (soluble COD).
    - Many biological processes lead to comparable results.

  - Nitrogen can be removed almost completely by application of nitrification/denitrification.
  - Advanced particle removal in the primary treatment step only gives limited advantages in the secondary step.
  - Removal of BOD, COD, N and P, if necessary, should be preferably done in the secondary treatment step.
  - Membrane bioreactors include some of the tertiary or advanced processes.
- Advanced treatment level
  - Porous media filtration is a common step for pretreatment when other tertiary processes are applied.
  - Advanced treatment processes are very specific for certain components.
- All processes
  - The sludge produced in the primary and secondary processes requires further and extensive treatment.

The next step, after the reduction of the number of treatment schemes, is the construction of the Reuse Matrix. This Reuse Matrix greatly depends on the existing wastewater treatment infrastructure and the possible applications. So it is a very specific instrument that can vary from case tot case.

Typical or standard schemes

The EU directives discharge limits should be the starting point for further treatment of municipal wastewater for reuse. Many countries will indeed strive to meet these standards in the near future. Therefore effluent will be the main primary source for wastewater reclamation in the short term. On the opposite, schemes alternative to the traditional chain can be a feasible option only in the long term. Based on this conclusion a set of typical or standard schemes was developed. These schemes have their own strength, are related to specific reuse applications and are mostly represented by many examples in practice. Without excluding any other possibilities these schemes seem to be representative for the majority of the possibilities in the reuse matrix. Shortly these schemes are:

standard or typical scheme	reuse application
Conventional wastewater treatment, including P- and N-removal, followed by:	
Dual media filtration and disinfection (UV or chlorine)	urban applications, green landscaping, industrial reuse
Double membrane filtration (MF/UF + RO) and disinfection (UV)	high quality applications: industrial, households, etc.
Chlorination	irrigation under restricted conditions
Soil aquifer treatment (SAT)	unrestricted irrigation (e.g. Israel)
(Constructed) Wetlands	nature conservation, agriculture
Lagoons or Pond systems, occasionally followed by chlorination	(very) restricted irrigation
Local Membrane BioReactor (MBR)	small scale treatment with reuse in the direct neighbourhood (toilet flush water)

Each of the standard schemes is illustrated by one or more case studies.

Innovating technologies

On the long term, schemes alternative to the traditional chain (i.e. secondary treatment including nutrient removal) can become feasible options. One of the innovating technologies is Direct Membrane Filtration of raw wastewater. This is a purely physical process by which particles (including micro organisms) are removed from the wastewater by membrane filtration (UF). To remove large particles from the wastewater simple pre-treatments such as screening, sedimentation or DAF can be applied. The effluent of this process is particle free water rich in dissolved components (among other things nutrients). Other innovating technologies are advanced oxidation processes like ultrasound, fenton and photocatalysis

Innovating technologies become more and more important since the awareness for the presence in water of components like endocrine disrupters, heavy metals, pesticides, personal care products, etc. is increasing. Traditional treatment processes are not fit for the removal of these components.

CONTENTS

1 INTRODUCTION 9

2 TREATMENT MATRIX 11

2.1 Introduction 11

2.2 Global matrix 11

2.3 Selection of standard treatment trains 12

3 STANDARD TREATMENT SCHEMES FOR WASTEWATER REUSE 14

3.1 Introduction 14

3.2 Typical or standard schemes 14

3.3 Case studies...16

3.3.1 Introduction 16

3.3.2 Effluent filtration... 17

3.3.3 High quality / double membrane 29

3.3.4 Only disinfection 39

3.3.5 Local MBR 48

3.3.6 Soil aquifer treatment 58

3.3.7 Wetlands.. 90

3.3.8 Pond systems 109

4 INNOVATIVE TECHNOLOGIES.. 116

4.1 Introduction 116

4.2 Approach 116

4.3 Innovating Technologies 118

4.3.1 Direct Membrane Filtration.. 118

4.3.2 Advanced oxidation processes 124

4.4 Non-standard parameters.. 131

4.4.1 Introduction 131

4.4.2 Presence of non-standard parameters in wwtp-effluent........... 137

4.5 Removal of non-standard parameters 140

4.5.1 Conventional water and wastewater treatment 141

4.5.2 Advanced methods of treatment 144

5 REFERENCES 149

6 ANNEXES 161

6.1 Global wastewater treatment matrix 161

6.2 Development of indirect potable reuse in impacted of the United States..164

1 INTRODUCTION

Europe has a long history in water management in general and more specifically in the "small water cycle"; the treatment and distribution of drinking water and the collection and treatment of wastewater are well developed practices. However, the recycling of treated wastewater has not been widely applied in most European countries. But due to the increasing need for protection of water resources, the growing environmental awareness and the public inclination to sustainability the pressure on water recycling is gradually increasing.

Therefore, in 2003 the Aquarec project sponsored by the European Commission under the Fifth Framework Programme was started. The general target of the Aquarec project is the development of 'integrated concepts for reuse of upgraded wastewater'; with special focus on the European Countries. To reach this target the project was divided in 8 workpackages; 3 on the strategic level (WP1-3), 3 on the management level (WP4-6) and 2 on the technological level (WP 7&8):

WP1:	Analysis of European water and supply & demand
WP2:	Definition of key objectives for water reuse concepts
WP3:	Development of integrated water reuse strategies
WP4:	Development of analysis tools for social, economical and ecological effects of water reuse
WP5:	Methodologies for public acceptance studies and consultation
WP6:	Management guidelines for the implementation and operation of water reuse cycles
WP7:	Characterisation and assessment of technology in water reuse cycles
WP8:	Development and validation of system design principles for water reuse systems

This report is the result of the research in workpackage 7, one of the workpackages on the technological level. The objective of workpackage 7 was the definition of wastewater treatment options in reuse systems, with focus on reuse of municipal wastewater.

The approach in workpackage 7 was as follows:

- First all available and applicable (waste)water treatment unit process operations were described. These descriptions were published in a separate internal report.
- Secondly a water treatment matrix was developed. In this matrix wastewater treatment process schemes are categorized as a function of the raw wastewater quality and the reuse application and are further characterised with respect to costs, operational critical control points and environmental aspects.
- To limit the number of treatment schemes that has to be considered, in the third step standard or typical treatment schemes were indentified. Subsequently all standard or typical treatment schemes were illustrated with the description of at least one existing full-scale or pilot-scale treatment plant (case studies).

The descriptions of unit process operations as well as the descriptions of existing plants have served as input for workpackage 8.

Discharge standards for effluent will become more and more stringent in the future and furthermore the awareness for the presence in water of components like endocrine disrupters, heavy metals, pesticides, personal care products, etc. (so called non-standard parameters) is increasing. Both factors will lead to higher requirements for the wastewater treatment processes. Therefore innovative water treatment processes and the removal of the non-standard parameters are also part of the research in workpackage 7.

The partners in workpackage 7 were:

- Delft University of Technology, section of Sanitary Engineering, Netherlands (work package leader)
- University of Barcelona, Department de Productes Naturals Biologica Vegetal i Edafologia, Spain
- University of Wollongong, Faculty of Engineering, Australia
- Centre for Research and Technology Hellas, Chemical Process Engineering Research Institute, Greece
- Aquafin NV – Water Body of Flanders, Belgium

In chapter 2 the water treatment matrix in developed. The selection and describtion of the standard or typical wastewater treatment schemes (case studies) can be found in chapter 3. The innovative technologies and the removal of non-standard parameters are the subjects of chapter 4.

In annex 6.2 a report regarding the "development of indirect potable reuse in impacted areas of the United States" can be found. This report gives additional and useful information to the case studies in chapter 3.

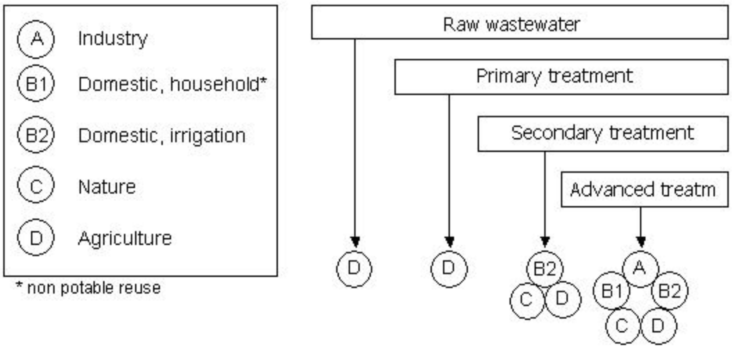
2 TREATMENT MATRIX

2.1 Introduction

One of the key elements in the Aquarec project is the development of a water treatment matrix in which wastewater treatment process schemes are categorized as a function of the raw wastewater quality and the reuse application.

The starting point for building a water treatment matrix is the definition of the conceivable reuse applications. Municipal wastewater can be reused for industrial, domestic (household/irrigation), natural and agricultural purposes. These reuse options require different kind of water qualities which can be achieved by using of specific levels of treatment (see Figure 2.1). In most situations, a series of treatment processes is needed to achieve the required water quality for reuse.

Figure 2.1 Reuse aims with their corresponding levels of treatment.



As a first step all realistic processes involved in these treatment schemes were described and investigated. Special attention is given to the efficiency of removing constituents to meet the water quality for various reuse applications. A clear distinction has been made between primary, secondary and advanced treatment processes, which include both conventional and innovative options. Detailed information is provided in the Aquarec report “D6: Review report on wastewater treatment unit operations”; the review of processes is mainly based on recent literature.

The treatment matrix is also an input for WP 8. In this workpackage the matrix is one of the approaches for constructing a full treatment scheme in the design and simulation software tool.

2.2 Global matrix

With the different primary, secondary and tertiary treatment processes numerous different treatment trains or schemes can be constructed. The possibilities of reuse greatly depend on the requirements set up for the various applications.

In fact, for each reuse application, there are a large number of possible combinations of treatment processes to meet the water quality requirements.

In WP 8 the reuse options have been defined somewhat different from what was presented in Figure 2.1:

- Industry (A)
- Potable (A / B1+)
- Urban (B1 & B2)
- Groundwater recharge (B1 (direct) or B2 (indirect))
- Environmental and recreational (B2 & C)
- Agricultural (D)

In annex 6.1 an outline of the global wastewater treatment matrix is given. In this matrix all conceivable treatment schemes are mentioned.

2.3 Selection of standard treatment trains

The matrix in annex 6.1 is not very simple for the user of a design and simulation software tool. Therefore a selection has to be made among the schemes leading to the Reuse Matrix with standard treatment trains.

From basic considerations a set of logical limitations can be deducted.

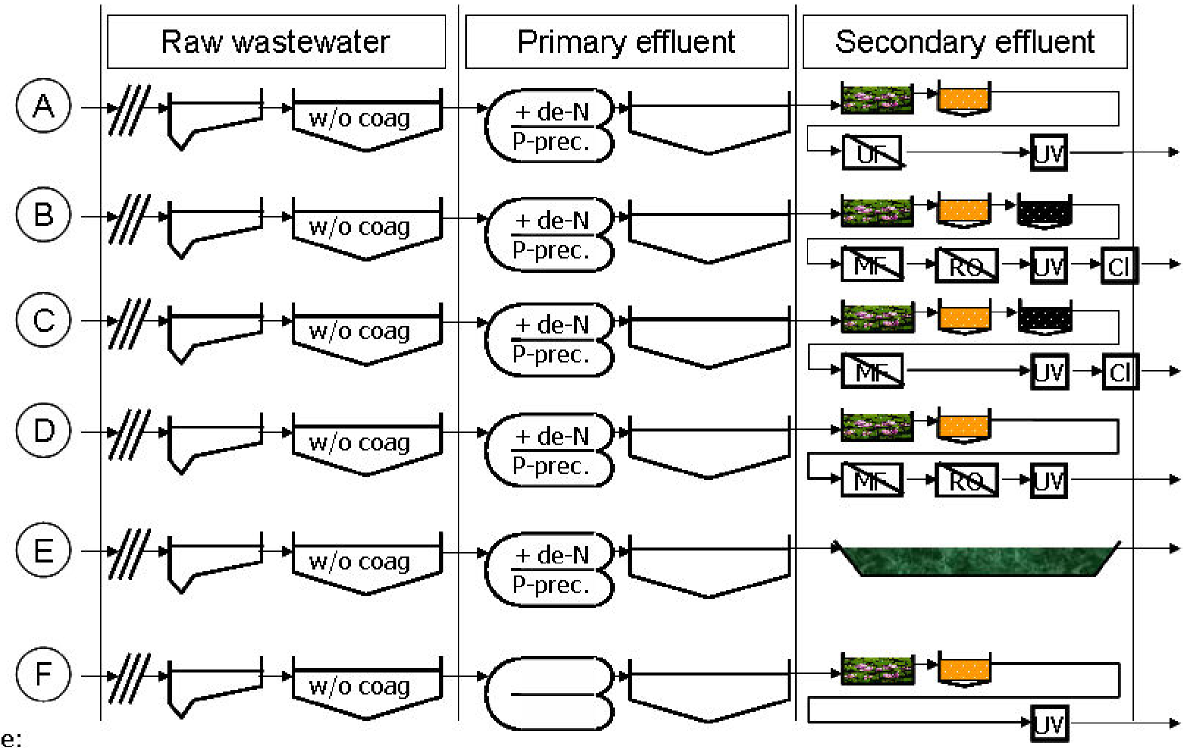
- Primary treatment level
    - Many processes can lead to comparable process results; so not all primary processes should be evaluated further.
    - Processes based on the solubilization of constituents have to be followed by biological secondary processes.
    - Total removal of particles can be realised by (a combination of) primary processes.
- Secondary treatment level
    - Biological processes can handle effectively the dissolved organic constituents (soluble COD).
    - Many biological processes lead to comparable results.
    - Nitrogen can be removed almost completely by application of nitrification/denitrification.
    - Advanced particle removal in the primary treatment step only gives limited advantages in the secondary step.
    - Removal of BOD, COD, N and P, if necessary, should be preferably done in the secondary treatment step.
    - Membrane bioreactors include some of the tertiary processes.
- Advanced treatment level
    - Porous media filtration is a common step for pretreatment when other tertiary processes are applied.
    - Advanced treatment processes are very specific for certain components.

- As to all processes
  - The sludge produced in the primary and secondary processes requires further and extensive treatment.

The next step, after building the treatment schemes, is the construction of the Reuse Matrix. This Reuse Matrix greatly depends on the existing wastewater treatment infrastructure and the possible applications. So it is a very specific instrument that can vary from case tot case.

An example of the Reuse Matrix is given in Figure 2.2.

Figure 2.2 An example of the Reuse Matrix



Reuse:
A: Industry, B: Potable, C: Urban, D: Groundwater recharge, E: Environmental and recreational, F: Agriculture

w/o coag = primary sedimentation without coagulation
+de-N P-prec. = secondary treatment with denitrification and P-precipitation

🟩 = constructed wetland ▽ = maturation pond 🟧 = sand filter ⬛ = activated carbon filter

3 STANDARD TREATMENT SCHEMES FOR WASTEWATER REUSE

3.1 Introduction

In the process of collecting information and comparing different treatment schemes, some observations have been made which are highlighted below.

1. The actual knowledge on municipal wastewater treatment is definitely well consolidated upto and including secondary treatment which includes biological and physical/chemical nutrients removal. Processes and schemes are well known and planning and management are reliable, whether physical-chemicals or biological treatments are involved. These processes can provide a satisfactory effluent quality for parameters such as BOD, COD, SS, N, P, which are still the basis of the EU standards for effluent discharge. Nevertheless, in some cases, the actual wastewater treatment plants need upgrades and renewals in order to satisfy the new directives.
2. The treatment of the effluent of secondary treatment is accomplished through more advanced techniques. Nowadays, rapid filtration and disinfection are regarded as traditional and common in practice, while other processes such as membrane filtration are applied less frequently. What makes the advanced treatment ‘different’ is the specificity of the treatment, which has to be calibrated based on the water quality requirements. As such preliminary experimentation becomes of major importance for good planning as each and every case is unique.
3. The EU directives discharge limits should be the starting point for further treatment for municipal wastewater for reuse. Many countries will indeed strive to meet these standards in the near future. Therefore effluent will be the main primary source for wastewater reclamation in the short term. On the opposite, schemes alternative to the traditional chain can be a feasible option only in the long term.

3.2 Typical or standard schemes

Based on the previous matrix and comments, a set of typical or standard schemes was developed. These schemes have their own strength, are related to specific reuse applications and are mostly represented by many examples in practice.

Without excluding any other possibilities these schemes seem to be representative for the majority of the possibilities in the Reuse Matrix. Shortly these schemes are:

Effluent filtration

Conventional wastewater treatment, including P- and N-removal, followed by dual media filtration and disinfection by UV or chlorine. The reuse varies from urban applications, green landscaping to industrial usage. This concept exists as standard in the USA.

High quality / double membrane

Conventional wastewater treatment, including P- and N-removal, followed by double membrane filtration (MF or UF followed by RO) and final disinfection by UV; eventually other processes such as advanced oxidation and activated carbon adsorption can also be applied. The treated water is of such a high quality that many applications (industrial, households, etc.) are possible. Examples of this concept are Water Factory 21, Sydney Olympic park and Torreele (Belgium).

Only disinfection

Conventional wastewater treatment, followed by chlorination, enables the reuse of the treated water for irrigation under restricted conditions. Many examples are available all over Europe.

Local Membrane BioReactor (MBR)

Small scale treatment of (part of the) wastewater using a package MBR system with reuse of the water in the direct neighbourhood (as toilet flush water). Typical solution for Japanese office buildings which is introduced in some Europeans sites now.

Soil aquifer treatment

Conventional wastewater treatment, including P- and N-removal, followed by infiltration through large ground areas; the extracted water can be reused for unrestricted irrigation. Examples are present in the Mediterranean region (e.g. Israel).

Wetlands

Conventional wastewater treatment, including P- and N-removal, followed by constructed wetlands as a natural polishing step. The treated effluent can be reused for nature conservation or agriculture. Applications are present in Northern Europe (Netherlands) as well as Southern Europe (Spain).

Lagoons or Pond systems

Treatment of wastewater by lagoons (several types in series), occasionally followed by chlorination; reuse of the effluent only for (very) restricted irrigation. This is typical application for Mediterranean countries with moderate treatment facilities.

Direct membrane filtration

Micro- or ultrafiltration of raw wastewater followed by agricultural applications. It is a new concept, which is investigated in several places (Netherlands, China, Israel).

At least one case study will be highlighted in the following section to illustrate each of the standard schemes, except for "direct membrane filtration". Direct membrane filtration is a new concept and dealt with in Chapter 4.

3.3 Case studies

3.3.1 Introduction

As stated before each typical scheme is illustrated by one or more case studies which are presented in the section. The case studies are:

- Effluent filtration:
    - Chalkida wastewater treatment plant (Greece)
    - Northen Shoalhaven reclaimed water management scheme (New South Wales, Australia)
- High quality / double membrane:
    - Wastewater reclamation facility Torreele (Belgium)
    - Combined municipal wastewater – stromwater recovery at Sydney Olympic Park (Australia)
- Only disinfection:
    - Water reclamation facility with ozone treatment (anonymous)
    - Palamos site research: Wastewater disinfection (Spain)
- Local MBR:
    - Wastewater reclamation based on MBR technology in Fulton County (Georgia, USA)
- Soil aquifer treatment:
    - The Dan region system (Israel)
    - Reclaimed water ASR at Bolivar (South Australia)
    - Infiltration – Percolation at Greater Agadir (Morocco)
    - Direct injection at Fred Hervey (California, USA)
    - Direct injection at WF21 and the groundwater replenishment system (California, USA)
- Constructed wetlands:
    - Wastewater treatment plant Els Hostalets de Pierola (Spain)
    - Constructed wetlands in Besòs River Bed (Catalonia, Spain)
    - Waterharmonica (Netherlands)
- Pond systems:
    - Waste stabilization pond system in Arad (Israel)

3.3.2 Effluent filtration

3.3.2.1 CHALKIDA WASTEWATER TREATMENT PLANT (GREECE)

Introduction

The Waste Water Treatment Plant (WWTP) in Chalkida in operation since September 1986 is the second unit of its kind in Greece (the 1st was built in Metamorphosi, Attica). It was constructed in two phases; the 1st phase begun in 1984 and finished in 1986. It could serve 25,000 PE. The 2nd phase begun in 1989 and upon completion in 1994, its capacity was increased to 75,000 PE. The treated flow is 12,500 m^3/day. Table 3.1 shows the total flow rate of effluents treated in the WWTP during the period 2001-2003.

Table 3.1: Secondary and Tertiary Flow Rate

Year	Total Flow rate (m^3/yr)	Tertiary Flow rate (m^3/yr)	Ratio (%)
2003	3,457,210	120,269*	3.5
2002	3,524,890	112,458	3.2
2001	4,244,460	91,366	2.15

* Current usage; design capacity 4,000 m^3/day (~ 1,460,000 m^3 / yr).

The present work is focussed on the environmental upgrading and the aesthetic improvement of the city of Chalkida, which will be achieved by the planting vegetation on the hills around the city and using upgraded effluent from the Chalkida WWTP for irrigation. The benefits of the application of the reused effluents are as follows:

- Remarkable increase in the domestic flora and fauna and favorable microclimate change.
- Aesthetic improvement of the scenery around Chalkida.
- The best possible water resources management.
- Possibility of utilizing the replanted area for outdoor activities.

The capital investment of the expansion of the main plant – the tertiary unit – was 700,000,000 dinars (app. 2.1 M€), which was mainly financed by the EU programme ''Environment''.

Description of the WWT plant

The WWTP in Chalkida consists of 4 main parts:

1. Primary treatment
    - *Screening*
    - *Grit removal, Degreasing*
    - *Pre-aeration*
    - *Flow equalization* (tank capacity 2,500 m^3 for regular effluents, 870 m^3 for heavily polluted ones)
    - *Addition of coagulants and primary settling* (2 cylindrical tanks, d = 22 m, V = 1,018 m^3)
2. Secondary treatment

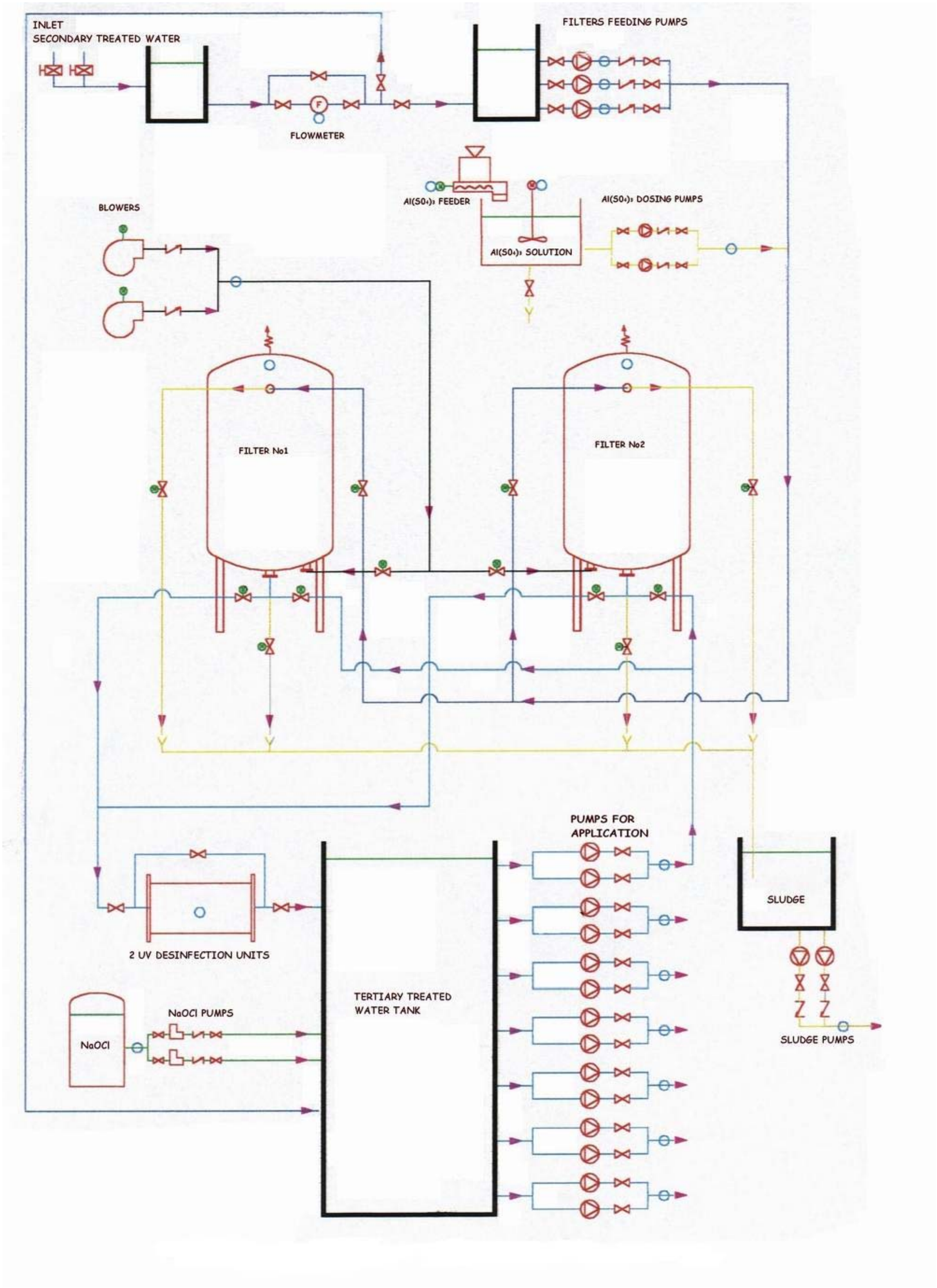
   - *Aeration - Activated sludge treatment.* Carrousel-type activated sludge bioreactors with 3 vertical aerators each and volume 1,600 m^3. Each aeration tank is preceded by a 200m^3 anaerobic treatment tank. Bioreactor parameters: loading 0.15-0.20 F/M and 4,000 mg/l MLSS.
   - *Secondary settling* (2 cylindrical tanks, d = 22 m, V = 1,018 m^3)

3. Tertiary (advanced) treatment
   - *Coagulation* (using alum)
   - *Filtration* (2 filters, Q = 100 m^3/h each)
   - *UV Disinfection*
   - *Chlorination*
4. Sludge treatment
   - *Sludge thickening*: 2 cylindrical vessels (V = 275 m^3)
   - *Sludge digestion*: Primary digestion (for 15-20 days) in two vessels (V = 900 m^3) at 35° C; then sludge is transferred to secondary digestion vessel (500 m^3). The produced methane gas is partly used to heat the digesters and the remaining part is burnt.
   - *Sludge dewatering*: Carried out after addition of poly-electrolytes and filtration using a belt-type filter-press of capacity 20 $m^{3/}$h. The product's dry solids content is ~25%.

Tertiary (Advanced) Treatment

A simplified flow sheet of the advanced treatment plant is given below in Figure 3.1.

Figure 3.1: Advanced treatment at WWTP Chalkida



The secondary treatment effluent is pumped to the filters. Addition of $Al_2(SO_4)_3$ solution (by dosimetric pumps into the transfer line feeding the filters) is necessary in order to improve the phosphorous removal throughout the process. Coagulant concentration greater than 70 mg/lit helps the satisfactory plant (filter) performance with regard to the reduction of Suspended Solids and micro organisms. Table 3.2 shows the characteristic parameters of the raw (input) and the secondary -treatment effluents. Table 3.3 gives the standards for tertiary-treated effluents to be reused. The advanced treatment plant has met these criteria. Typical results of fecal coliform reduction between the stages of tertiary treatment are shown in Table 3.4.

Table 3.2: Typical parameters of raw (input) and secondary-treatment effluents

		Municipal (main input)	Intermittent Input*	Secondary output	National standards
pH	-	-	-	7.5	-
COD	mg/l	450	2850	54	150
SS	mg/l	250	1700	12	40
BOD-5	mg/l	250	1400	9	40
N-NH4	mg/l	45	126	6.6	15
N-NO3	mg/l	2	2	5.5	20
P-PO4	mg/l	12	22	4	5

* heavily polluted, transported by tank-cars /vans

Table 3.3: Criteria of unrestricted use of tertiary-treatment effluents of Chalkida WWTP

	Limits
Suspended Solids (SS)	<10 mg/l
Fecal Coli	<2.2/100 ml (50% of samples)
Fecal Coli	<12/100 ml (80% of samples)
Residual Chlorine	0.5 mg/l
Turbidity	<2 NTU

Table 3.4: Reduction of fecal coliforms between the stages of tertiary-treatment

	F.C. (cfu/100mL)
Secondary effluent	60000-100000
Filter effluent (at alum dose > 50ppm)	2000-3000
UV effluent	8-45
Chlorinated effluent	0

The ***effluent filtration*** is carried out with two filters, with a capacity of 100 m^3/hr each. There is a capability for future installation and use of a third filter. The present filters are conventional downflow, backwashable, multilayered filters, with total depth 5.65 m and diameter 2.54 m. The effluent filtration is achieved using two types of materials:

- Anthracite, grain diameter 1.4 – 2.5 mm
- Sand, diameter 0.7 – 1.25 mm

The support layer of the filters is made up of a layer of gravel, approximately 200 mm high. Two pumps (maximum flow rate 150 m^3/hr) supply the water for backwashing. This washing water is then collected at the pumping station and pumped back to the main treatment unit.

Following the filtration unit is the ***UV disinfection*** unit. There are two sub-units: the first unit is a *closed-type*, operating with UV dose of 55 mWs/m^2 and the second one is a *channel-type* using UV dose of 65 mWs/m^2. UV radiation at 254 nm is employed.

The effluents exiting the disinfection unit enter, by gravity, the chlorination unit where the final disinfection is achieved using a solution of sodium hypochlorite (conc: 14% in chlorine). The chlorine dosage is 20 l/h. The treated water is stored in a 200 m^3 tank and twelve pumps are employed to pump the treated water to the distribution network.

The whole process is computer controlled with an electronic system consisting of two PLCs, a PC with the software SCADA for remote-control of all the data collected by the PLCs and a mimic diagram for the visual supervision of the plant.

Energy Consumption

Table 3.5 presents the energy consumption in both the advanced and the secondary treatment phase.

Table 3.5: Energy consumption in KWh/ 1000 m^3 treated sewage

Year	Advanced treatment	Secondary treatment
2003	610	466
2002	674	468
2001	881	376

Tertiary-treatment effluent reuse

A design study which has not been fully implemented yet, foresees two main effluent reuse applications. They are as follows:

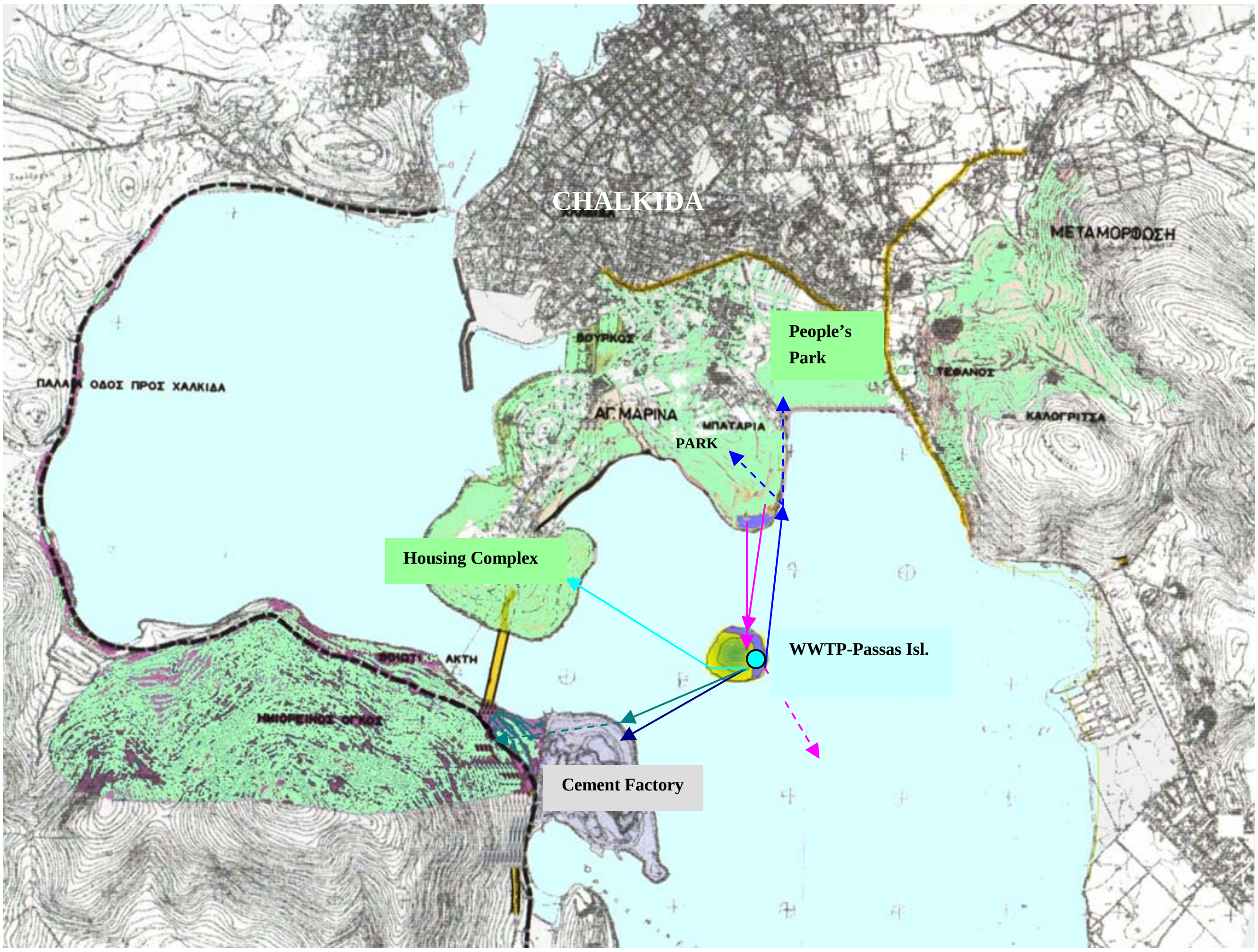
- Irrigation (parks, trees) (~ 2,500 m^3 /day)

- Parks outside city of Chalkida
- At a housing complex
- At Boiotia beach
- Industrial usage (~ 1,500 m^3 /day)
- Cement factory

Pipelines connect the WWT plant (which is located on the small Passas island) to the sites where effluents are reused. The locations of these sites are indicated on the map of Figure 3.2.

At present only the pipeline to a *housing complex* is in operation and has a flow rate of approx. 350 m^3/ day.

Figure 3.2: Chalkida wastewater treatment plant - Location of tertiary-treatment effluent reuse



LEGEND

1 → Untreated effluent pipelines, to WWTP.

2 ⇢ Pipeline for treated effluent disposal.

Tertiary- treatment effluents :

3 → Pipeline to parks

4 → Pipeline to Cement factory

5 → Pipeline to Boiotia Beach

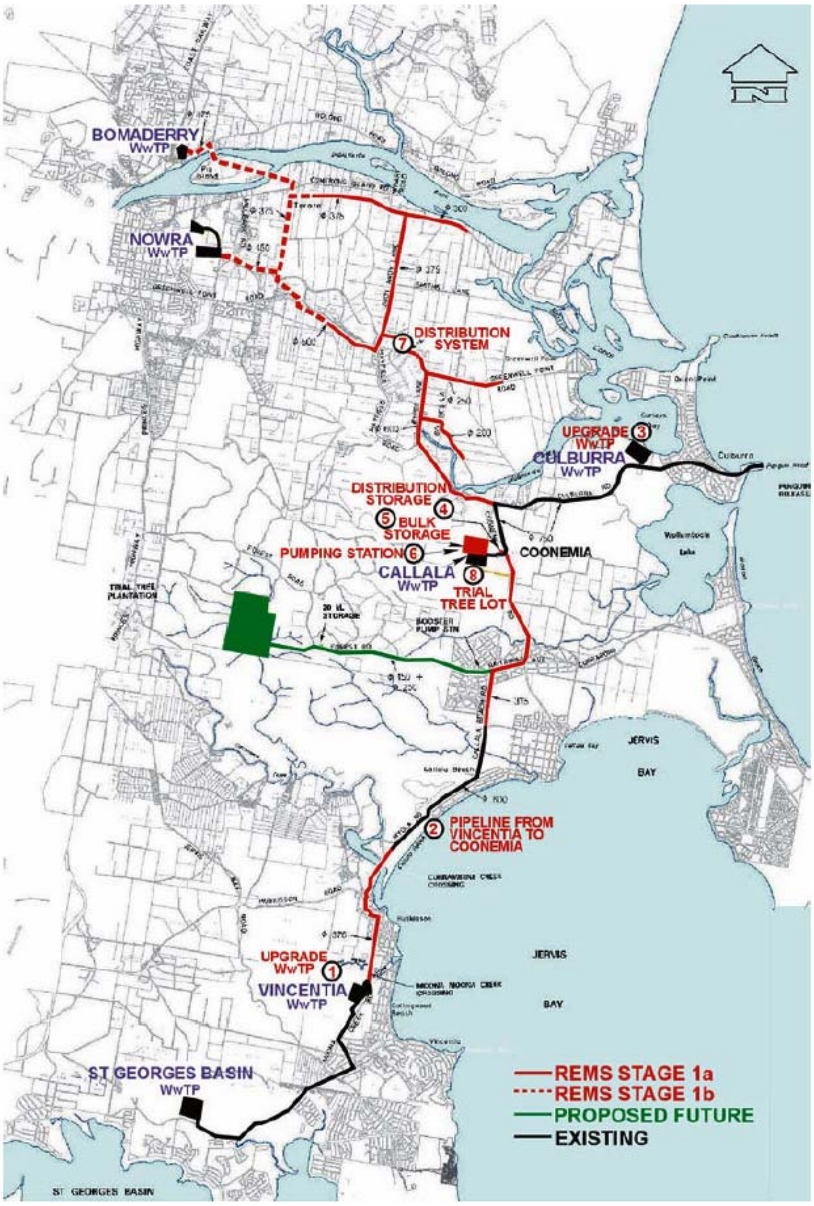
6 → Pipeline to housing district

3.3.2.2 Northern Shoalhaven Reclaimed Water Management Scheme (New South Wales, Australia)

Introduction

The Northern Shoalhaven Reclaimed Water Management Scheme (REMS) has been developed to reuse about 80% of the water reclaimed at six municipal WWTPs at the South Coast of New South Wales, Australia. The plants are namely Bombaderry, Nowra, Culburra, Callala, Vincentia, and St. Georges Basin. Reclaimed water is predominantly reused for irrigation purposes on dairy farms, golf courses and recreation fields. The water is also used for dairy yard wash down. An overview on the scheme is given in Figure 3.3.

Figure 3.3: Overview on the Shoalhaven Reclaimed Water Management Scheme [www.shoalhavenwater.nsw.gv.au]



The scheme was commissioned in 2000, supplying water to an irrigation area of 370 ha. WWTPs in St. Georges Basin, Vincentia, Callala and Culbarra provide the reclaimed water which is distributed through a net with seven pumping stations and 74 km of pipeline. A major component is also a 650 ML storage reservoir in Callala to ensure a stable supply over the year. In its final stage about 58,000 people will be connected to the integrated WWTPs. Further stages of the implementation will add more irrigation area (e.g. 380 ha farm land) to the scheme. Ultimately up to 1,200 ha of land will be irrigated under the scheme.

Anticipated benefits of the scheme, which provided the justification for the implementation which worth almost 65 million AUS$ in the final stage, included decreased effluent discharge into Jervis Bay, the Shoalhaven River and to the Pacific Ocean in Pengiun Head. These measures were driven by community interest to protect the sensitive environment and the recreational areas, as the whole areas belongs to prime wildlife and nature reserves with a huge attractiveness for visitors and tourists. Moreover, the long-term sustainability of the local dairy farms and other agricultural industries should be promoted. The scheme has also a role in the regional development as the cost effective provision of sub-potable quality water source can support the development of other rural industries.

The wastewater treatment plants in the scheme have been upgraded to tertiary treatment with filtration of biologically treated effluent and disinfection. The total output of the scheme was 5,400 ML/year in 2001 and will in increase to 7,900 ML/year by 2016. Surplus effluent which cannot be reused in some seasons will be discharged through an ocean outfall (Moore *et al.*, 2002).

Wastewater reuse scheme

Influent wastewater criteria of reuse plant

The Callala WWTP is taken as an example to describe the treatment technology and the water quality features of the scheme. The influent concentrations of the main water quality parameters are indicated in Table 3.6 for different sampling campaigns.

Table 3.6: Influent concentrations of Callala WWTP [Shoalhaven Water]

Concentration	SS [mg/L]	BOD_5 [mg/L]	NH_4-N [mg/L]	TN [mg/L]	TP [mg/L]	TDS [mg/L]	Thermotol. Col. Bacteria [CFU/100mL]
June 2002	156	125	42	52	8	448	75,000
December 2002	215	290	51	54	12	392	1,700,000
December 2003	236	278	39	55	12	388	6,200,000
December 2004	270	366	58	64	17	472	600,000
Average	**219**	**265**	**48**	**56**	**12**	**425**	**2,143,750**

Description of wastewater treatment

The WWTPs within the REMS scheme are low loaded activated sludge systems composed by oxidation ponds with surface aerators followed by sand filtration stage and disinfection with chlorine gas. Phosphorus removal is not a prime objective because of the agricultural application. The WWTP is operated by Shoalhaven Water – a Division of the Shoalhaven City Council. The WWTPs have a nominal capacity of 53,000 PE (2001). In 2016 the WWTPs will serve 78,000 PE.

- Design flow rate: 600 m³/d (Callala Sewerage Scheme)
- Reuse purpose: Irrigation (dairy farm pasture, golf courses, recreational areas)
- Classification within standard reuse trains: Title 22

The composition of the Callala wastewater treatment and water reclamation facility is given in Table 3.7.

Table 3.7: Composition of the water reclamation facility [Shoalhaven Water]

Treatment stage	Description
Preliminary treatment	Fine screen grit arrester, flow equalising,
Biological treatment	Intermittently Decanted Extended Aeration Tank (IDEA)
Phosphor removal	Alum dosing into the biological stage
Sludge treatment	Excess sludge storage, stabilisation and thickening in lagoons
Intermediate storage	IDEA effluent is stored in lagoons for flow equalisation (further fine screening and alum dosing possible)
Tertiary treatment	Pressure sand filters
Disinfection	Chlorine gas

Figure 3.4 depicts a view on the tertiary sand filter units and storage reservoirs of the Callala treatment plant.

Figure 3.4: Callala WWTP Plant and Storage Reservoir [Shoalhaven Water]

Design and measured water quality

The design water quality levels for the Callala WWTP are given in Table 3.8.

Table 3.8: Design effluent concentrations of Callala WWTP [Shoalhaven Water]

	BOD$_5$ [mg/L]	NH-N$_4$ [mg/L]	TN [mg/L]	TP [mg/L]	FC [CFU/100 mL]
Concentration	15	5	15	1	200

Effluent criteria and water quality data

The standards applicable for the reclaimed water utilized for pasture and golf course irrigation are given in Table 3.9.

Table 3.9: WWTP Effluent standards for water reuse (yearly averages)

	BOD$_5$	COD	SS	TN	TP	TDS	Faecal col.
Concentration standards [mg/L]	<10		<15	<15	<10	<700	<200/100mL

Results obtained and different sampling periods with respect to the quality of the tertiary effluent are given in Table 3.10 and Table 3.11.

Table 3.10: Effluent results of WWTPs: Test Result [Shoalhaven Water]

Concentration	SS [mg/L]	BOD$_5$ [mg/L]	NH$_4$-N [mg/L]	TN [mg/L]	TP [mg/L]	TDS [mg/L]	Thermotol. Col. Bacteria [CFU/100mL]
June 2002	2	1	0.1	2.6	1.7	396	400
December 2002	6	1	0.12	1.4	1.2	224	450
December 2003	22	6	0.16	3.8	5.5	304	170
December 2004	1	2	0.05	1.7	4.8	248	12
Average	**7.8**	**2.5**	**0.11**	**2.8**	**3.3**	**293**	**258**

Table 3.11: Water from reclamation scheme in distribution system (average)

Parameter	Concentration	Parameter	Concentration
Faecal coliforms	<1-120 CFU/mL (7.4)	Manganese	<0.001-0.005 ppm (0.003)
pH	7.0 – 9.2 (7.6)	Copper	<0.05 ppm
Conductivity	815-1,200 µS/cm (957)	Zinc	<0.005-0.01 ppm (0.008)
Chloride	131-320 ppm (172)	Boron	0.07-<0.1 ppm (0.08)
Sulphate	45-142 ppm (13)	Fluoride	0.64-0.8 ppm (0.69)
Magnesium	9-18 ppm (13)	Chromium	<0.001 ppm
Sodium	102-164 ppm (134)	Molybdenum	<0.005 ppm
Total hardness	112-134 ppm (122)	Nickel	<0.01 ppm
Total dissolved solids	448-648 ppm (528)	Lead	<0.005 ppm
Iron	<0,002 ppm	Total PAHs	<0.0005-0.007 ppm (0.001)

Design criteria

Table 3.12 gives an overview on the key figures of the Shoalhaven Reclaimed Water Management Scheme and illustrates the different development steps REMS 1a and 1b with their respect impacts on the size of the scheme.

The development and design of the scheme was and is built on a strong community involvement. An extensive community consultation programme was conducted to raise public awareness and assess the acceptance of land-based application of reclaimed water for purposes such as agricultural irrigation. Through a process of "Stakeholder liason", different interest groups and individuals were involved in the decision making process. Potential users of the reclaimed water were identified and informed about water reuse options and practices. This end-user liason led to a full (even over)subscription of the reclaimed water use in the first stage. Although the region does generally experience moderate to high rainfall, the investment in irrigation equipment paid off for the users in the recent drought periods.

The suitability of the reclaimed water application was assessed on basis of the soil salinity and water allocation rates were agreed with the different users.

Table 3.12: REMS Facts

	2001	2006
Population connected	53,000	78,600
Wastewater treatment plants	4	6 (2005)
Effluent produced [ML/year]	5,400	7,900
Bulk Storage [ML]	600	1,500
Irrigation area (Ha)	360	1,000
Capital Cost (M AUS$)	30.9	42.5

The applied irrigation displays a huge benefit for the farmers and the rural community as such. The reclaimed water application enables a top up of the natural rainfall to achieve a better adaptation to the seasonal evapotranspiration pattern. A accompanying farm monitoring programme revealed that the productivity of the irrigated land is significantly higher than the non-irrigated, allowing higher stocking rates (+19%), pasture utilisation (+33%) and specific milk production (+22%).

Requirements

Chemical requirement for the wastewater treatment and reclamation process are given in Table 3.13.

Table 3.13: Chemicals used in the REMS

Product	Dosed to	Range (mg/l)	Comment
Alum	Primary and secondary effluent		P-removal and coagulation
Chlorine	Tertiary effluent	0.05-0.22	Disinfection and Bio-fouling prevention

Monitoring:

Effluent water quality, regional groundwater, rivers, ocean releases, and irrigation areas are regularly monitored.

Environmental impact of complete reuse scheme

Effect on groundwater

Prior to the implementation of the scheme, water table heights and salinity levels have been monitored. Areas with high water tables or high levels of salinity will not be irrigated.

Both groundwater levels and groundwater quality is monitored at 11 observation wells and the results are compared to the pre-irrigation situation. So far, no significant changes in the groundwater levels could be detected and the water quality data showed only a few “excessions” in terms of nitrogen and phosphorous parameters but could not be confirmed (Shoalhaven Water, 2004a).

Effect on the coastal environment

The potential effect of the ocean discharge of treated effluents has been assessed by a dye test, which demonstrated the high dilution of the released water already close to the discharge point. At a distance of 140m from the discharge point, only 1% of the original concentration can be detected. Also different ecological indicators have been investigated to monitor the impact of the temporary discharge on the aquatic environment.

There was not detectable impact on the bathing water quality at the beaches and the overall nutrient levels discharged into the ocean are significantly lower than in the original situation. The study of ocean ecology included the intertidal zone fauna and flora, bioaccumulation in invertebrates as well as nutrient accumulation in macro-algae. The results indicated no organochlorins in the tissues of invertebrates, no elevated level of phosphorous in algae compared to the control and only slightly higher nitrogen isotope levels in algae close to the discharge point (Shoalhaven Water, 2004b).

Cost statements

Construction

The implementation of the scheme had a total cost volume of 30.9 M AUS$ in the first stage.

The Shoalhaven Reclaimed Water Management Scheme can be regarded as a best practice example in terms of participative planning of a water reuse scheme, including an holistic assessment of the environmental and economic impact, the design and operation of an appropriate technical infrastructure and an ongoing end-user guidance and effect monitoring scheme.

3.3.3 High quality / double membrane

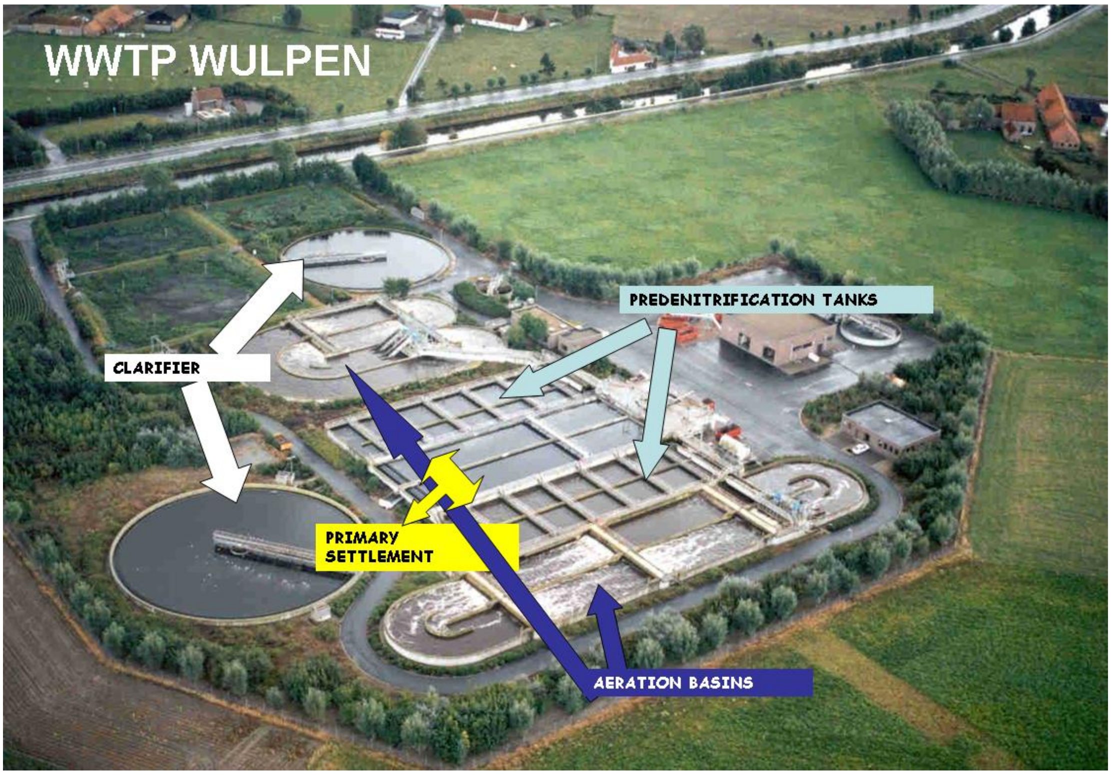
3.3.3.1 WASTEWATER RECLAMATION FACILITY TORREELE (BELGIUM)

In order to reduce the extraction of natural groundwater for potable water production and hold back the saline intrusion at the Flemish coast of Belgium, 2,500,000 m³ of wastewater treatment plant effluent per year is infiltrated in the dunes after treatment with MF, RO and UV. The RO filtrate is reconditioned to match the natural salt content in the dune water. The recharged water is recaptured after a minimum residence time of 40 days in the dune aquifer. The drinking water quality standards are met; the recharge system performs as expected and resulted already in softer water adding to the comfort of the customers.

Description of the wastewater treatment plant preceding the water reclamation step

The WWTP of Wulpen operated by Aquafin NV is a low loaded activated sludge system which consists of oxidation ditches preceded by a pre-denitrication step (see Figure 3.5). Phosphorus removal is achieved by the dosage of ferric salts. The WWTP has a nominal capacity of 83,000 PE.

Figure 3.5: WWTP Wulpen (source: Aquafin NV)



Despite the fact that the WWTP is overloaded – in 2003 the WWTP has served 108,000 PE – it complies with the Urban Wastewater Treatment Directive for sensitive areas and with the stricter local wastewater treatment norms. The influent and effluent yearly-average water quality concentrations in the year 2003 are illustrated in Table 3.14. The WWTP effluent norms are also reported.

Table 3.14: Influent and effluent concentrations of WWTP Wulpen: yearly average in 2003(50 24-h composite measuring points)

	BOD	COD	SS	TN	TP
Influent [mg/L]	278	650	286	56.7	9.7
Effluent [mg/L]	0.5	33.8	6.6	10.4	1.3
WWTP effluent norms:					
- concentrations [mg/L]	25	125	35	15	2
- removal efficiency [%]	90	75	90	80	80

Part of the dry weather flow is conveyed to the water reclaimation facility.

Description of the water reclamation plant

The water reclamation facility is operated by the local drinking water company I.W.V.A. and was built close to the WWTP at a dsign flow rate of 6,850 m³/d. The treatment steps of the water reclamation facility are given in Table 3.15.

Table 3.15: Composition of water reclamation facility

Treatment stage	Comment
Pre-screening and pre-chlorination	
Microfiltration and post-chlorination (monochloramines)	
Cartridge filtration	3 parallel cartridge filters (200 m³/h each, 15 µm)
Reverse osmosis	2 parallel RO skids with 36 8” pressure vessels each. Each skid can treat 140 to 193 m³/h of MF filtrate at a recovery of 75 %
Ultraviolet irradiation	dose of 40 mJ/cm²
Infiltration pond	Total capacity of the artificial recharge: 2,500,000 m³/year

Performance of the water reclamation treatment processes

The regulatory water quality standards of the water reclamation scheme before infiltration are reported in Table 3.16.

Table 3.16: Water reclamation scheme before infiltration

Parameter	Concentration	Parameter	Concentration
Temp	25 °C	manganese	50 ppb
pH	6.5 – 9.2	copper	100 ppb
Conductivity	1000 µS/cm	zinc	200 ppb
Chloride	250 ppm	phosphorous	0.4 ppm
Sulphate	250 ppm	fluoride	1.5 ppm
Magnesium	50 ppm	cyanide	10 ppb
Sodium	150 ppm,	chrome	50 ppb
total hardness	40 °F	mercury	1 ppb
nitrate	15 ppm	nickel	50 ppb
nitrite	0.1 ppm	lead	20 ppb
ammonia	1.5 ppm	antimony	10 ppb
aluminium	0.2 ppm	selenium	10 ppb
iron	0.2 ppm	THM' s	200 ppb

The water reclamation facility complied with the standards for infiltration for 100% of the times of operation. Table 3.17 to Table 3.20 report on the water quality performance of the different water reclamation steps for a time-span of two years, starting from the start-up of operation in August 2002.

Table 3.17: Quality of different water between 16th of August 2002 en 1st of October 2002

		MF filtrate			RO filtrate			Infiltration water			Groundwater		
		Mean	*Min*	*Max*	*Mean*	*Min*	*Max*	*Mean*	*Min*	*Max*	*Mean*	*Min*	*Max*
Conductivity	µS/cm	1,298	473	1,591	26	21		185	179	192	638	610	654
pH			7.64	8.22		5.42	7.49		6.08	6.35		7.09	7.29
Chloride	mg/l	226	70	289	2	2	3	28	26	30	42	42	42
Sulfate	mg/l	106	44	127	<1	<1	3	12	12	17	73	73	73
Total hardness	°F	32.2	12.8	38.1	<1	<1		4.3	3.9	4.6	31.9	31.9	31.9
Bicarbonate	°F	24.3	8.3	32.4	<1	<1		3.2	3.1	3.3	25.1	25.1	25.1
Total nitrogen	mg/l	10.8	5.0	16.0	<2	<2		2.0	2.0	2.0			
Nitrate	mg/l							7.1	2.7	9.6	2.9	2.7	3.3
Nitrite	mg/l							0.11	0.05	0.16	0.06	0.05	0.06
Ammonia	mg/l							0.22	0.17	0.27	0.50	0.47	0.53
Total phosphorous	mg/l	2.0	1.1	3.2	<0.1	<0.1		0.3	0.2	0.3	0.2	0.2	0.2
TOC	mg/l	8.9	4.8	10.9	<0.2	<0.2		1.1	1.1	1.1	4.0	4.0	4.0
sodium	mg/l	140.7	47.7	186.0	4.6	4.2	4.9	21.9	20.4	23.4	28.8	28.8	28.8
calcium	mg/l							13.0	13	13	122.0	122	122
magnesium	mg/l							1.7	1.7	1.7	5.4	5.4	5.4
potassium	mg/l							4.2	4.2	4.2	3.9	3.9	3.9
fluoride	mg/l							21	21	21	109	109	109
silicium	mg/l	21.5	8.9	25.5									
total THM's	µg/l								<0.1	3.2	0.5	0.5	0.5
Total pesticides	µg/l							0.024	0.021	0.027	<0.01	<0.01	

Table 3.18: Quality of different water between 1st of October 2002 and 1st of January 2003

		MF filtrate			RO filtrate			Infiltration water			Groundwater		
		Mean	*Min*	*Max*	*Mean*	*Min*	*Max*	*Mean*	*Min*	*Max*	*Mean*	*Min*	*Max*
Conductivity	µS/cm	1,032	519	1,406	<20	<20		115	35	168	817	599	904
pH			7.54	8.14		5.23	7.54		5.70	6.61		6.96	7.35
Chloride	mg/l	171	63	305	2	1	2	19	17	21	67	67	68
Sulfate	mg/l	87	42	118	2	1	3	9	8	17	114	114	114
Total hardness	°F	27.6	15.9	41.0	0.2	0.2	0.2	3.5	2.8	4.2	43.6	43.2	43.9
Bicarbonate	°F	20.1	10.9	29.8	0.6	0.5	0.6	2.3	1.7	2.8	31.5	31.3	31.7
Total nitrogen	mg/l	10.0	6.0	17.0	<2	<2		2.5	2.0	3.0			
Nitrate	mg/l							4.7	1.2	8.1	5.5	2.3	10.1
Nitrite	mg/l							0.05	0.02	0.08	0.05	0.02	0.11
Ammonia	mg/l							0.26	0.06	0.70	0.39	0.31	0.54
Total phosphorous	mg/l	1.0	0.6	1.6	<0.1	<0.1		0.1	0.1	0.1	<0.1	<0.1	
TOC	mg/l	6.9	4.3	9.1	<0.2	<0.2	0.2	0.7	0.6	0.8	3.1	3.1	3.2
sodium	mg/l	120.3	48.1	177.0	2.1	0.9	3.5	14.1	12.7	15.5	40.6	40.1	41.1
calcium	mg/l							8.5	8	9	163.0	161	165
magnesium	mg/l							1.2	1.0	1.3	6.5	6.4	6.5
potassium	mg/l							2.2	2.0	2.4	6.0	6.0	6.0
fluoride	mg/l							26	26	26	52	38	66
silicium	mg/l	19.4	10.6	29.7									
total THM's	µg/l							0.5	0.5	0.5	0.3	0.3	0.3
Total pesticides	µg/l	0.311	0.246	0.376		<0.1		0.031	0.024	0.037	<0.1	<0.1	

Table 3.19: Quality of different waters between 1st of January 2003 and 1st of June 2004

		MF filtrate			RO filtrate			Infiltration water			Groundwater		
		Mean	*Min*	*Max*	*Mean*	*Min*	*Max*	*Mean*	*Min*	*Max*	*Mean*	*Min*	*Max*
Conductivity	µS/cm	1,290	627	1,798	26	20		146	26	229	448	390	555
pH			7.47	8.11		4.82	7.72		5.62	7.27		7.08	7.57
Chloride	mg/l	225	18	370	2	1	3	20	1	36	42	31	75
Sulfate	mg/l	103	54	139	1	1	3	10	7	17	42	32	56
Total hardness	°F	30.5	11.2	38.8	0.7	0.3	1.0	3.4	1.8	4.9	19.9	14.2	24.9
Bicarbonate	°F	21.1	7.3	28.6	0.8	0.2	1.3	2.4	1.3	3.2	15.8	12.6	20.5
Total nitrogen	mg/l	12.9	3.7	25.4	0.7	0.0	2.2	3.0	2.0	3.9			
Nitrate	mg/l							7.0	1.5	16.1	1.9	1.0	3.4
Nitrite	mg/l							0.12	0.02	0.29	0.03	0.02	0.04
Ammonia	mg/l							0.30	0.07	0.84	0.35	0.22	0.56
Total phosphorous	mg/l	1.1	0.3	3.4	<0.1	<0.1	0	<0.1	<0.1	0.2	0.2	<0.1	0.4
TOC	mg/l	7.9	4.8	10.9	<0.2	<0.2	0.4	0.9	0.5	2.0	2.7	2.1	3.9
sodium	mg/l	160.7	78.1	249.5	2.8	1.0	5.4	16.4	6.0	26.1	24.9	21.6	28.4
calcium	mg/l							10.1	6	13	72.3	55	94
magnesium	mg/l							1,4	0.7	1.9	3.3	2.4	4.3
potassium	mg/l							2.5	0.3	4.2	3.0	2.4	3.7
fluoride	mg/l							26	17	47	156	132	196
silicium	mg/l	20.3	8.4	26.0									
total THM's	µg/l							6.0	3.0	17.7	0.8	0.2	2.4
Total pesticides	µg/l										<0.1	<0.1	

Table 3.20: Quality of different waters between 1st of June 2004 and 15th of September 2004

		MF filtrate			RO filtrate			Infiltration water			Groundwater		
		Mean	*Min*	*Max*	*Mean*	*Min*	*Max*	*Mean*	*Min*	*Max*	*Mean*	*Min*	*Max*
Conductivity	µS/cm	1.246	657	1,505	27	20		55	41	73	363	235	648
pH			7.88	8.22		5.19	5.50		6.27	7.16		7.37	7.68
Chloride	mg/l	233	115	294	3	2	4	3	2	4	34	19	78
Sulfate	mg/l	73	45	84	<1	<1	3	<1	<1		29	25	37
Total hardness	°F	26.9	16.2	31.3	<1	<1		<1	<1		15.8	13.5	19.0
Bicarbonate	°F	23.5	12.3	28.6	<1	<1		2.6	2,1	2.8	14.1	12.9	15.3
Total nitrogen	mg/l	7.8	3.7	11.8	<2	<2		<2	<2				
Nitrate	mg/l							2.3	1.1	3.6	1.5	1.0	2.0
Nitrite	mg/l							0.30	0.03	0.51	0.02	0.02	0.03
Ammonia	mg/l							0.21	0.05	0.61	0.27	0.10	0.74
Total phosphorous	mg/l	1.3	0.6	3.0	<0.1	<0.1		<0.1	<0.1		0.2	<0.1	0.2
TOC	mg/l	8.7	6.5	10.1	0.3	0.2	0.4	0.2	0.2	0.2	2.2	2.1	2.3
Sodium	mg/l	160.7	79.6	203.2	3.9	1.7	5.6	12.8	9.6	14.5	21.5	19.8	24.2
calcium	mg/l							<2	<2		58.7	50	71
magnesium	mg/l							<0.1	<0.1		2.6	2.3	3.1
potassum	mg/l							0.7	0.5	0.8	3.0	2.9	3.1
fluoride	mg/l							<20	<20		147	132	162
silicium	mg/l	19.1	11.0	22.8									
total THM's	µg/l							4.9	4.4	5.4	<0.15	<0.15	
Total pesticides	µg/l							0.02	0.02	0.02	<0.1	<0.1	

Despite the presence of small amounts of pesticides in the infiltration water, the pesticide level in the groundwater is below the detection limit (0.01 µg/l) (the drinking water standards are 0.1 µg/l for an individual pesticide and 0.5 µg/l for total pesticides).

Requirements

Energy

The energy consumption is on average 0.82 kWh/m³, of which:

±0.2 kWh/m³ for the MF unit

±0.6 kWh/m³ for the RO unit

Chemicals

Table 3.21 reports on the chemical requirements of the scheme, including the point and range of dose.

Table 3.21: Chemicals requirements

Product	Dosed to	Range (mg/l)	Comment
Chlorine		4.0 – 5.5	Biofouling prevention
Ammonia chloride		2.8 – 5.5	Biofouling prevention
Sulfuric acid	MF filtrate	25 – 50	pH adjustment
scale inhibitor (HYPERSPERSE MDC 220)	MF filtrate	0.1 – 0.4	
Bisulfite	MF filtrate		to protect RO membranes
UV	RO filtrate	40 mJ/cm²	

Manpower

The water reclamation scheme is operated by1 full-time employee.

Monitoring

The water quality monitoring programme of the MF and RO units are summarised in Table 3.22. Besides, conductivity is monitored regularly on every pressure vessel.

Table 3.22: Monitoring requirements

Parameter	Frequency
Flow, conductivity, pH and temperature on all waters, Turbidity on MF filtrate, pressures and energy consumption of processes	Online
SDI, conductivity, pH on MF and RO filtrate	Daily
bacterial analysis, salt and nutrient content	Weekly
greater set of parameters (to comply with the norms)	Monthly

Environmental impact of complete reuse scheme

Emissions

Two waste streams are produced, namely:

Reject water MF:	12.5% of production volume
Brine RO:	25% of production volume

Up to now the waste streams are discharged into a canal. Research is being conducted to evaluate the viability of a number of brine treatment technologies (www.reclaim-water.org).

Footprint

Table 3.23 provides information with respect to the footprint of the different treatment units, including the extraction wells.

Table 3.23: Footprint of water reclamation scheme

Treatment step	Land requirement (ha)
Tertiary/quaternary	0.25
Infiltration pond	2
Extraction wells	15

Effect on groundwater

The softening of the water results in a better taste of the drinking water for the inhabitants and a reduced formation of scaling in equipments such as boilers etc.

The salt content gradually declined from ±750 µS/cm to about 400 µS/cm.

The total hardness declined from about 40°F to about 20°F.

Cost statements

Construction

The construction costs amounted to € 7,000,000:

€ 2,500,000 for the civil works

€ 3,500,000 for the electromechanical equipment.

€ 1,000,000 for the infiltration pond

O&M

- 1 operator daily on site
- Power supply: 0.08 €/m³ infiltration water
- Chemicals : € 0.03 / m³ infiltration water
- Taxes for discharge and recharge : € 0.13 / m^3 infiltration water

Waste handling

The reject water from the MF and the RO systems is discharged into a canal. I.W.V.A has to pay a fee for this discharge. The fee varies according to the flow and to the water quality discharged.

3.3.3.2 COMBINED MUNICIPAL WASTEWATER- STORMWATER RECOVERY AT SYDNEY OLYMPIC PARK (AUSTRALIA)

Introduction

The Sydney Olympic Parklands covers an area of 425 ha and consist of remnant woodland, fresh and saltwater woodlands, remediated lands and areas of cultural significance. This area also encompasses Bicentennial Park which is well known for its mangroves and bird life. Situated within Homebush Bay, this area has over 100 ha of wetlands and waterways draining from a 7.6 km^2 local catchment.

The planning of the Water Reclamation and Management Scheme (WRAMS) was initiated by the Olympic games 2000 authorities to design and built an Olympic park. Soon it was realized that in the foreseen area of the Olympic park site, complex interdependencies exist between sewage, stormwater, recycled water and potable water. As a result, the planner focused on planning and designing in a sustainable whole-of-catchment strategy to minimize the impacts on both land and water (Sydney Olympic Park Authority, 2004a).

Taking into account the regional considerations, the Water Reclamation and Management Scheme (WRAMS) was set up at Sydney Olympic Park which was built as part of the Olympic Games in 2000. The scheme is designed to treat raw domestic sewage into recycled water which is then sold back to consumers. The main elements of WRAMS are a water reclamation plant (WRP), a water treatment plant (WTP), storm water collection, clean water storage and recycled water delivery systems. WRAMS is owned by the Sydney Olympic Park Authority and operated by United KG. It provides continuous recycled water for irrigation, water fountains and domestic/residential uses to Sydney Olympic Park and the surrounding suburb of Newington. The scheme saves more that 800,000 m^3 of drinking water each year and this saving is projected to increase up to more than 1,000,000 m^3 in coming years.

Recycled water produced by WRAMS is supplied to homes in Newington and to Sydney Olympic Park through over 300,000 m of water pipelines (lilac). In terms of health and safety, the recycled water is suitable for toilet flushing, watering lawns and gardens, washing cars, in construction and industry and in fire fighting (Sydney Olympic Park Authority, 2004b). The recycled water is distributed by a series of colour co-ordinated pipelines with separate meters and taps for drinking/potable water.

The venues and facilities serviced by WRAMS include:

- Stadium Australia- toilet flushing, irrigation*
- Sydney Superdome- toilet flushing, irrigation*
- NSW Tennis Centre- toilet flushing, washdown, irrigation*
- Sydney Showground- toilet flushing, washdown, irrigation*
- NSW Hockey Centre- toilet flushing, irrigation*
- Millenium Parklands- irrigation
- Novatel and Ibis Hotels- toilet flushing
- Olympic Park Station- toilet flushing
- Public Amenities and Carparks- toilet flushing, irrigation
- Newington Village- toilet flushing, gardens, car washing etc.

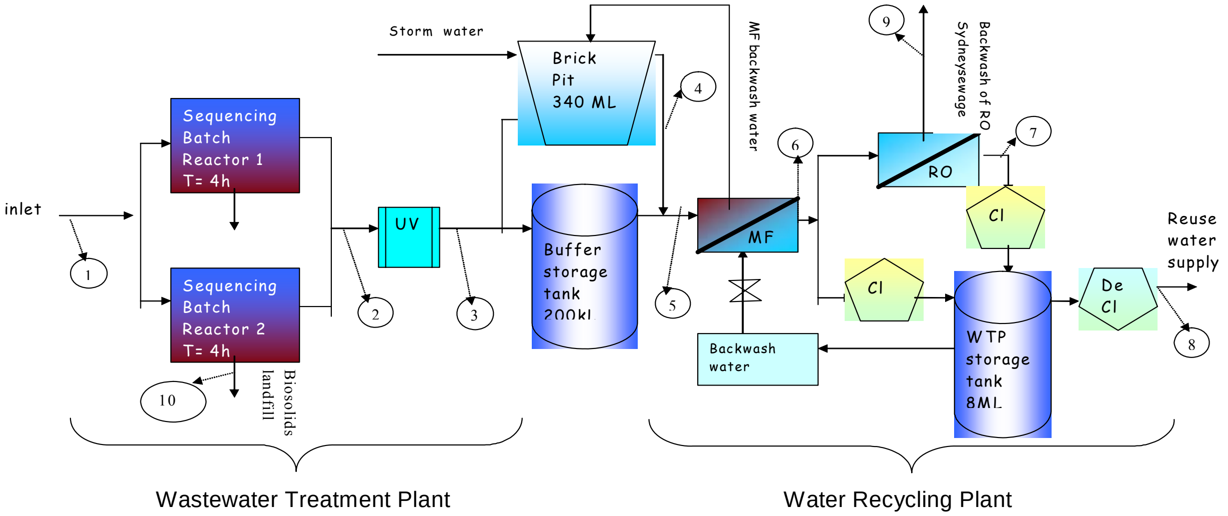
(* irrigation after Sydney 2000 Olympics)

The price of recycled water from WRAMS is set at around 0.15 AUS\$/m^3 whereas drinking water is priced at 0.90 AUS\$/m^3 and other recycled water at 0.75 AUS\$/m^3. These prices are set by the Independent Pricing and Regulatory Tribunal (IPART) and are subject to change (WRAMS, 2005a & 2005b).

Treatment scheme

A flow diagram of WRAMS is represented in Figure 3.6, and the major features are discussed in the following.

Figure 3.6: Flow diagrams of WRAMS, with sampling points (numbers)



Water Reclamation Plant (WRP)

The WRP is a primary sewage plant designed to treat raw domestic sewage to secondary effluent grade, removing solids, phosphorus, BOD and ammonia. It was designed to treat an average of 2,200 m^3 per day, but has the hydraulic capacity of 3,100 m^3 per day. The heart of the WRP is sequence batch reactor (SBR) consisting of two basins which operate in unison. The dual basin SBR operate in continual four hour cycles all day, regardless of flow. Each treatment cycle consists of two hours intermittent aeration, followed by a two hour settle and decant phase. Aluminium sulfate is added at the end of each aeration cycle to aid the removal of phosphorus. In addition to the SBR, the WRP also has a screening/grit removal chamber and a sludge dewatering belt. However, the waste sludge the grit and screenings are treated off-site. The effluent from the WRP is then pumped through UV disinfection stage before going to the WTP for further treatment.

Water Treatment Plant (WTP)

The WTP treats a combination of secondary effluent and stormwater. It consists of continuous-flow microfiltration (CMF) and reverse osmosis (RO) with a total capacity of 7,500 m^3 per day. The WTP is designed to filter all the water through the CMF units and only a maximum of 2,000 m^3 per day through the RO units. The CMF filters are 0.2 micron, hollow fibre (Memcor) filters arranged in three, 90 module blocks. Each block can operate between a range of 70 and 110 m^3/h, giving a total flow rate of 2,500 m^3 per block per day. *If the water to be recycled consists of reclaimed wastewater only, then MF is used followed by chlorination and dechlorination. RO is used only when the water contains stormwater and total dissolved solids (TDS) are to be removed.* The two RO modules have a fixed flow rate of 1,000 m^3 per day each, thus depending on the flow rate through the WTP, the proportion of water filtered by the

RO units can vary from half to a fifth of the reclamed water. Permeate from the CMF and RO filters is mixed before entering the chlorine contact tank and the subsequent recycled water reservoir.

The WTP is built on top of an 8,000 m³ reservoir, which stores the water until it is pumped out to the customers. The pressure in the entire recycled water network at WRAMS is lower than that in the potable water network to ensure that in case of cross-connections, potable water would enter the recycled water network and not the opposite. In the event of a major failure or contamination of the recycled water reservoir, the network can be fed with potable water. The recycled water reservoir "controls" the entire WTP. When the reservoir level drops, the PLC speeds up the filtration rate of the CMF filters to achieve a constant reservoir level. If the CMF filtration rate exceeds the secondary effluent flow rate being sent from the WRP, then the WTP draws its feed water from the stormwater reservoir. Alternatively, if the WTP does not need all the water being sent from the WRP, then the excess secondary effluent flows into the stormwater reservoir.

Stormwater reservoir (“Brickpit”)

A 200,000 m³ previously quarry site was adapted as the stromwater reservoir. All stormwater from the Olympic Park can flow into the Brickpit through a network of ponds, pipes and wetlands. Excess secondary effluent can also be diverted into the Brickpit to be stored until it is needed at the WTP. The Brickpit plays a very important role at WRAMS as it enables the WTP to operate at any rate (up to 7,500 m³/day) independent to the sewage flows into the WRP. In this way WRAMS is able to cope with large events such as sporting events, as well as quiet days.

Dual reticulation network

After the treatment in the WTP, the recycled water is pumped back to the Olympic venues and Newington village with the help of a dual reticulation network. It uses a colour coding system to enable the end user to distinguish non-potable water from the WTP and potable water. The water from the WTP can only be used for toilet flushing, irrigation, general wash down purposes, in ornamental ponds and for fire fighting. In order to prevent an accidental use of water from the WTP for drinking purposes, the garden taps in Newington village have removable handles.

Effluent criteria

Table 3.24: WRAMS recycled water guidelines (Chapman H., 2005)

Test	Recycled water limits
Ammonia	2 mg/L
Total Phosphorus	1 mg/L
BOD	<20 mg/L
Total Nitrogen	12 mg/L
Turbidity	<2 NTU
pH	6.5-8
Free Chlorine	0.5 mg/L
True Colour	15 TCU
Conductivity	1000 µs/cm
Total Coliform	<10 units/100 ml
Faecal Coliform	<1 unit/100ml

Requirements

Chemicals

Aluminum sulfate is used in the WRP, while chlorine disinfection is done using sodium hypochloride. In addition, the membrane systems may require chemical cleanings from time to time.

Manpower

Two full-time staff.

Monitoring

The tests in Table 3.24 are performed and recorded weekly as part of the WRAMS operating guidelines, while every 6 months a metal scan and virus/parasite test is performed on the recycled water. The WTP also has an online water analyser station that continuously monitors the turbidity, pH, conductivity and free chlorine. If the recycled water quality falls outside the operating guidelines the online instruments will create alarms to notify the operators.

3.3.4 Only disinfection

3.3.4.1 WATER RECLAMATION FACILITY WITH OZONE TREATMENT 1 (AFIN-OZ-1)

Introduction

In order to reduce the extraction of natural groundwater for cooling water make-up a pharmaceutical company makes use of 2,000,000 m³ per year of treated municipal wastewater. The secondary-treated wastewater is ozonated and blended with groundwater and used as industrial cooling make-up.

The quality standards to discharge cooling water are met and the reclamation system performs as expected.

Wastewater reuse scheme

Influent wastewater criteria of reuse plant

The wastewater treatment plant (WWTP) of CASE STUDY AFIN Oz-1 is composed by a low loaded activated sludge system (oxidation ditch) with enhanced biological phosphorus removal. The WWTP is operated by Aquafin NV.

The WWTP has a nominal capacity of 29,000 PE.

The WWTP is fully loaded. In 2003 the WWTP has served on average 26,287 PE, in terms of nitrogen load (1 PE = 10 g N/d). The WWTP complies with the European Urban Wastewater Treatment Directive for sensitive areas.

Part of the WWTP effluent (in 2003: 75% of the flow; in 2005 almost 100% of the flow) is conveyed to the water reclamation facility. The facility is built at the industrial site, where groundwater is extracted and mixed with reclaimed water.

Description of the reclamation treatment

The reclamation treatment is composed by the sole ozonation unit (i.e. no filtration unit required). The nominal capacity is:

- Maximum nominal flow rate: 1260 m^3/h
- Maximum ozone generator rate: 1500 g O_3/h

Figure 3.7: Ozonation contactor (source: Aquafin NV)

Reuse treatment process

General regulatory requirements for the discharge to the receiving body of the cooling water generated from cooling water make-up with reclaimed water are (VLAREM II (Flemish Environmental Regulations)):

1. Disinfection is necessary if the amount of pathogens discharged can produce a threat to the receiving medium.
2. pH: 6.5 – 8.5.
3. Dissolved oxygen: > 4 mg/L.
4. Temperature of the cooled water must not exceed 30°C.
5. In accordance with the EC Directive 76/464/EC, a specific permit is granted with regards to the dangerous substances listed in the appendix and measured 4 times per year.
6. The difference in COD between the discharged and the receiving water body may not exceed 30 mg/L.

The facility complied with the requirements for 100% of the time.

- Removal efficiencies for turbidity, SS, BOD, COD, N, P, FC, intestinal nematode eggs, E. coli, reuse-treatment specific parameters: not available

Design criteria

These are not known (the facility has been dimensioned by the ozone manufacturer), but it is likely that the following criteria were adopted:

- 500 ppb O_3 in the cooling water makeup.
- HRT = 3 hour

Requirements

Energy consumption

The energy consumption of the treatment scheme is 0.9 kWh/m^3.

Chemicals

No chemicals (including fouling and anti-scaling agents) are added, in full accordance with the IPPC Directive.

Manpower

Planned maintenance (routine interventions): 1 man-day per month.

Monitoring

The water quality monitoring programme is summarized in Table 3.25. Besides, conductivity is monitored regularly on every pressure vessel.

Table 3.25: Monitoring requirements.

Parameter	Frequency
Flow, conductivity, turbidity, pH and temperature on all waters (groundwater and reclaimed water before ozonation), ozone concentration	Online
Additional compliance parameters	3-Monthly

Major control actions are:

- Ozone concentration in the water make-up reservoir (set-point: 3-4 mg/L).
- Turbidity levels above 2 NTU or conductivity levels above 2000 µS/cm prompt the diversion of the WWTP effluent to the nearby river and the supply of the mix condensers water make-up by groundwater supply only

Environmental impact of complete reuse scheme

Emissions

- Waste production: none

Chemical consumption

- None (in accordance with the IPPC BREF document)

Footprint

Treatment step	Land requirement (ha)
Tertiary:	0,2

Effect on surface water:

Not known (an EIA has been carried out and relevant performance parameters are followed)

Effect on groundwater:

At steady state the local groundwater table is expected to rise from the current -25 m to -15 m (due to the reclamation and reuse of the WWTP effluent).

3.3.4.2 PALAMOS SITE RESEARCH: WASTEWATER DISINFECTION (SPAIN)

Site description

The Palamós activated sludge facility serves several municipalities in a summer tourist area, with 32,000 inhabitants in winter and up to 60,000 during summer.

The secondary effluent from this plant was reclaimed by using different combinations of pre-treatments and disinfection. Tested pre-treatment processes are: infiltration-percolation, ring filtration, sand filtration and coagulation-filtration. These processes were combined with the disinfection processes: chlorine dioxide, peracetic acid, ultraviolet, and ozone (with the exception of coagulation-filtration which was tested only in combination with ultraviolet and ozone). The main characteristics of the technologies used are as follows:

1. Pre-treatment processes

- *Infiltration–percolation (IP)*. Filtrating surface 554.7 m^2, depth 1.50 m of sand (98% below 1 mm); drainage layer 10 cm of fine gravel and 30 cm of coarse gravel.
- *Ring filtration (RF)*. Two filtration modules: the first has two filters with a filtration degree of 50 µm K 10–15%; the second has three filters with a filtration degree of 25 µm K 10–15%; the maximum flow rate is 12–13 m^3/h.
- *Sand filtration (SF)*. Classical filter, diameter: 2 m, surface area: 3.14 m^2, depth: 45–50 cm, filtration velocity: 8.12 m^3/h m^2, sand size: 0.6–1.2 mm.
- *Coagulation-filtration (CF)*. Combination of filtration and coagulation (40 ppm Fe); flow rate: 7 m^3/h; contact time: 6 minutes.

2. Disinfections processes

- *Chlorine dioxide (ClO_2)*. The pilot has a reactor with a capacity of 1 m^3, a homogenisation tank and a generator of chlorine dioxide.
- *Peracetic acid (PA)*. The pilot has a reactor with a capacity of 1 m^3, a homogenisation tank and a pump that doses the PA.
- *Ultraviolet (UV)*. Closed cylinder; medium pressure and high intensity lamps; 14% of radiation is 253.7 nm.
- *Ozone(O_3)*. Gas source: air; temperature: 0–50°C; pressure: 4–20 mbar.

Physical, chemical, and microbiological parameters were determined at the inlet and outlet of the different filtration and disinfection systems. The analytical methods were those indicated by standard Methods for the Examination of Water and Wastewater (1999), except for bacteriophage (ISO), Giardia lamblia (EPA) and Cryptosporidium parvum (EPA).

Results

Removal of "contaminants" depends on the filtration system as well as the different equipment and lines generated treated wastewater with different qualities. This fact influenced the dose and contact time of studied disinfection systems because "pre-treatments" generated such differences in effluent quality.

1. Results of pre-treatment processes

Physical, chemical, and microbiological parameters variations are presented in Table 3.26 and Figure 3.8 to Figure 3.10. The IP system is the most effective treatment in comparison with the rest of the employed filtration systems (RF, SF, and CF). Outlet water from IP has a removal of suspended solids of 64.2%, COD and TOC are reduced by 36.9 and 46.2% respectively. BOD5 is below the detection limit (<5 mg/L). With respect to microbiological parameters, IP improves the microbiological quality. Fecal coliforms removal is 2.19 Ulog/100 mL, while the somatic coliphages are reduced with 2.62 Ulog/100 mL, Bacteriophages RNA F-specific removal is 3.30 Ulog/100 mL. Sand filtration and ring filtration remove suspended solids, and consequently the organic matter content is reduced. These filtration systems are not effective for bacteria and virus removal because they are not designed to do it.

Table 3.26: Removal efficiencies of pre-treatment processes

		Pre-treatment process			
Parameter	Unit removal	IP	RF	SF	CF
SS	%	64.2	5.7	42.1	42.4
Turbidity	%	95.3	7.2	43.9	67.7
COD	%	36.9	5.0	12.5	11.7
BOD	%	100	6.9	36.3	100
TOC	%	46.2	0	11.0	24.8
Fecal coliform	Ulog/100 mL	2.19	0.01	0.29	0.66
Coliphage	Ulog/100 mL	2.62	0.05	0.35	0.20
Bacteriophage	Ulog/100 mL	3.30	0.11	0.12	0.10

Figure 3.8: Suspended solids and Turbidity

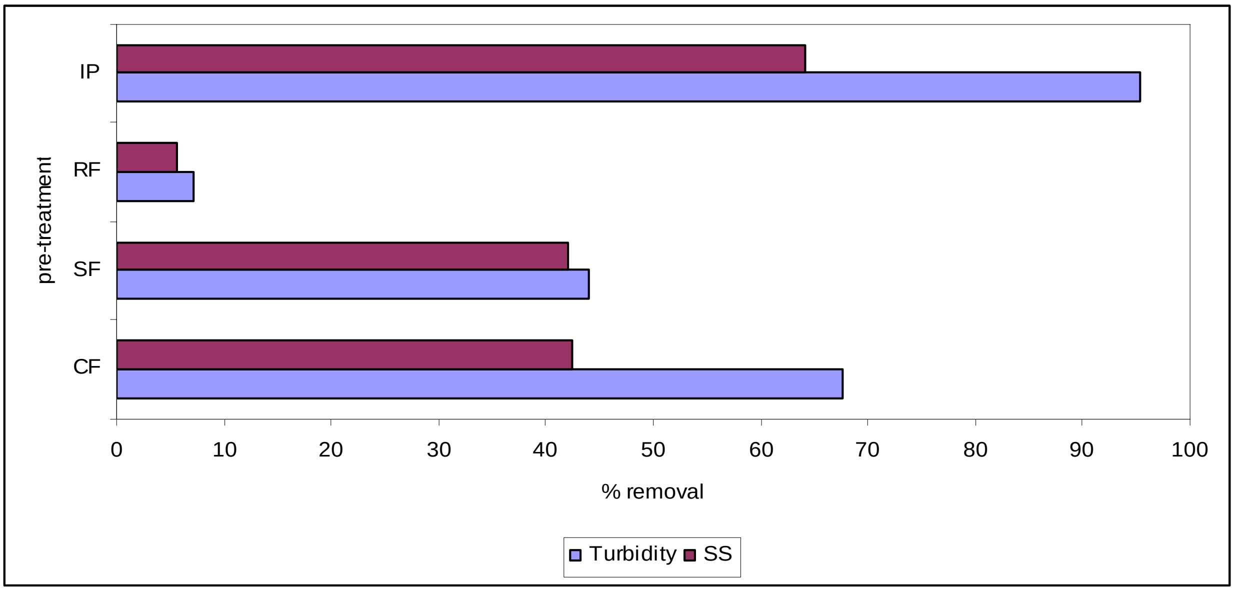


Figure 3.9: COD, BOD, TOC

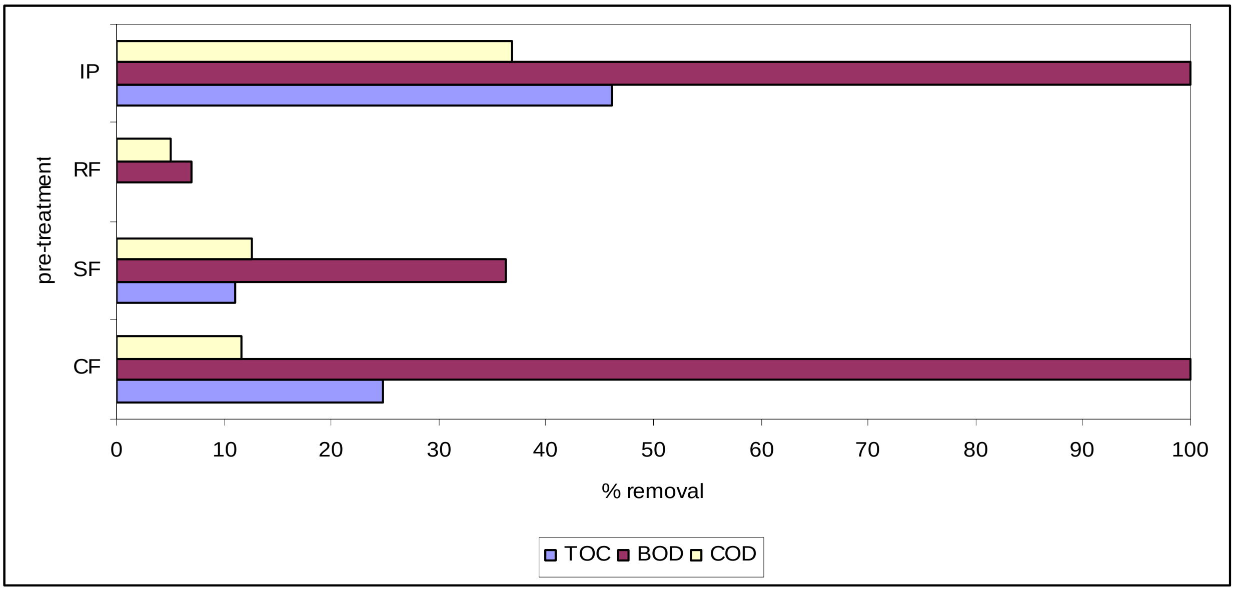
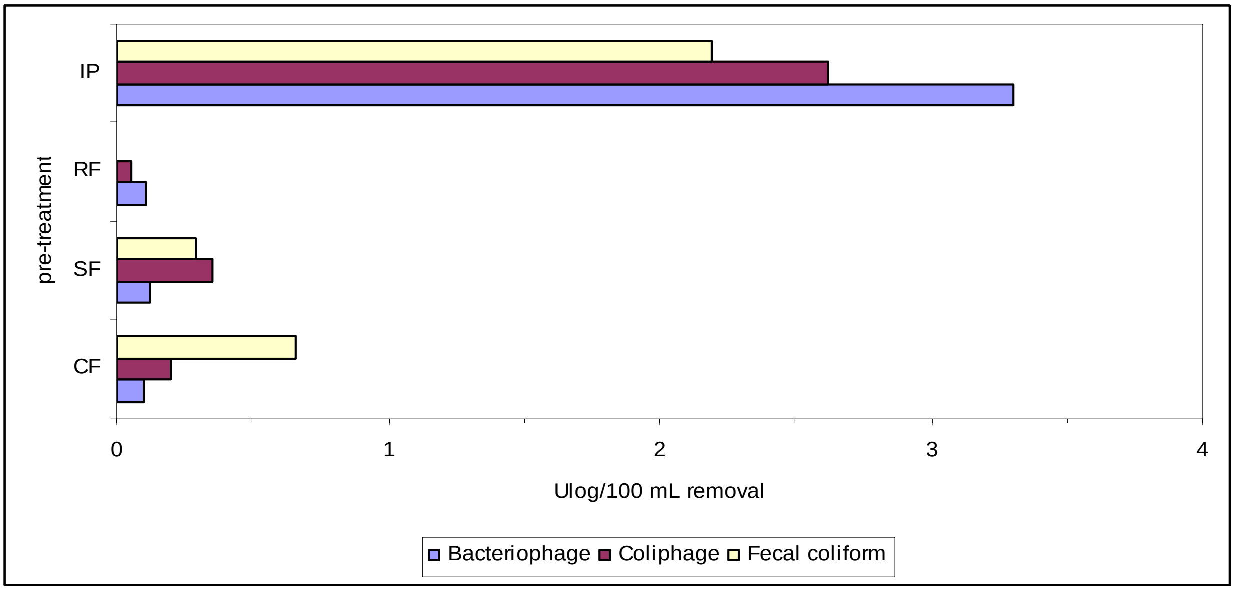


Figure 3.10: Fecal coliform, Coliphage, Bacteriophage



In relation to protozoa removal, SF obtained better results than RF due to the granulometry of the SF sand.

The physical–chemical system generates an effluent with better quality characteristics than SF, due to the previous addition of flocculants. The PC system achieves comparable reduction to IP in relation with suspended solids, BOD_5, and turbidity. This system is very effective in protozoa removal, although it has no effect on bacteria and viruses.

2. Results of treatment combinations

Working conditions varied in relation with the origin of the effluent (filtration systems) and are presented in Table 3.27.

Table 3.27: Working conditions in each treatment line

Filtration System	Working Conditions			
	UV	O_3	PA	ClO_2
SF	Dose: 778.8 mW.s/cm^2 Flow: 2 m^3/h	Water flow: 1.2 m^3/h O_2 flow: 202-216 Ln/h Contact time: 2 min Dose: 19.07-26.32 mg/L Transferred dose: 17.38-25.92 mg/L	Flow: 5.5 m^3/h Contact time: 10 min Dose: 30 mg/L	Flow: 1.0 m^3/h Contact time: 55 min Dose: 9 mg/L
RF	Dose: 693.6 mW.s/cm^2 Flow: 2 m^3/h	Water flow: 1.2 m^3/h O_2 flow: 213-215 Ln/h Contact time: 2 min Dose: 21.10-27.55 mg/L Transferred dose: 15.54-21.77 mg/L	Flow: 5.5 m^3/h Contact time: 10 min Dose: 30 mg/L	Flow: 1.0 m^3/h Contact time: 10 min Dose: 8 mg/L
IP	Dose: 431.9 mW.s/cm^2 Flow: 5 m^3/h	Water flow: 1.2 m^3/h O_2 flow: 205-216 Ln/h Contact time: 2 min Dose: 12.13-12.54 mg/L Transferred dose: 10.45-11.45 mg/L	Flow: 5.5 m^3/h Contact time: 10 min Dose: 15 mg/L	Flow: 1.0 m^3/h Contact time: 10 min Dose: 3 mg/L
CF	Dose: 390.8 mW.s/cm^2 Flow: 6 m^3/h	Water flow: 1.2 m^3/h O_2 flow: 216-217 Ln/h Contact time: 2 min Dose: 16.06-16.76 mg/L Transferred dose: 13.42-15.54 mg/L	-	-

Chlorine dioxide combinations.

The application of chlorine dioxide to wastewater allows a total elimination of fecal coliforms in all treatment lines (see Table 3.28). Somatic coliphages reduction of 3 Ulog was achieved. Bacteriophages RNA F-specific were below detection limit (< 0.1 × 102 ufp/100 mL) (see Table 3.28). Chlorine dioxide had the same removal for bacteria and viral indicators (see Table 3.28).

Table 3.28: Filtration systems combined with ClO_2

Parameter	IP + ClO_2		RF + ClO_2		SF + ClO_2	
	IP outlet	ClO_2 outlet	RF outlet	ClO_2 outlet	SF outlet	ClO_2 outlet
Fecal coliform (Ulog)	2.39	0.00*	4.84	0.00*	4.24	0.00*
Somatic coliphage (Ulog)	n.d	1.7	3.00	b.d.l.	3.08	b.d.l
Bacteriophage RNA F-specific (Ulog)	n.d	b.d.l.	b.d.l.	b.d.l.	n.d	n.d
Giardia (cysts/L)	n.d	<1	72	25	1	<1
Cryptosporidium (oocysts/L)	n.d	<1	5	3	4	3

Peracetic acid combinations.

PA disinfection generated an effluent with approximately 1 Ulog/100 mL of fecal coliforms in the studied lines. Treated water from IP required lower doses than the rest of the filtration systems (for equivalent flow and contact time) (Table 3.29). Viral indicators removal varies from 1.7–2.0 Ulog/100 mL. PA as a disinfectant is more effective for bacteria than viruses (see Table 3.29).

Table 3.29: Filtration systems combined with Peracetic Acid (PA)

Parameter	IP + PA		RF + PA		SF + PA	
	IP outlet	PA outlet	RF outlet	PA outlet	SF outlet	PA outlet
Fecal coliform (Ulog)	2.30	0.09	5.32	0.89	5.02	0.69
Somatic coliphage (Ulog)	n.d	b.d.l	4.80	3.73	4.86	3.74
Bacteriophage RNA F-specific (Ulog)	<1	n.d	n.d	n.d	n.d	n.d
Giardia (cysts/L)	n.d	<1	n.d	n.d	n.d	n.d
Cryptosporidium (oocysts/L)	n.d	<1	n.d	n.d	n.d	n.d

Ultraviolet combinations.

UV treatment removes 2.5-3 Ulog/100 mL of fecal coliform content in all cases, except for RF. UV efficiency depends on suspended solids content and turbidity. The best disinfection results are obtained with effluents from IP and CF (characterised by their low content in suspended solids and turbidity), where the applied dose was the lowest (see Table 3.30). The equipment used in this experimentation was characterised by a central lamp, with medium pressure and high intensity. This model is normally used for potable water and does not adjust to treated wastewater characteristics. Equipment with more lamps is more adequate.

Table 3.30: Filtration systems combined with Ultraviolet (UV)

Parameter	IP+UV		RF+UV		SF+UV		CF+UV	
	IP outlet	UV outlet	RF inlet	UV outlet	SF outlet	UV outlet	CF outlet	UV outlet
Fecal coliform (Ulog)	4.28	1.74	6.21	6.18	5.51	2.65	4.40	1.44
Somatic coliphage (Ulog)	b.d.l.	b.d.l.	5.12	5.13	6.15	2.54	5.15	1.75
Bacteriophage RNA F-specific (Ulog)	b.d.l.	1.70	3.25	3.11	4.18	2.44	3.13	1.30
Giardia (cysts/L)	n.d	<1	3	10	1	2	1	1
Cryptosporidium (oocysts/L)	n.d	<1	14	21	2	6	2	1

Ozone combinations.

Ozone treatment is able to remove almost all fecal coliforms from all treated effluents, achieving reductions of 5 Ulog/100 mL (see Table 3.31). The effluents, which needed lower ozone dosages were those from the IP and CF pilot. Both treatments have the lowest organic matter concentration. Organic matter content affects the transmitted ozone dose which consequently influences disinfection efficiency (see Table 3.31). With respect to viral indicators, a reduction of 5 Ulog/100 mL of somatic coliphages was achieved, while for bacteriophage RNA F-specific the maximum reduction was 3 Ulog/100 mL (see Table 3.31). Once again, the best removal results were obtained in the effluents which come from IP and PC systems (see Table 3.31).

Table 3.31: Filtration systems combined with Ozone (O_3)

Parameter	IP+O_3		RF+O_3		SF+O_3		CF+O_3	
	IP outlet	O_3 outlet	RF outlet	O_3 outlet	SF outlet	O_3 outlet	CF outlet	O_3 outlet
Fecal coliform (Ulog)	4.28	0.27	6.18	0.66	5.63	1.72	4.41	0.87
Somatic coliphage (Ulog)	b.d.l.	1.30	5.13	1.68	6.15	1.45	5.15	b.d.l.
Bacteriophage RNA F-specific (Ulog)	b.d.l.	b.d.l.	3.11	2.31	4.18	1.30	3.13	b.d.l.
Giardia (cysts/L)	n.d	<1	10	4	1	1	n.d	n.d
Cryptosporidium (oocysts/L)	n.d	<1	21	25	2	1	n.d	n.d

b.d.l.: below detection limit; n.d : not determined; *: cfu (colony forming units)

Conclusions

A filtration treatment, or equivalent, is usually necessary to eliminate suspended solids before wastewater disinfection. The best filtration system tested in the project was IP. This system is characterised by an extremely good elimination of suspended solids and microorganisms retention. Consequently, the effluent needed lower doses and shorter retention time in the advanced disinfection processes to achieve the same disinfection degree as the rest of the filtration treatments. CF treatment was more effective than SF and RF. This can be explained by the addition of flocculants, which improve the physical and chemical parameters involved in disinfection processes (suspended solids, BOD_5, and turbidity).

As to the disinfection systems, chlorine dioxide and ozone lines are the most effective, although homogeneous results are not guaranteed with ozone. On the other hand, chlorine dioxide offers more constant results. In all treatment lines, it was observed that viruses are more resistant to disinfection than bacteria. The evaluation of this resistance varies in relation with the employed viral indicator.

Further studies are needed with regards to *Giardia lamblia* and *Cryptosporidium parvum*.

The chosen treatment is conditioned by other parameters:

- legal requirements
- treatment reliability
- technologies available in the country
- economical viability.

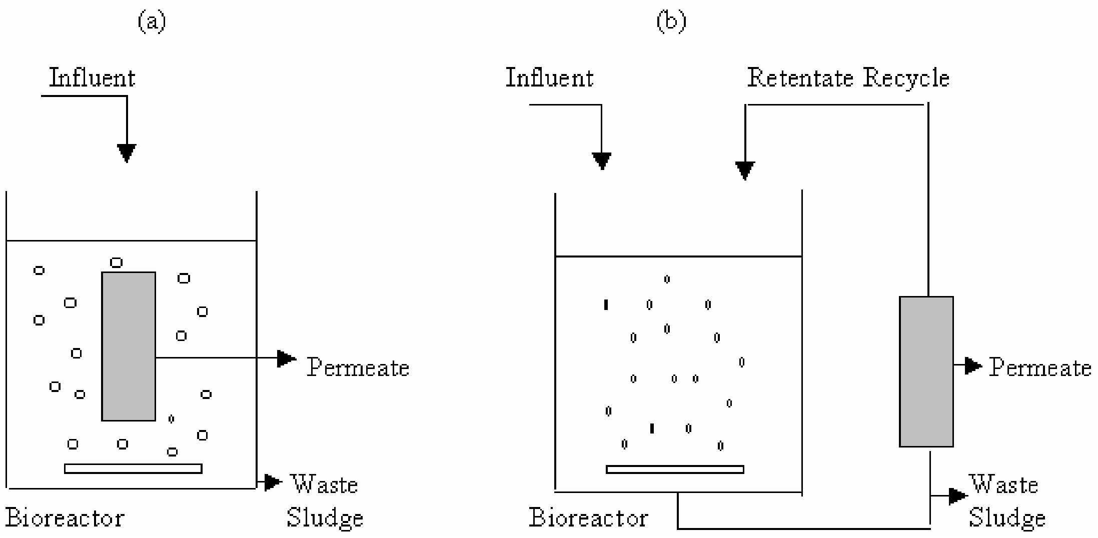
3.3.5 Local MBR

3.3.5.1 INTRODUCTION

Treatment technology for water recycling encompasses a vast number of options. Membrane processes are regarded as key elements of advanced wastewater reclamation and reuse schemes and are included in a number of prominent schemes world-wide, e.g. for artificial groundwater recharge, indirect potable reuse as well as for industrial process water production. Membrane bioreactors (MBRs) are a promising process combination of activated sludge treatment and membrane filtration for biomass retention.

A membrane bioreactor (MBR) combines the activated sludge process with a membrane separation process. The reactor is operated similar to a conventional activated sludge process but without the need for secondary clarification and tertiary steps like sand filtration. Low pressure membrane filtration, either microfiltration (MF) or ultrafiltration (UF), is used to separate effluent from activated sludge (Stephenson *et al.*, 2000). The two main MBR configurations involve either submerged membranes or external circulation (side-stream configuration), see Figure 3.11.

Figure 3.11: Configuration of MBR systems:, (a) submerged MBR, (b) side stream MBR configuration



Sufficient pre treatment has to be installed to prevent clogging of the membranes by fibres, hairs, or other extreme contents. Pre filtration with a grid distance of maximum 3 mm has been advised.

As in most membrane filtration processes the flux declines during filtration. This is mainly caused by membrane fouling. Controlling membrane fouling is the key issue in the operation of an MBR. Membrane fouling is significantly influenced by the hydrodynamic conditions, by membrane type and module configuration and by the presence of higher molecular weight compounds, which may be produced by microbial metabolism or introduced into the sludge bulking process (e.g. poly-electrolytes).

For continuous separation of activated sludge with high MLSS concentrations, only cross flow filtration is suitable. Shear forces can be used to control the cake layer formation, so that a stable flux is attained. In a submerged MBR, these shear forces are induced by the turbulence of uprising air and liquid in the submerged membrane modules. The air flow rate used to agitate the membrane fibres is a critical parameter with respect to the rate of membrane fouling. Severe membrane fouling occurs above a critical permeate flux or at too low aeration rate. In case of a temporary increase in the permeate flux, membrane fouling can be controlled by increasing the air flow rate. Submerged MBRs are usually operated at low differential pressure and well below the critical permeate flux, where fouling control is more feasible.

MBR systems offer the option of independent selection of hydraulic retention time (HRT) and sludge retention time (SRT), which permits a more flexible control of operational parameters. High sludge concentrations in the bioreactor allow efficient treatment of high-strength wastewater. The retention of activated sludge containing solids and macromolecules in combination with long sludge age extends the contact time of sludge and critical classes of substrates. This allows the development of specialised, slow-growing micro-organisms able to remove low-biodegradable pollutants contained in wastewater, resulting in improved removal of recalcitrant compounds.

Because membranes are an absolute barrier for bacteria and in the case of UF also for viruses, the MBR process provides a considerable level of physical disinfection. The main advantages of MBR technology compared to conventional activated sludge systems are (Melin *et al.*, 2006):

- Smaller footprint and smaller reactor volume as a consequence of higher MLSS concentration and loading rate (option for low to moderate sludge age).
- Decreased sludge production (option for high sludge age).
- Higher and more consistent effluent quality as a result of membrane filtration.
- Lower sensitivity to contaminant peaks.

The main disadvantages of MBRs are:

- Relatively expensive to install and operate.
- Frequent membrane monitoring and maintenance.
- Limitations imposed by pressure, temperature, and pH requirements to meet membrane tolerances.
- Membranes may be sensitive to some chemicals.
- Less efficient oxygen transfer caused by high MLSS concentrations.
- Treatability of surplus sludge is questionable.

Since the early MBR installations in the 1990s, the number of MBR systems has grown considerably; projected total European revenue for the MBR market is around €40 million in 2005 with a steady growth rate of 9% thereafter. One key trend driving this continued growth in the next 5 to 10 years is the use of MBR systems for decentralised treatment and water reuse. Around 60 companies now offer MBR solutions with the majority of the systems originating from 9 main manufacturers. The majority of the currently operational and commissioned plants are small to medium size with a large percentage employed for decentralised treatment or water recycling duties (Melin *et al.*, 2006).

Comparison with other technologies used for water recycling reveals that MBRs not only produce lower residual concentrations but do so more robustly than the alternatives (Jefferson *et al.*, 1999 and 2001). That is to say the distribution of effluent qualities produced shows less variation in MBR processes compared to the other technologies.

The successful introduction of MBR systems into small scale and decentralised applications has led to the development of packaged treatment solutions from most of the main technology suppliers. Most manufactures offer systems which has meant that effluent qualities of 5:5:5 [mg/L] (BOD: NH4-N:SS) are now routinely available to end users as standard treatment options. Sports stadiums, shopping complexes and office blocks are becoming typical end users, especially in areas of water stress.

Another growing market for MBR technologies is in the production of high purity water were the use of a MBR process upstream of reverse osmosis has been shown to be highly effective (Lawrence *et al.*, 2002).

The operational experience with full-scale MBRs indicates that this relatively new technology poses a challenge to the water utilities. Many areas such as fouling control, pre-treatment, maintenance, and operators training have to be established in the operational procedures and drawbacks are expected in the uptake of this technology. which define the need for more intensive and practitioner-oriented research on MBRs (Melin *et al.*, 2006).

3.3.5.2 WASTEWATER RECLAMATION BASED ON MBR TECHNOLOGY FULTON COUNTY (GEORGIA, USA)

Introduction

The advanced wastewater treatment facility for water reclamation described here is based on MBR technology and is located in Fulton County, Georgia, USA. Prior to its commissioning, the existing wastewater treatment plant in the John’s Creek basin was nearing its design capacity, and could not handle any additional sewage flows from new developments in the area. To compound the problem, a lack of rainfall and drought-like conditions, had many commercial developments concerned that limits would be placed on the amount of water that could be drawn from the nearby Chattahoochee River for irrigation purposes.

In April of 2002, the Cauley Creek Water Reuse Facility was commissioned. The ZeeWeed MBR plant is the first of its kind in the state of Georgia, and is designed to treat a maximum daily flow of 13,500 m^3/d, with an average daily flow of 9,500 m^3/d. In October of 2002, the Fulton County Board of Commissioners approved the expansion of the plant to 19,000 m^3/d.

Effluent from the reuse facility surpasses tertiary standards, and is provided to local golf courses, subdivisions, schools and churches for irrigation purposes, thereby reducing the amount of water drawn from the Chattahoochee River. During the wet weather season, when irrigation water is not required, effluent quality surpasses all state requirements for discharge directly to the River. The Cauley Creek Water Reclamation Plant received the state’s first cold weather discharge permit.

Water characteristics and regulations

Influent wastewater and product effluent water characteristics are presented in Table 3.32.

Table 3.32: Influent-Effluent Characteristics

Characteristics	Feed	Effluent
BOD_5 (mg/L)	200	$\le$3
COD (mg/L)	N/A	N/A
TSS (mg/L)	200	$\le$2
TN (mg-N/L)	N/A	$\le$5
TP (mg-P/L)	6.5	$\le$0.13
Turbidity (NTU)	N/A	$\le$0.2*

*California Title 22 Water Reuse Standards

Local regulations for irrigation reuse and discharge are shown in Table 3.33.

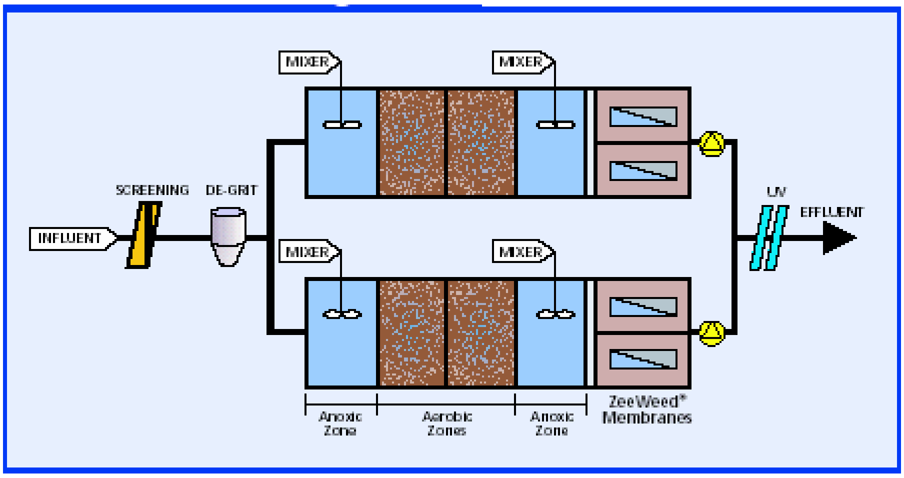
Table 3.33: Discharge Regulations

Parameter	Land Application Permit (May-October)	Point Source Discharge Permit (November-April)
Flow	9,500 m^3/day (monthly average) 11,800 m^3/day (maximum day)	9,500 m^3/day (monthly average)
Volume	-	$1.04 \cdot 10^6$ m^3 (maximum annual)
BOD_5	5 mg/l	5 mg/L
TSS	5 mg/l	5 mg/L
NH_3	-	1 mg/L
Total Phosphorus	-	0.13 mg/L
Turbidity	3 NTU	3 NTU
Fecal Coliform	23 counts/ 100mL	23 counts/ 100mL
PH	6-9 s.u.	6-9 s.u.

Process description

A block flow diagram of the applied process is shown in Figure 3.12.

Figure 3.12: Flow diagram Cauley Creek treatment plant



The Cauley Creek treatment plant consists of two separate membrane filtration trains, each with a set of ancillary equipment – air blowers and permeate pumps. Raw wastewater is pumped to the headworks and prescreened with a fine, self-cleaning screen (2mm traveling band screen), followed by vortex grit removal and dosed with ferric chloride (55 mg/L) to meet the TP <0.13 mg/L requirement. In addition sodium hydroxide (caustic) is used to comply with permit limits for effluent pH and to provide sufficient alkalinity for biomass growth and nitrification. Caustic is currently added during preliminary treatment. The amount of caustic used is dependent on the quantity of chemical dosed for phosphorus removal. During the point-source discharge season, caustic is typically dosed at approximately 130 mg/L (as NaOH). The caustic dose decreases to approximately 40 mg/L (as NaOH) during the land application season. It should be noted that the high caustic usage is due in part to low influent pH, typically between 5.9 and 6.3.

The water then flows by gravity to an anoxic zone with a low dissolved oxygen level of 0.5 mg/L, where most of the denitrification occurs. The mixed liquor then flows by gravity to zones two and three, which are aerated intermittently to create an alternating sequence of aerobic and anoxic conditions. Both nitrification and denitrification occur in this zone, minimizing the ammonia and nitrate concentrations, without the need for excessively high recirculation rates. Mixed liquor then flows to a second anoxic zone, followed by the UF membrane filtration. Finally, after passing through UV disinfection, the treated effluent is stored in a 40,500 m², 170,350 m³ water reservoir. Two separate pipelines distribute the water for reclamation applications.

Membrane Bioreactor Characteristics

Filtration is achieved by drawing effluent through the surface of the hollow-fiber membrane under a low-pressure vacuum of –7 to –55 kPa. Once drawn through the lumen of the membrane fiber, treated water is conveyed to the main effluent discharge pipes. The facility has two membrane trains, each with two membrane compartments. Each train has a total of twenty-two installed Zenon ZW500c-22 cassettes with one empty space. Mixed liquor recirculation pumps are used to return concentrated solids from the membranes trains to the upstream end of the first anoxic zone. A summary of the membrane system characteristics is shown in Table 3.34.

Table 3.34: Membrane bioreactor system summary

System summary	
Membrane Type	ZeeWeed®500
Process Trains	2
Membrane Trains	4
Total Membrane Cassettes	44
Plant Footprint	1,900 m²

The surface of the membrane fiber is kept clean through two primary methods, aeration and backpulsing. Diffused air bubbles travel up the surface of the membrane fiber, removing any solids that may have adhered. At pre-set time intervals, the membranes are back-pulsed. This is accomplished by briefly reversing the flow of the effluent through the membrane to remove any particles that may have obstructed the pores during membrane operation. Backwash water is supplied from two tanks. After passing through UV disinfection, the treated effluent is stored in a 40,500 m², 170,350 m³ water reservoir on the property. Two separate pipelines distribute the water for reclamation applications.

Finally, three methods for chemical cleaning of the membranes are utilized, including chemically-enhanced backpulse, maintenance cleaning, and recovery cleaning:

Membrane Chemically-Enhanced Backpulse Cleaning

Chemically-enhanced backpulse cleaning is used to remove deposits from the surface of the membranes and to maximize the time period between more intensive cleaning methods, such as maintenance and recovery cleaning. Backpulse cleaning is performed by pumping chlorinated (in the form of 12.5-percent sodium hypochlorite) permeate through the membranes at low pressure and high flow. Currently, backpulse cleaning is carried out automatically for 45 seconds every 12 minutes. Backpulsing of the two trains is staggered. A sodium hypochlorite dose of 2.5 mg/L (as Cl_2) and a flux of approximately 35 litre per m² per day (L/(m².day)) are used during chemically-enhanced backpulse cleaning.

Membrane Maintenance Cleaning

Maintenance cleaning of the membranes is used to sustain higher fluxes and increase the interval between recovery cleanings. Maintenance cleans using sodium hypochlorite and citric acid are currently scheduled three times and one time per week, respectively. Maintenance cleaning consists of halting permeate production and alternating between backwashing with chemical solution at approximately 20 L/(m².day) for 30 seconds and then "relaxing" the membranes for 5 minutes. This procedure is repeated 10 times prior to the train being aerated and being placed into service.

Membrane Recovery Cleaning

During recovery cleaning, the membrane cassettes are soaked in a solution of sodium hypochlorite for 18 to 24 hours and then a solution of citric acid for another 18 to 24 hours. Recovery cleans are performed every 6 months or if transmembrane pressure (TMP) increases to 48 to 55 kPa. Additional chemicals, including sodium metabisulfite and caustic, are used to neutralize sodium hypochlorite and citric acid, respectively, between recovery cleanings.

Sludge Treatment

Solids handling processes at the Cauley Creek water treatment facility include thickening, aerated sludge holding, centrifugal dewatering and landfill disposal. A membrane sludge thickener is used to minimize the aerobic digester tank volume. The ZeeWeed membrane thickener is designed to handle waste activated sludge (WAS) flow of 100,000 gpd at 10,000 mg/L TSS and the thickened sludge produced is 25,000 gpd at 40,000 mg/L TSS. The thickener characteristics are shown in Table 3.35.

Table 3.35: Membrane sludge thickener

Cauley Creek Thickener	
Location	Cauley Creek, Georgia
Commissioning Date	July 2004
Flows	285 m³/day
Flux	3.4 – 5.1 L/(m².day)
Solids Concentration	35 – 45 g/L

Polymer is used by the facility for centrifugal sludge dewatering. The facility uses approximately 16 pounds of polymer per dry ton.

Cost estimates

Information on operation and maintenance costs is presented below [Cote 2004]. However, information on installation costs for the facility could not be made available.

Cost of Chemicals

As discussed in the previous section, at the Cauley Creek WRF chemicals are used to meet both effluent total phosphorus and pH limits as well as for membrane cleaning and sludge dewatering.

Chemical Phosphorus Removal

Assuming an average flow rate for year 2003 of 7,600 m^3/day, the annual cost for chemical phosphorus removal at the facility was approximately US$17,000. During land application season, ferric chloride is not used. However, if the facility were required to meet the total phosphorus limit year-round, the cost for chemical phosphorus removal would increase to US$34,000.

Alkalinity Addition

The annual cost of caustic addition at the Cauley Creek WRF is approximately US$82,000. If the facility were required to discharge to a point source year-round, this cost would increase to approximately US$124,000.

Membrane Chemically-Enhanced Backpulse Cleaning

The cost for chemically-enhanced backpulse cleaning with sodium hypochlorite is approximately US$1,500 per year.

Membrane Maintenance Cleaning

Currently, the sodium hypochlorite cost for maintenance cleanings is approximately US$5,000 per year. The citric acid cost for maintenance cleanings is approximately $1,000 per year.

Membrane Recovery Cleaning

Assuming two recovery cleanings per train per year, the annual sodium hypochlorite and citric acid chemical costs are approximately US$3,000 each. The annual costs for neutralization chemicals, including sodium metabisulfite and caustic, are US$700 and US$300, respectively.

Sludge Dewatering

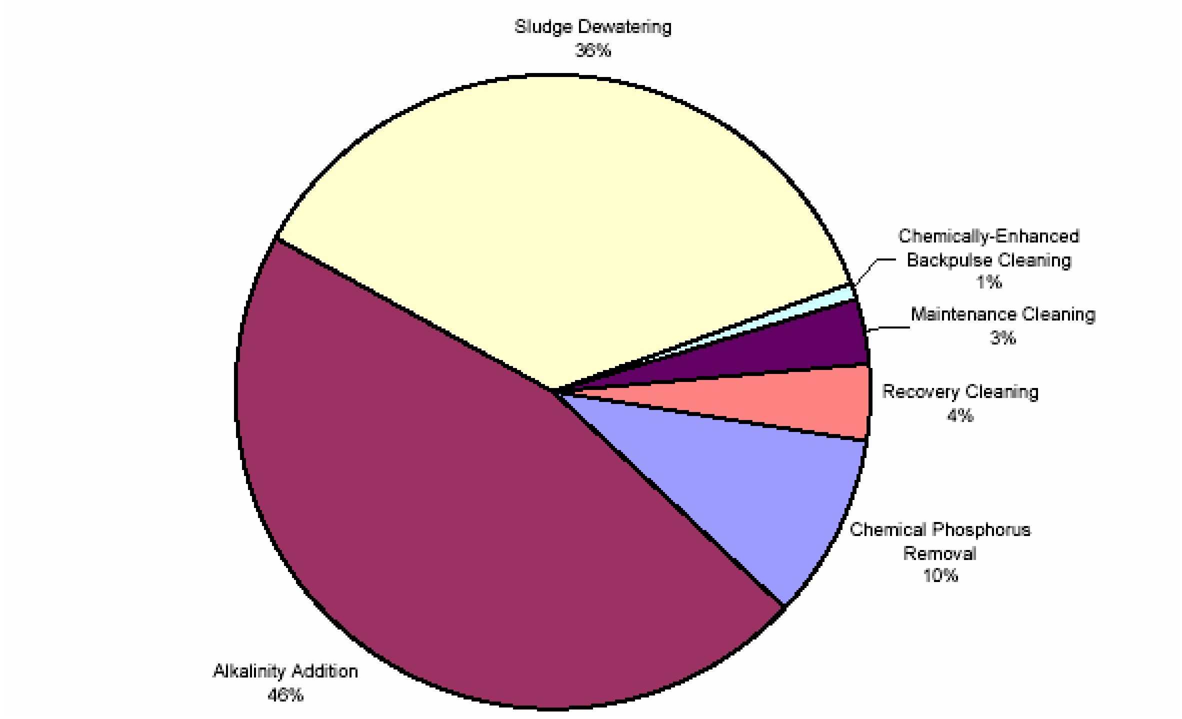
For the year 2003, the cost for dewatering polymer was approximately US$64,500.

A summary of annual costs for chemicals is presented in Table 3.36, and the cost distribution is presented in Figure 3.13.

Table 3.36: Cauley Creek WRF Summary of Annual Cost of Chemicals

Parameter	Cost (US$)
Chemical Phosphorus Removal	17,000
Alkalinity Addition	82,000
Membrane Chamically – Enhanced Backpulse Cleaning	1,500
Membrane Maintenance Cleaning	6,000
Membrane Recovery Cleaning	7,000
Sludge Dewatering	64,000
Total Annual Cost of Chemicals	178,000

Figure 3.13: Cauley Creek WRF Annual Chemicals Cost by Function



Power Consumption and Costs

Approximately 80% of the total plant power consumption is directly related to MBR system equipment (including process aeration blowers and anoxic zone mixers). Other major non-MBR system electrical loads at the WRF include the reuse pump station, UV disinfection system, odor control fan, dewatering centrifuge, and blower for the sludge holding tank and vortex grit chamber.

The Cauley Creek WRF currently pays approximately US$0.05 per kWh. This results in a total power cost ranging from US$600 to US$700 per day for the period analyzed.

Labor Requirements and Costs

The Cauley Creek WRF is currently staffed seven days per week, twelve hours per day. Including fringe benefits and additional overhead, labor costs average approximately US$300,000 per year.

Corrective Maintenance Requirements and Costs

Most corrective maintenance has focused on repairs of the influent fine screen and UV disinfection system and the replacement of pumps in the reuse pump station and the cyclic aeration valves for the MBR process. It is estimated that the annual cost for corrective maintenance is approximately US$10,000.

Laboratory Costs

Annual laboratory costs for permit parameters are approximately US$25,000. Laboratory analyses required for process control cost approximately US$10,000 annually.

Sludge Disposal Costs

Solids handling processes at the Cauley Creek WRF include aerated sludge holding, centrifugal dewatering, and landfill disposal. Total solids production for the year 2003 was approximately 2,400 dry tons. With a landfill disposal fee of US$15 per dry ton and a hauling fee of US$95 per load, the total cost for landfill disposal of sludge was US$53,000.

O&M Cost Summary

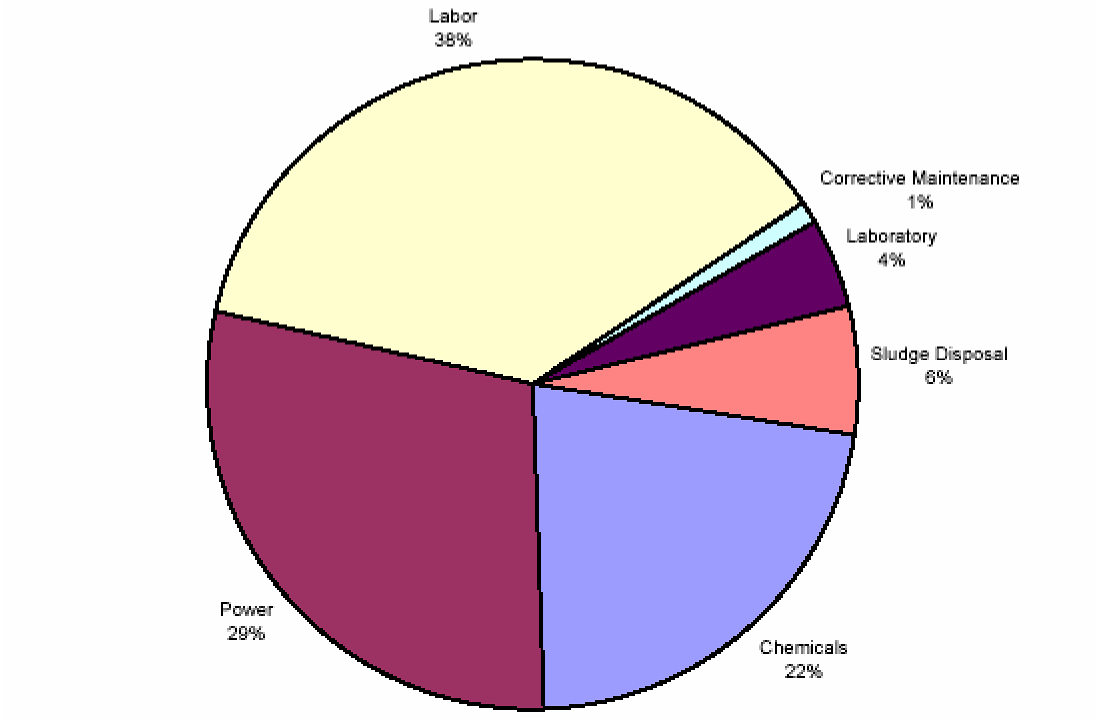
A summary of the estimated annual O&M costs for the Cauley Creek water reclamation facility is presented in Table 3.37.

Table 3.37: Cauley Creek WRF Summary of Annual O&M Costs

Parameter	Cost (US$)
Chemicals	178,000
Power	240,000
Labor	300,000
Corrective Maintenance	10,000
Laboratory	35,000
Sludge Disposal	53,000
Total Annual O&M Cost	816,000

Assuming an average flow rate of 7,600 m³/day for the year 2003, the total annual O&M cost is approximately US$0.15 per m³ treated. The total annual O&M cost is distributed among the categories above as shown in Figure 3.14.

Figure 3.14: Cauley Creek WRF Total Annual O&M Cost Distribution



3.3.6 Soil aquifer treatment

3.3.6.1 THE DAN REGION SYSTEM (ISRAEL)

Introduction

The Dan region wastewater plant treats an average flow of 330,000 m^3/d. Effluent from the Dan Region WWTP is conveyed to four recharge basins covering a total area of 80 ha. Hydraulic loading to the basins varies between 80 and 150 m/yr, depending on the infiltration capacity of the basins. The infiltration into the groundwater is carried out by alternate flooding and drying, a method designed to maintain aerobic conditions in the soil aquifer treatment. The effluent percolates vertically through 15 to 30 m of the unsaturated zone, and spreads horizontally (radially) through the saturated zone, outward from the recharge basins to a series of recovery wells surrounding the recharge area. Passage through the soil aquifer filters the effluent and extends the biological treatment by means of the additional contact with oxygen present in the upper soil layers. Physical-chemical processes such as adsorption, ion-exchange and sedimentation also take place in the unsaturated zone. The long retention time in the saturated zone destroys harmful bacteria and viruses.

Approximately 100 recovery wells, located 300 to 1,500 m from the recharge basins, pump the recharged water from a depth of 100 to 200 m. In addition to the water quality improvement, the Soil Aquifer Treatment (SAT) system provides seasonal and multi-year water storage. Water recovered from the SAT system is of extremely high quality and can be used for unrestricted agricultural irrigation.

Table 3.38 and Table 3.39 show the efficiency of the Soil Aquifer treatment (SAT).

The different fields in the project (see also Figure 3.15) are: SOREQ, YAVNE 1,2,3 and 4.

The operation and maintenance cost study will be performed on the YAVNE 4 site, which is a very new site. The study will show an example of planning, construction and operation costs of an infiltration field.

Table 3.38: SAT performance - Basic Wastewater Parameters (2003)

Parameter	Units	Before SAT (PS 6)	After SAT SOREQ	After SAT YAVNE 1	After SAT YAVNE 2	After SAT YAVNE 3	Removal %
Susp. Solids	mg/L	11	0	0	0	0	100
105°	-	7.41	7.3	7.4	7.3	7.4	
pH	mg/L	268	275	290	300	293	
Alkalinity as	mg/L	12	<0.5	<0.5	<0.5	<0.5	>95
$CaCO_3$	mg/L	2					
BOD	mg/L	49					
BODf	mg/L	36	4.5	5	4	4.5 –	87.5
COD	mg/L	12	1.5	0.8	1.2	5.0	90
CODf	$cm^{-1}x10^3$	223	38	36	42	1.1	82.7
DOC	mg/L	6.53	0.2	<0.02	<0.02	3.8	>99
UV_{254}	mg/L	9.1				<0.02	
Absorbance	mg/L	8.2	1.16	0.44	0.33		93
Ammonia as N	mg/L	1.00	2.64	6	6.5	0.3	
Kjeldahl-N	mg/L	1.237	0.02	0.004	<0.01	6.75	>99
Kjeldahl-Nf	mg/L	3	0.03	0.03	0.06	<0.004	99
Nitrate as N	mg/L	0.22	0.12	<0.1	<0.1	0.02	>55
Nitrite as N	mg/L	<2	<1	<1	<1	<0.1	>50
Phosphorus	#/mL	8.0E+05	454 –	2	22	<1	3log
Detergents	mpn/100 mL	4.1E+05	455	<2	<2	7 – 8	5log
Phenol	mpn/100 mL	2.8E+04	<2	<2	<2	<2	4log
Total	mpn/100 mL	9.0E+03	<2	<2	<2	<2	3-4log
bacteria	pfu/30-400	2	<2			<2	
Coliforms	L						
Faecal							
Coliforms							
Strept.							
Faecalis							
Enteroviruses							

Table 3.39: Comparison between the drinking water standards for specific organics and the results obtained in

Parameter	Units	Observatio well 54 (21.7.03)	Dinking water standards
Alachlor	μg/L	<0.1	20
Atrazine	μg/L	0.1	2
Benzene	μg/L	0.1	10
Benzopyrene	μg/L	<0.1	0.7
1,2 Dichlorobenzene	μg/L	<0.2	1000
1,4 Dichlorobenzene	μg/L	<0.2	300
Carbon tetrachloride	μg/L	<0.2	5
Cis-1,2	μg/L	<0.2	-
Dichloroethylene	μg/L	<0.1	2
Chlordane	μg/L	<1	100
Choroform	μg/L	<0.1	2
DDT	μg/L	<0.01	1
1,2 Dibrome-3	μg/L	<0.2	5
Chloropropane	μg/L	<0.2	30
1,2 Dichloroethane	μg/L	<0.1	2
1,1 Dichloroethylene	μg/L	<0.005	0.03
Endrin	μg/L	<0.1	0.4
Ethylenedibromide	μg/L	<0.1	2
Heptachlor	μg/L	<0.5	300
Lindane	μg/L	<0.1	20
Monochlorobenzene	μg/L	<0.1	-
Methoxychlor	μg/L	0.41	2
Prometryn	μg/L	<0.1	50
Simazine	μg/L	<0.2	10
Styrene	μg/L	<0.2	700
Tetrachloroethylene	μg/L	<0.2	100
Toluene	μg/L	<0.2	200
Trans-1,2	μg/L	<0.2	50
Dichloroethylene	μg/L	<0.1	-
1,1,1 Trichloroethane	μg/L	<0.1	1000
Trichloroethylene			
Trifluralin			
Xylene			

Cost analysis

Dan Region Project cost of m3 of water for unrestricted irrigation

The costs involved in the treatment of wastewater for unrestricted reuse in agriculture are:

- Collection and transport of wastes.
- Treatment of wastes by activated sludge system and tertiary treatment by SAT
- Pumping to SAT system and reclaiming and storage
- Conveyance to the irrigation sites (end – users)

The alternative cost of safe disposal to river, lake or sea will also be considered (tertiary treatment to obtain an effluent with 10 mg/L BOD, 10 mg/L TSS).

The cost of reclaimed water including infiltration is about 0.35 €/m^3, to which the cost of storage and conveyance to the irrigation points in the south in the case of the Third Line needs to be added (0.23-0.25 €/m^3). Thus the total cost for reclaimed water is about 0.57-0.60 €/m^3.

The alternative for the disposal of the treated effluents to a water body is about 0.24 €/m^3. Therefore the additional cost to treat effluents (to quasi-drinking standards) and for reuse, is about 0.33-0.36 €/m3.

Investment and operational costs- Example for a new infiltration field: YAVNE 4

The purpose for constructing a new field:

The need to construct a new infiltration field was the inability to treat 122 Mm^3/yr of effluents in the existing infiltration fields due to clogging that slow down the infiltration rate during the 25 years operation of the fields.

The mass balance in (2003) before the operation of the YAVNE 4 field (see Figure 3.15 and Figure 3.16) was:

1.	Raw wastewater treated in the secondary system:	122	Mm^3/yr
2.	Sludge disposed:	5	Mm^3/yr
3.	Available for SAT:	117	Mm^3/yr
4.	Alternative disposal due to infiltration constraint:	9	Mm^3/yr
5.	Total effluents pumped to SAT system:	108	Mm^3/yr
6.	Total recovered effluents:	127.9	Mm^3/yr

After construction of the new YAVNE 4 infiltration field for 20 Mm^3/yr

No effluent will be disposed to the sea. In the first stage, 15 Mm^3/yr of effluents will be recovered through YAVNE 4 system bringing the recovered water amount to 137.1 Mm^3/yr

YAVNE 4 reservoir general data:

Area: 300,000 m^2

SAT system water production capacity: 20 Mm^3/yr

Single recovery well production capacity: 1.75 Mm^3/yr

Pipe line length total: (See also detailed length and diameter layout in Figure 3.16).

From Pump station 7 : Main pipe line : 3 km. to Yavne 2 and 3 junction 44” and to the fields 4 km. 36” Pipes stainless steel 316. Another 3 km. for topography and internal lines.

COST: 2000 SH (or as 5.8 SH/€) 345 €/m^2 or on the total 2.4 M€ piping

Pumping station for 20 Mm^3/yr: 1.72 M€

Figure 3.15: The 5 parts of the DAN PROJECT- Conveyance to SAT, SAT system, reclaim system, main distribution and storage system, pumping and distribution to end users after the reservoirs

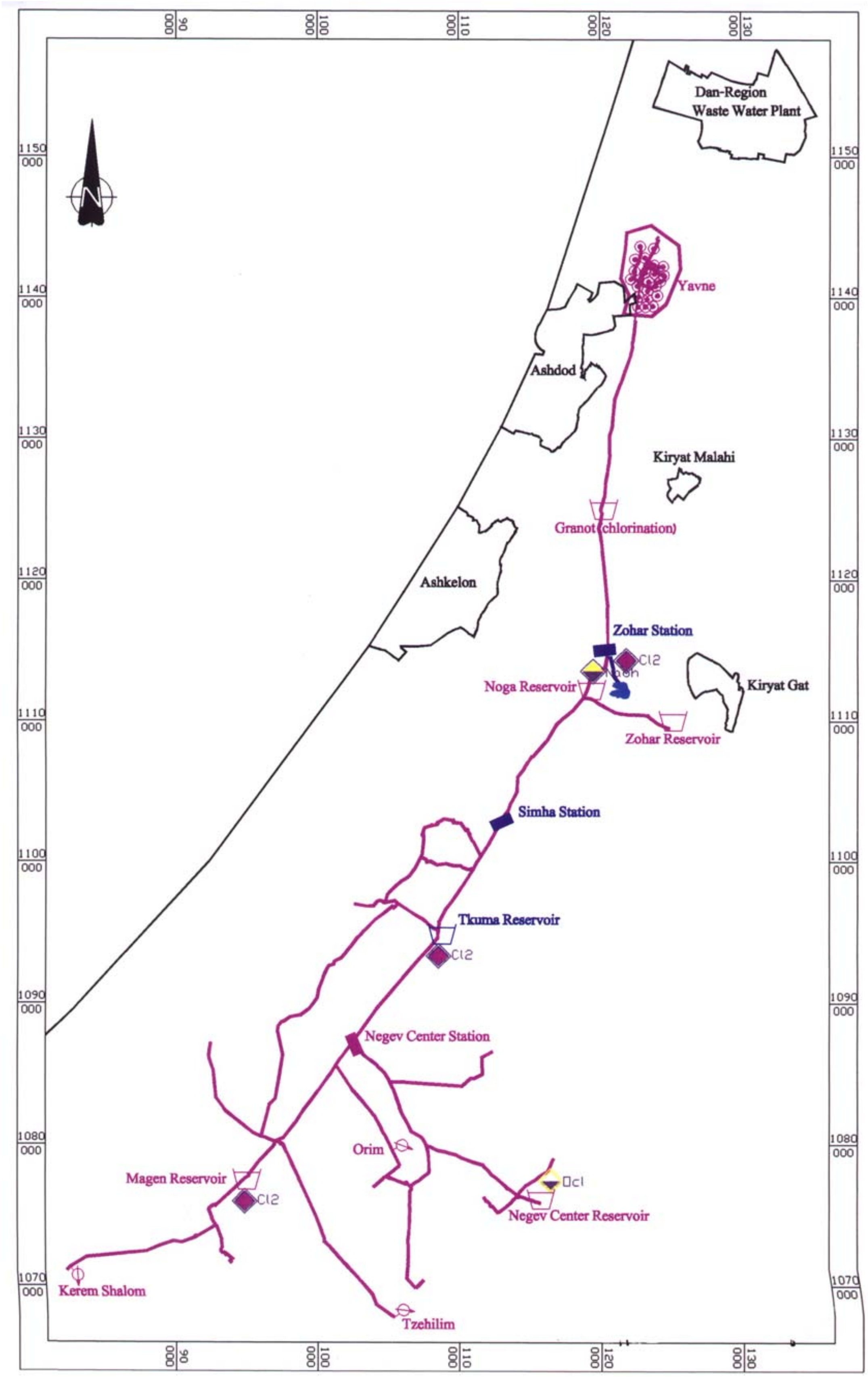
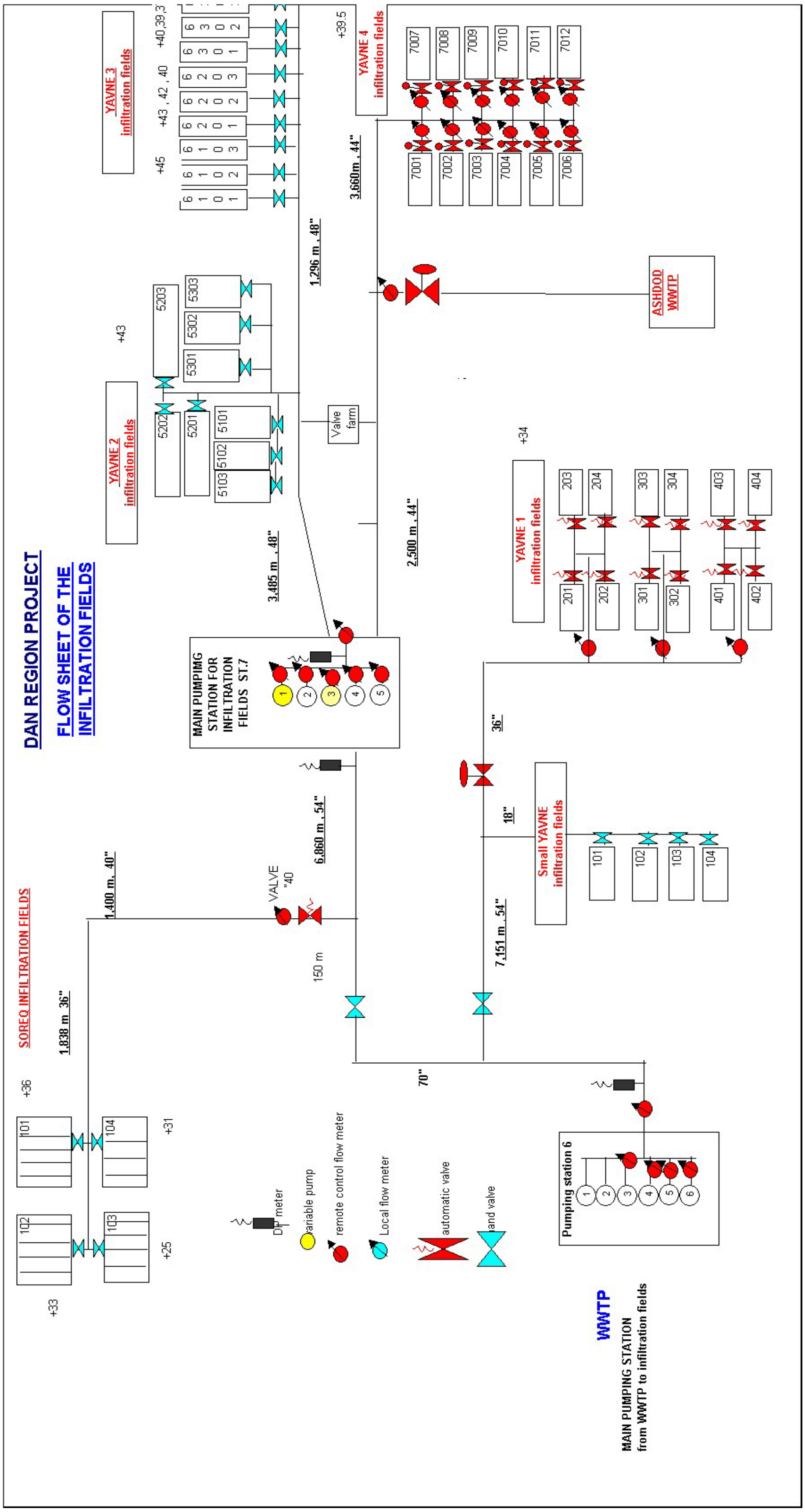


Figure 3.16: Dan Region Project technical layout of the YAVNE infiltration fields



3.3.6.2 RECLAIMED WATER ASR AT BOLIVAR (SOUTH AUSTRALIA)

Introduction

Adelaide has the most vulnerable water resources of the Australian capital cities, as a result of annual rainfall variability and long term water quality deterioration. Opportunities for further expansion of traditional water resources are limited. To cope with the problem, a series of stormwater ASR (Aquifer Storage and Recovery) projects commenced in South Australia in the early 1990's, led by the Department of Water Land and Biodiversity Conservation (as it is currently known). Thanks to the good results and experience achieved, ASR systems have been considered also to different water sources.

In 1999 the Bolivar Water Reclamation Plant and Virginia Reclaimed Water Pipeline were commissioned and these currently provide the capability for reuse of up to 22,000,000 m^3/year of effluent from the Adelaide metropolitan area for irrigation of horticulture on the Northern Adelaide Plains. An aquifer storage and recovery (ASR) trial was established to test the technical viability, environmental sustainability and economic feasibility of storing reclaimed water during winter when irrigation demand is low, and recovering it in summer to meet peak demand (Dillon *et al.*, 1999; Martin *et al.*, 2000) in the event that this rose beyond the current capacity for treatment and transmission in the pipeline. The source water used for this study contains much higher organic loadings than the authors have seen in the literature for ASR. Confidence to undertake the study is based on the previous successes with ASR using urban stormwater in the target aquifer.

The research at this site includes assessing physical and biological clogging and related near-well biogeochemical processes, quantifying pathogen survival rates including within biofilms at the well-face, the hydraulic characteristics of the aquifer, measuring the fate of the injected water at the observation wells and using cross-hole electrical resistance tomography, modelling piezometric head and conservative solute responses in the aquifer, evaluating well maintenance procedures, assessing the structural integrity of the overlying aquitard, and exploring the subsurface geochemical transformations using 'natural' tracers and isotopes.

This section presents those aspects of the Bolivar project directly related to the changes in water quality that occur during storage of the injectant in the aquifer. These include observations on the dilution of injectant in ambient groundwater, inorganic geochemical reactions, characterisation of natural organic matter in injectant and ambient groundwater, fate of pathogens and lessons learnt on measurement techniques, changes in disinfection by-products and their formation potentials, and a small summary of the development of caffeine as a tracer of the injected waters.

Figure 3.17: Bolivar ASR trial site in relation to the water reclamation plants and pipeline on the Northern Adelaide Plains in South Australia.

Site Hydrogeology

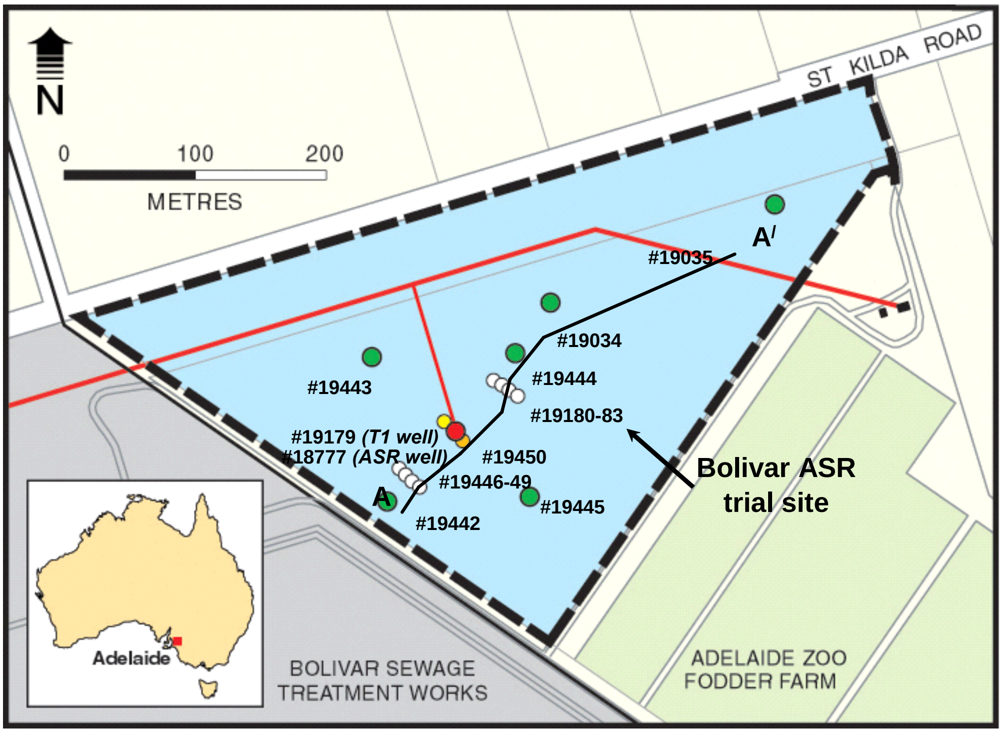
The Bolivar experimental ASR site is located on the Northern Adelaide Plains (NAP) in South Australia (Figure 3.17). At the site one major Tertiary aquifer, T1, is used for irrigation and the target aquifer for ASR is the underlying T2 aquifer, between depths of approximately 100 and 160 meters. The T2 aquifer is confined by an 8 m layer of clay and consists of variably consolidated calcarenite and sandstone of marine origin. Aquifer transmissivity, as determined from aquifer pump testing, is approximately 180 m^2 day^{-1} (Martin *et al,* 1998). The average porosity, as determined from core analyses, is 0.45. Locally, groundwater in the T2 aquifer has a salinity of ~2100 mg/L TDS. Mineralogical composition of the aquifer is dominated by calcite and quartz, but small quantities of ankerite, mica and albite are typically present (Table 3.40). There are trace amounts of organic carbon and some cation exchange capacity.

Table 3.40: Mineralogy of T2 aquifer (n=11)

Mineral	Percent
Calcite	49 - 88
Quartz	7 - 41
Ankerite	<1 - 17
Mica	<1 - 4
Albite	<1 - 2
Pyrite	<1
OC	0.08 - 0.25
$CEC_{(NH4)}$ (cmol(+)/kg)	0.9 - 3.6

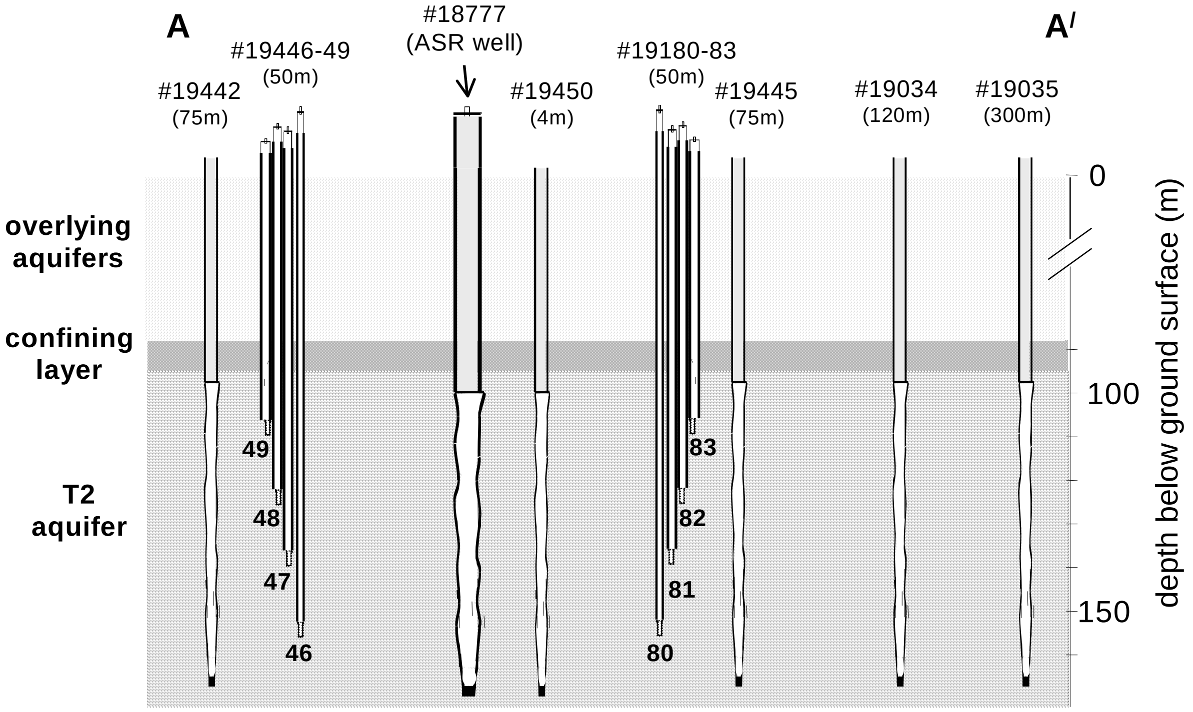
The production (ASR) well was constructed by rotary mud drilling and cased in 203 mm ID fibre reinforced plastic to 103 m and the remaining depth completed as open hole to ~160 m. To study the fate of the injected water, 16 observation wells have been drilled in the T2 aquifer.

Figure 3.18: Bolivar reclaimed water ASR trial site, showing ASR well and observation wells



Wells at radial distances of 4, 75, 120 and 300 m fully penetrate T2 (102-160 m), and the eight 50 m piezometers upgradient (NE) and downgradient (SW) of ASR well are completed over four distinct intervals of the aquifer, as illustrated in the cross section given in Figure 3.19.

Figure 3.19: Simplified vertical section showing location of ASR and observation wells



Experimental program

The initial aim is to inject 250 ML of reclaimed water before commencing recovery. At this volume it is anticipated that complete breakthrough would be observed at the majority of the 50 m piezometers, and that the salinity of an adequate volume of the recovered water would be acceptable for irrigation. Injection commenced in October 1999, and by November 2000 a net total of 132,000 m^3 had been stored during three injection tests Table 3.41. This cycle will be completed by a brief storage period followed by recovery until mixing with ambient groundwater precludes the use of the water for irrigation. Subsequent injection and recovery cycles are documented in Vanderzalm *et al,* (2003).

Table 3.41: Dates and volumes of injection events

Injection test	Period	Net volume (m^3)
test 1	11 Oct - 23 Nov 1999	30,000
test 2	6 Apr - 21 Apr 2000	7,000
test 3	4 Aug - 30 Nov 2000	95,000

Quality of Source Water and Groundwater

The ASR trial utilises water from the nearby Bolivar wastewater treatment plant and after storage in oxidations ponds, it is passed through a water reclamation plant involving dissolved air flotation filtration (DAFF) followed by disinfection. This water is delivered to the ASR site via the Virginia Pipeline Scheme, and since October 1999 has provided water on demand to farmers across the Northern Adelaide

Plains (Kracman *et al.,* 2000). This water is suitable for unrestricted irrigation in accordance with statutory requirements of the South Australian Government. Typical injected water quality is described in Table 5.3 along with that of the ambient groundwater, recovered water an a piezometer within the mixing zone. The groundwater is a sodium-chloride type of water and only the high concentration of ions prevents its use for irrigation (Table 3.42).

Results

Chemical and isotopic tracing of the injected water

A number of physical and chemical characteristics have been measured, and typical concentrations for several of these constituents are given in Table 3.42, racing the physical movement of the injected water in the aquifer requires good distinction between the injected water and the ambient groundwater. Chloride behaves conservatively in this system. The end members are distinctly different (407 *cf* 970 mg/L). However spatial variability in the chemical and isotopic composition of the aquifer (the aquifer exhibits distinct stratification), coupled with the temporal variability in the composition of the injectant, suggests that a multi-tracer approach would be useful in validating the mixing ratios that are derived (see below).

In addition to parameters such as EC, chloride and temperature that are listed in Table 3.42, deuterium, oxygen-18, carbon-14 and bromide, amongst others, are also being routinely monitored. Results to date show good agreement between breakthrough curves determined with stable isotopes, chloride and chloride to bromide ratios.

Table 3.42: Composition of typical injected water and ambient groundwater at the Bolivar ASR site

Parameter (mg/L)	Injectant [I]	Ambient Groundwater [II]	Recovered water [III]	50 m piezo water [IV]
EC (µS/cm)	2160	3710	2110	2720
Temp (^{o}C)	13.8	25.7	20.3	21.8
pH	7.1	7.3	7.2	7.0
DO	5.2	0.5	0.12	0.36
Eh (mV)	+641	-38	-55	+79
TSS	6	3	2	4
Turb (NTU)	4	7.8	10	9.7
Na	282	494	315	423
Ca	39.7	156	52.1	106
Mg	33.8	82	37.8	61.6
K	44.2	13.9	44.6	14.6
Cl	407	970	450	702
HCO_3	317	278	331	306
SO_4	194	279	199	269
Al_{tot}	0.30	N/A	<0.002	0.08
As_{tot}	<0.002	0.005	0.008	0.004
B	0.39	0.09	0.41	0.25
Cd_{tot}	<0.0002	<0.0002	N/A	<0.0005
Fe_{tot}	0.06	1.09	0.18	0.92
Pb_{tot}	0.002	<0.001	N/A	<0.0005
NO_x- N	1.22	<0.005	<0.005	0.16
NH_3- N	28.5	0.05	20.5	5.0
TKN - N	32.2	0.07	24.2	5.4
P_{react}	0.63	<0.005	1.69	0.007
P_{tot}	0.97	0.023	1.74	0.038
DOC	16	<0.3	13.9	5.5
TOC	18	<0.3	14.8	5.7
BOD	3	N/A	N/A	
AOC (µg/L)	1893	N/A	N/A	154
TTHMs (µg/L)	22	absent	1	<1
HAA (µg/L)	20			
Caffeine (µg/L)	<0.1	<0.1	N/A	N/A
E Coli. (cells/100mL)	0	0	0	0
Het. Plate Count (cells/mL)	450	N/A	10	3800
Clostridium perfingenes (cells/mL) [V]	>3000	0	>3000 [VI] 0 [VII]	0
Enteroviruses	N/A	N/D	N/A	N/D

[I] as measured on 08 Aug 00

[II] #18777 - ASR well (pre-injection)

[III] recovered from #18777 during pumping test, 16 weeks after end of test 1 on 16 Mar 00

[IV] #19181 on 19 Oct 00 after almost entire breakthrough

[V] results based on redevelopment undertaken in November 1999

[VI] from sample collected at 5 minutes after commencing redevelopment

[VII] for samples collected after 20 minutes of redevelopment

N/A not analysed

N/D Not detected

The mixing fraction "*f*" can be estimated from the following simple mass balance equations:

$$[C]_{mix} = f[C]_{inj} + (1-f)[C]_{amb} \qquad (1)$$

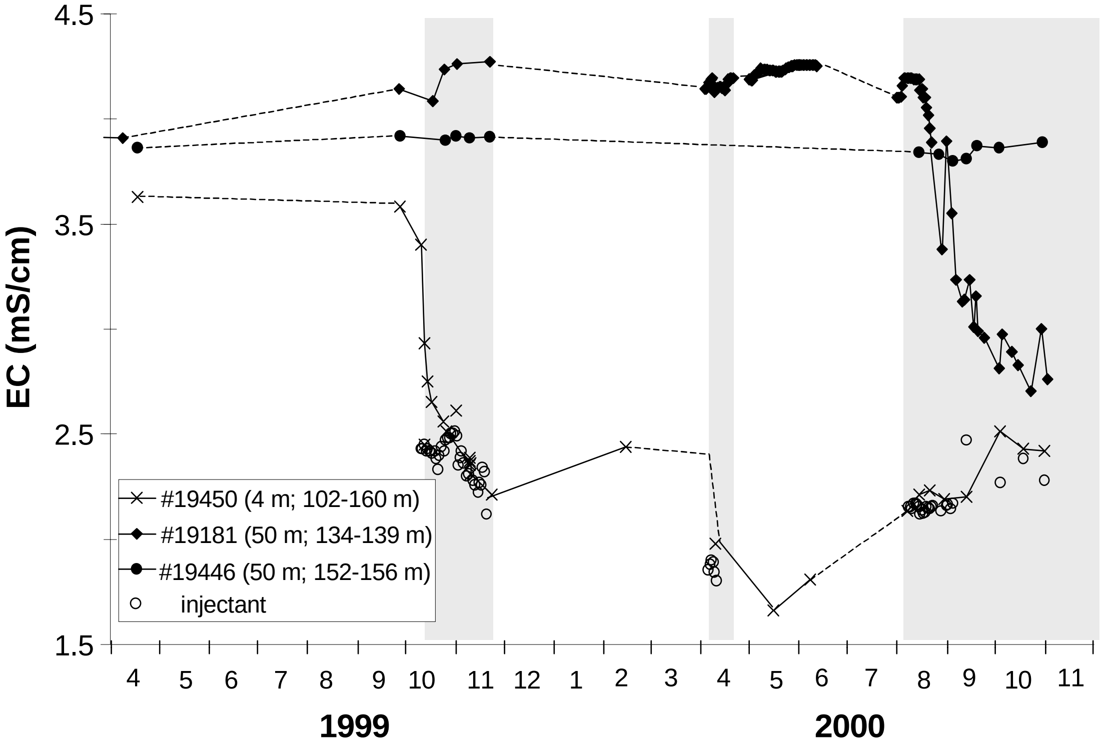
$$f = ([C]_{mix} - [C]_{amb}) / ([C]_{inj} - [C]_{amb}) \qquad (2)$$

where $[C]_{inj}$ and $[C]_{amb}$ are end-member concentrations of some given solute or isotope "[C]" in the injected water and ambient groundwater respectively. *f* represents the fraction of injected water present in a water sample only if the parameter considered behaves conservatively. For non-conservative parameters, comparing f with that calculated for conservative species provides one way to discriminate between mixing and attenuating processes, such as adsorption, precipitation and degradation.

Breakthrough of injected water at observation wells

Injection of the first 132,000 m³ has resulted in breakthrough at the 4 m well and in three of the 50 m piezometers. There has been no significant response for the other remaining piezometers/wells. Figure 3.20 shows the EC responses at several representative wells in addition to that of the injectant.

Figure 3.20: Electrical conductivities at observation well at 4m and two piezometers at 50m (injection periods are shown by shaded background; EC of injectant is also shown)



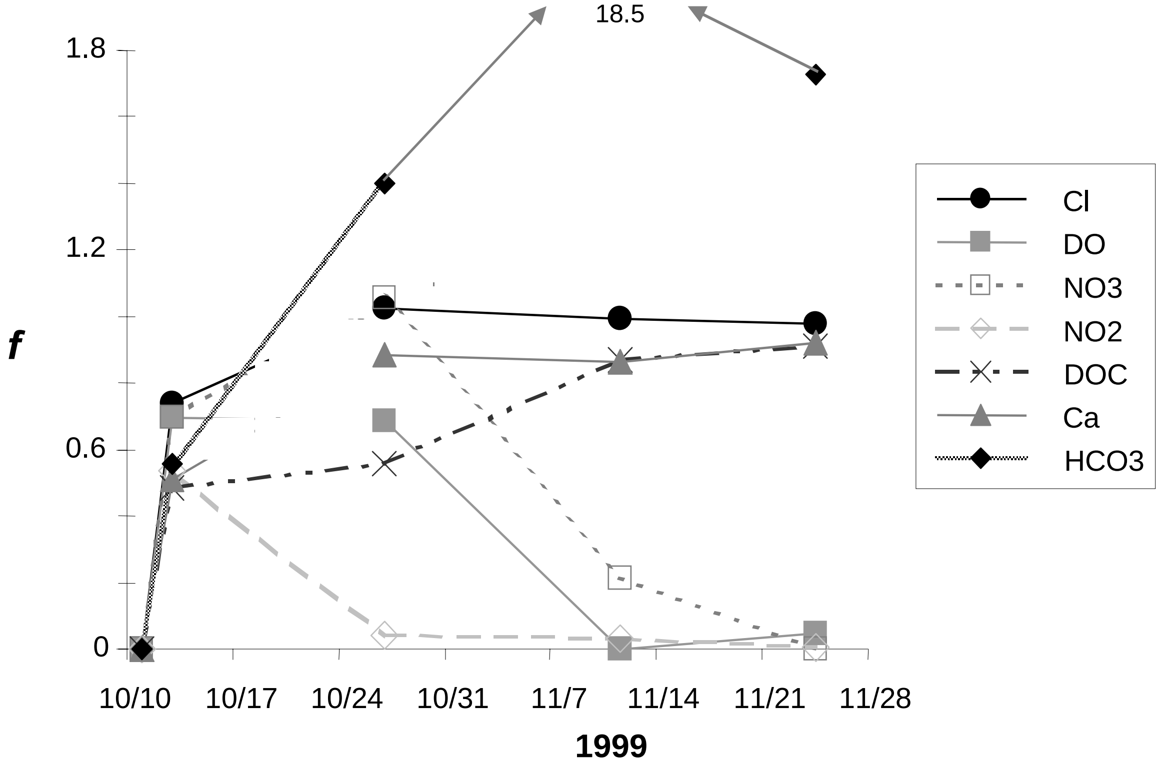
Downhole EC and temperature profiling signified the presence of injected water at the 4 m observation well within hours of the start of injection on 11 October 1999. Variability in the permeability and hence pore water velocity in different horizons can be inferred from the shapes of the profiles during the passage of the injection front. For any well that is uncased over the whole aquifer thickness mixing within the well may be significant where vertical hydraulic gradients occur (Georgiou, 2002). The temporal trends in water quality at 4 m following full breakthrough reflect variations in the quality of the injectant.

The water quality responses to injectant at 50 m piezometers to date have varied. At a depth of 134-139 m (at #19181) there has been almost complete breakthrough (Figure 3.20) (f = 0.58 +/- 0.05), based on chloride concentrations in equation 2, where the temporal variation in injectant concentration is the cause of uncertainty in f. At other piezometers, such as #19446, (Figure 3.20) completed over the deepest 152-156 m interval, there is no evidence of the presence of any injectant (ie. f~0).

Inorganic geochemistry

The near well geochemistry during the initial injection test of approximately 30 ML was dominated by oxidation of organic matter with influent oxygen and nitrate. The reaction sequence occurring was studied utilising conservative and reactive tracers and mass balance calculations (Vanderzalm *et al.*, 2000). Chloride was considered to be conservative. Figure 3.21 shows the mixing fraction "f" (equation 2) for chloride and various reactive species (dissolved oxygen (DO), nitrate (NO3), nitrite (NO2) dissolved organic carbon (DOC), calcium (Ca) and bicarbonate (HCO3)) during the initial injection test.

Figure 3.21: Mixing fractions (f) for chloride (Cl), dissolved oxygen (DO), nitrate (NO_3), nitrite NO_2), dissolved organic carbon (DOC), calcium (Ca) and bicarbonate (HCO_3) at the 4 m observation well during injection test 1



Oxic conditions were established soon after the commencement of injection. Conditions became anoxic between 27th October and 11th December, after approximately four weeks of injection. Microbial growth and the subsequent formation of a biofilm in the vicinity of the injection well were responsible for the consumption of the influent oxygen. Increasing bacterial biomass and polysaccharides during the injection trial were quantified using in situ sand chambers at the 4 m well (Rinck-Pfeiffer, 2000).

The organic matter in the influent was predominantly in the dissolved fraction (DOC) and therefore major consideration is given to this phase. Clearly DOC was depleted in comparison to chloride, notably in the first two to three weeks of injection. This large deficit was partly due to oxidation of influent organic matter, via aerobic respiration, which can be represented by the following reaction:

$$CH_2O + O_2 \rightarrow CO_2 + H_2O \qquad (3)$$

While Rinck-Pfeiffer (2000) witnessed the consumption of injected oxygen by nitrification of ammonium, this was not evident in the field trial where ammonium exhibited conservative behaviour within the 4 m radius. The oxygen deficit could be wholly explained by DOC degradation.

The oxidation of organic matter generates carbon dioxide (and water), which can induce dissolution of the calcite matrix as a buffering process:

$$CaCO_3 + CO_2 + H_2O \leftrightarrow Ca^{2+} + 2HCO_3^- \qquad (4)$$

Samples obtained from the 4m well had an excess of calcium with respect to mixing concentrations. Note that because the calcium concentration in injectant (40 mg/L) is lower than that in ambient groundwater (156 mg/L), from equation 2 a value of f less than one indicates relative enrichment (not depletion) with respect to conservative mixing. It appears that the initial oxidation of organic matter lead to dissolution of the aquifer matrix. Bicarbonate is also an end product of calcite dissolution but it is difficult to use in mass balance calculations as it is involved in various reactions. Its f reaches high values due to the relatively small difference between concentrations in injectant (317 mg/L) and ambient groundwater (278 mg/L).

In the latter stage of injection the deficits between DOC concentrations at the 4m well and those calculated for mixing were considerably smaller. The reduced depletion of DOC corresponded to the onset of anoxic conditions and anaerobic processes at the 4m well.

Oxygen levels below 0.5 mg/L at the 4m well allowed nitrate (NO_3^-) and nitrite (NO_2^-) to become the electron acceptors for the oxidation of organic matter, or denitrification:

$$4NO_3^- + 5CH_2O + 4H^+ \rightarrow 2N_2 + 5CO_2 + 7H_2O \qquad (5)$$

$$4NO_2^- + 3CH_2O + 4H^+ \rightarrow 2N_2 + 3CO_2 + 5H_2O \qquad (6)$$

Both nitrate and nitrite were completely removed from the groundwater with the breakthrough as shown in Figure 3.21.

The initial reductions in DOC seen at the 4 m well were larger than those calculated for oxidation alone. This suggests additional processes, such as sorption, contributed to the DOC depletion. Sorption of the higher molcular weight organic matter has been illustrated (Skjemstad *et al*, 2002). Later in the injection period, the decrease in DOC levels was less than that predicted for denitrification. A possible explanation is the turnover of microbial biomass or consumption of injected OC that had previously sorbed to the matrix. Oxidation of DOC appears to be limited by the availability of oxygen and nitrate. This suggests that higher influent nitrate, achievable through a more efficient nitrification of ammonium in the treatment process, may allow more degradation of organic matter through denitrification.

The third injection test, which included an additional chlorination step prior to entering the ASR well, has produced breakthrough of injectant at three of the piezometers at the 50 m radius. Movement of the injectant to the 50 m radius resulted in some retardation of potassium and ammonium, possibly due to ion exchange with calcium and magnesium (Vanderzalm *et al.*, 2003). Adsorbed ammonium can later be oxidised if sufficient oxygen or nitrate is added to exceed that required by the influent DOC.

During the storage period between injection and recovery major changes in the reclaimed water were decreases in dissolved oxygen, nitrate and organic matter and some buffering of pH, calcium and bicarbonate (Vanderzalm *et al.*, 2002). Microbial activity in the vicinity of the ASR well produced some dramatic water quality variations within the first 1 ML of recovered water. Deeply reducing conditions, with both sulfate reduction and methanogenesis, were found adjacent to the well-face. However at the 4 m radius and further into the aquifer, sulfate remained stable. Thus the general quality of the recovered water was not affected by excessive microbial activity. Removal of nitrate and dissolved organic carbon by natural attenuation has been illustrated.

It is proposed to consolidate information obtained from mass balance methodology with data from isotopes of carbon, sulfate and nitrate. While these analyses are in the preliminary stages, these data should provide valuable information for interpretation of the reactions occurring. Isotopes can add valuable information to elucidate the reaction pathways including the consumption of available electron donors (Le Gal La Salle, 2002). While isotopes have been widely used in studies of recharge and pollution studies, their utilisation in ASR is small.

Natural organic matter (NOM)

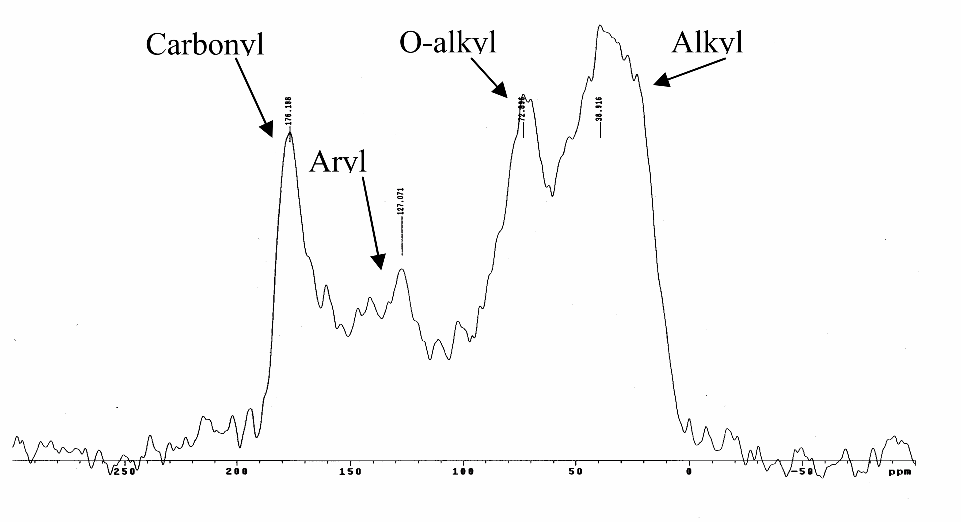
The treated Bolivar water contains significant quantities of NOM. The carbon content of the injectant is typically 15-20 mg-C/L. At the 4 m well, this has been reduced to near 14 mg-C/L but by breakthrough at the 50 m radius well this is substantially reduced to near 5 mg-C/L (Table 3.42). The substantially lower *f* of ~0.3 for TOC as compared with ~0.6 for Cl suggests that there are organic carbon losses to 50 m. This reduction in DOC can potentially result from biological or chemical oxidation, precipitation or adsorption within the aquifer.

Each of these processes has consequences for aquifer sustainability with precipitation potentially limiting storage. As well, little is known about the chemical nature of reclaimed water and the possibility exists for the formation of mutagenic or carcinogenic substances as a result of chlorination. If particular precursors are removed within the aquifer by the processes described above, then the potential for the production of such substances is reduced.

Solid state ^{13}C NMR spectroscopy has been employed on a series of injection waters to assess variability in the organic functionalities with time. The samples analysed at the time of writing indicate that the waters have a similar chemistry dominated by short-chained alkyls, polysaccharides and carbonyl materials (Dillon *et al*, 2005). The latter are a mixture of acids and amides and there is little aromatic material present. An example spectrum of the injectant is given in Figure 3.22. Analyses had yet to be made on water from the 4 m or 50 m piezometers.

If precipitation or adsorption are significant processes within the aquifer, it is likely that particular fractions of the DOC are involved and not the DOC as a whole. High pressure size exclusion chromatography (HPSEC) was used to test if particular molecular weight fractions were lost during the passage of the DOC through the aquifer. This technique showed that the breakthrough water at the 50 m piezometer contained DOC that appeared to have lost the highest molecular weight fraction.

Figure 3.22: ^{13}C NMR spectrum of injectant (after Skjemstad et al 2002).



It will be important therefore to determine whether the loss is largely due to precipitation or adsorption since the former may clog pores and thus limit the life of the storage system. If adsorption is the major mechanism, it would be expected that once the surfaces were saturated, DOC would have little further interaction with the matrix but may affect biomass production within the aquifer.

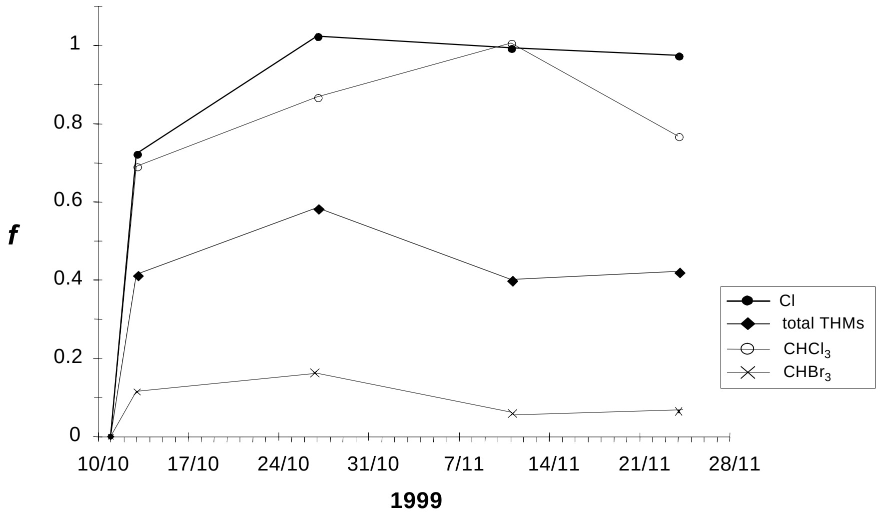
Disinfection by-products (DBPs)

Although DBPs are not an issue at this site since the recovered water will not be used for potable purposes, the detailed characterisation of the aquifer material and ambient groundwater, monitoring the quality of the chlorinated injectant for a range of characteristics (including NOM), and sampling from a number of observation wells and later in recovered waters, will to lead to a better understanding of the fate and transport of DBPs within the aquifer.

Results of trihalomethane (THM) analyses reveal concentrations in the injectant, as measured at the well head, ranging from 5-22 µg/L. These values are relatively low, possibly due to the high level of ammonia in injectant (eg 28.5 mg/L, Table 3.42), which preferentially reacts with chlorine gas to form chloroamines.

Information on the fate of THMs is emerging from results of breakthrough at the 4 and 50 m wells. The breakthrough of THMs at the 4 m well are presented in Table 3.43. Although virtually none of the brominated species were detected, chloroform was highly mobile, with little or no attenuation observed. The residence time of the injected water at this well, as determined from the chloride breakthrough response, varies from 1 to 2 days according to flow rates. Subsequent sampling from the ASR well on 16 March 2000, where the minimum storage time of the injected water was 16.3 weeks, found chloroform concentration to be only 1 µg/L, substantially less than the average concentration injected of 6 µg/L. Other THMs were below detectable limits. Similarly, data from 50 m piezometer #19181 shows no detectable THMs, even though, as previously mentioned, there was approximately 60% breakthrough of chloride from injectant as of the 19 October 2000 sampling. The residence time of this water is of the order of at least several months.

Figure 3.23: Mixing fractions (f) for various THMs at 4 m observation well (#19450) during injection test 1.



These data suggest that although degradation rates for chloroform are lower than brominated compounds, that it may be persistent only over a limited time frame. The extended spatial and temporal scales associated with the 50 m piezometer appears to have been sufficient for degradation to occur. THM attenuation at this site is studied further in Dillon *et al* (2005a).

Since the start of test 3 in August 2000, analyses were extended beyond THMs to include haloacetic acids (HAAs) and formation potentials (FP) of THMs and HAAs. An example of these results is given in Table 5.4, where the total THMs and HAAs of the injectant, 4 m and 50 m well water and their formation potentials are shown for the 19 October 2000 sampling. The higher THM-FPs at the 50 m well than in the injectant or 4 m well may be due to the lower ammoniacal-nitrogen concentrations. It is probable that the 20 mg/L chlorine dosing concentration used to determine FP may be inadequate to consume the ammonia present.

A more comprehensive evaluation of the fate of DBPs at the Bolivar site is given in Nicholson *et al,* (2002) and Dillon *et al,* (2005).

Table 3.43: Total THMs and HAAs and their formation potentials (FP) of injectant and groundwater at 4 m and 50 m wells as sampled on 19 October 2000

	f	NH_3-N (mg/L)	TTHM (µg/L)	TTHM-FP (µg/L)	HAA (µg/L)	HAA-FP (µg/L)
injectant	1.0	24.3	13	21	6	22
4 m (#19450)	1.0	24.7	7	24	<5	35
50 m (#19181)	0.58	5.0	<4	49	<5	23

Microbial pathogens

Current research has focused on the survival of microbial pathogens in the T2 aquifer fed by nutrient rich injectant, with particular reference to the use of *Cryptosporidium* parvum as an inoculant organism. Some associated research has also been done to further develop methods for the rapid genotyping of *Cryptosporidium parvum* isolates.

The pathogen survival experiment was undertaken by suspending chambers containing selected microbial pathogens in the 4 m and 300 m observation wells. The pathogens studied were Cryptosporidium parvum oocysts, MS2 coliphage, E. coli and Aeromonas hydrophila. The chambers used for the bacterial strains were the modified McFeters chambers (Pavelic *et al.*, 1998), while the Cryptosporidium oocysts and viruses were contained within single-use chambers hung in groups within each of the wells. Each chamber contained a predetermined number of pathogens suspended in either filter sterilised or non-sterile groundwater.

An initial sample (day 0) was analysed and then the chambers were sampled after weeks 1, 2, 4, 6, 8, and 10. The bacteria in the chambers were sampled by removing approximately 1 mL of sample from the chamber that was transferred to a sterile 2 mL screw capped tube. On each sampling occasion, one of the single-use chambers containing oocysts and viruses in sterile groundwater and one chamber containing these microorganisms in non-sterile groundwater were removed from the string of single-use chambers suspended in each of the wells. The collected samples and chambers were then packed in a biohazard transportation box and air transported to the CSIRO microbiology laboratory in Perth where they were processed immediately on receipt. Bacterial numbers were determined by plating each sample onto selective media (Chromocult™ , Merck) and incubating for 48 hours at 37 ºC. The presence of *Cryptosporidium* oocysts was determined by immunofluorescence and PCR (Gobet and Toze, 2001). The sample for coliphage analysis was concentrated and the MS2 coliphage was detected by infecting a culture of *E. coli* host. The number of microorganisms detected on each sampling occasion was then determined (the concentration factor was also taken into account at this stage for the MS2 bacteriophage). At the completion of the experiment a one $\log_{10}$ removal time τ for each organisms was determined using the following equation:

$$\tau = t/\log_{10}(C_t/C_0) \text{ (days)} \qquad (7)$$

where t = incubation time, C_t = number of organisms at day t, C_0 = number of organisms at day 0.

A laboratory experiment was undertaken to confirm the results obtained from the field-based experiment. The laboratory experiment enabled a wider range of microorganisms to be tested (including poliovirus and coxsackievirus, that were unavailable at the time of the field experiment) and allowed study of the decay of these selected microorganisms under controlled conditions. The complete details of the experimental plan and results for the laboratory experiment are given in Toze and Hanna (2002). In addition, the methods used to study pathogen decay within a laboratory environment are described in Dillon *et al* (2005a).

The one $\log_{10}$ removal times for the microorganisms studied in the field experiment are given in Table 3.44 while the results of removal times obtained for the laboratory experiment are given in Table 3.45. The decay of the organisms in the field experiment can be seen in Table 3.44 and in Table 3.45 for the laboratory experiment.

It should be noted that it was found that the majority of the chambers containing either filtered groundwater or filtered injectant were contaminated by groundwater microorganisms. This was probably due to failure during the filtration of the groundwater or injectant used to fill the chambers designated to contain filtered water to remove all of the microorganisms present in the sample. This would have been most likely due to the need to set up the chambers in the field which allowed cross contamination of filtered and non-filtered water to occur. The experimental method will have to be assessed as to modifications required to the set up of future field experiment. Thus, all of the chambers were treated as non-filtered and to have groundwater microorganisms present. This is not of particular concern as it has been established that the presence of indigenous groundwater microorganisms are the most significant factor controlling the decay of introduced microbial pathogens (Toze and Hanna 2002, Gordon *et al.* 2002).

Difficulties were encountered in the detection of the *Cryptosporidium* oocysts from the chambers using immunofluorescence. Further investigation has shown that the use of bleach in purification of the oocysts from contaminated faecal matter significantly reduces the sensitivity of the immunofluorescence. The PCR results have indicated that there appeared to be no appreciable decrease in detectable Cryptosporidium DNA from any of the chambers over the period of the experiment, however, quantitation of these PCR results could not be performed.

In the field experiment all of the bacteria and MS2 had one $\log_{10}$ removal times of less than 17 days apart from *E. coli* in the “filtered” injectant sample where a removal time of 33 days was observed and *A.hydrophila* in the non-filtered injectant (53.8 days) and the filtered injectant where no significant decay was observed over the period of the experiment. The observed trend for *E. coli* decay in all of the water types was for viable cell numbers to be relatively stable for the first 7 to 14 days after which rapid loss of the cells in the chamber was observed Figure 3.24. *E. coli* was observed to persist for longer in the injectant than the ambient groundwater suggesting that the injectant was providing an environment (possibly via nutrient supply) which allowed a temporary persistence of the *E. coli* cells. This was also observed for *A. hydrophila* cells where a slow to negligible removal was observed in the injectant and a much faster loss in the groundwater. The removal times for both *E.* coli and *A.* hydrophila were similar in the groundwater. In contrast, the bacteriophage MS2 was rapidly removed from both groundwater and the injectant which was almost always faster or similar to the removal times for the bacteria.

Table 3.44: One $\log_{10}$ removal times (days) for E. coli and A. hydrophila in injectant and groundwater at the Bolivar ASR site

Water type	Water treatment	Microorganisms Tested		
		E. coli	*A. hydrophila*	MS2
Injectant	Filtered	33.2	ND§	4.2
Injectant	Non-filtered	10.9	53.8	3.6
Groundwater	Filtered	6.2	7.5	5.1
Groundwater	Non-filtered	10.8	6.1	12.8

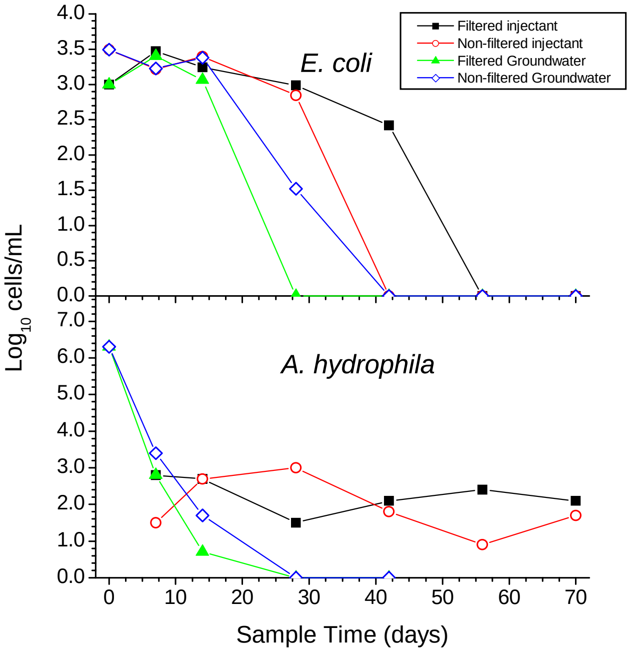
§ ND = No decay observed

Table 3.45: One $\log_{10}$ removal times (days) of tested pathogens and indicator microorganisms in the laboratory

Water type	Water treatment	Microorganisms Tested					
		E. coli	*S. typhimurium*	*A. hydrophila*	MS2	*Poliovirus*	*Coxsackie-virus*
Distilled water		3.8	3.4	4.8	25.6	23.3	20.4
Injectant	Filtered	12.3	4.3	7.7	4.3§	2.6§	17.5§
Injectant	Non-filtered	0.7	0.4	2.2	4.3	3.0	7.1
Groundwater	Filtered	5.2	5.0	5.7	4.4§	27.8	9.9§
Groundwater	Non-filtered	1.0	1.1	1.7	3.4	2.7	7.1

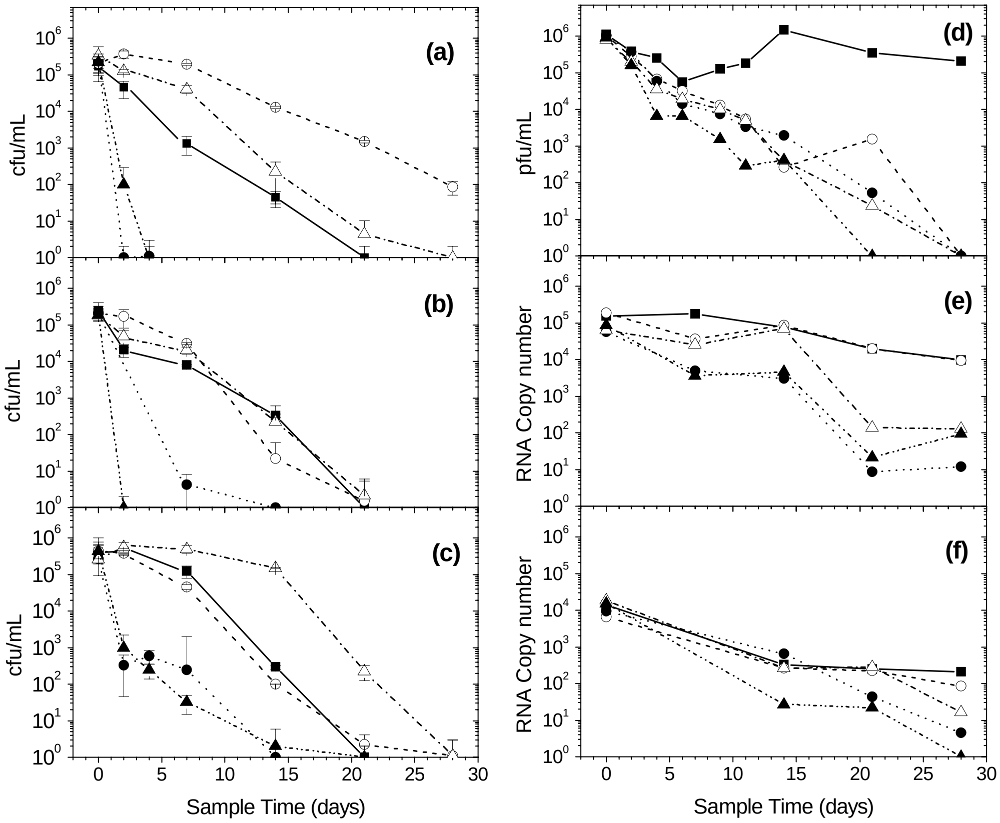
§ Groundwater bacteria detected in microcosms after day 7

Figure 3.24: Survival of *E. coli* and *A. hydrophila* in injectant and ambient groundwater at the Bolivar ASR site.



The removal times obtained from the field survival experiment differ slightly from the results obtained in the laboratory experiment (Table 3.45 and Toze and Hanna 2002), with slightly faster removal times for *E. coli*, *A. hydrophila* and MS2 observed in the laboratory experiment. The $\log_{10}$ removal times determined for these microorganisms in the laboratory experiment in injectant or groundwater were still less than 13 days. In addition, the survival potential of *Salmonella typhimurium*, poliovirus and coxsackievirus were able to be studied. The results obtained showed that *S. typhimurium* had a similar survival potential to *E. coli* but poliovirus and coxsackievirus had slightly slower removal times than the bacteria. None of the microorganisms tested, however, had one $\log_{10}$ removal times larger than 20 days apart from poliovirus in filtered groundwater (Table 3.45). Decay profiles for *E. coli* and *A. hydrophila* in the laboratory experiment (Table 3.45) were similar to those observed in the field experiment (Figure 3.24) with initial lags of persistence followed by rapid decay.

Figure 3.25: Survival of (a) E. coli, (b) S. typhimurium, (c) A. hydrophila (d) MS2, (e) poliovirus and (f) coxsackievirus during laboratory based experiment in ■ distilled water; ○ sterile injectant; ● non-sterile injectant; Δ sterile groundwater and ▲non-sterile groundwater.



Apart from the survival experiments other pathogen research undertaken as part of the Bolivar project has involved the concentration of *Cryptosporidium parvum* oocysts from water samples using immunomagnetic separation (IMS) and work on the establishment of an original PCR-restriction fragment length polymorphism (PCR-RFLP) protocol for the genotyping of *Cryptosporidium* isolates.

The IMS technique has been presented in the literature as an effective technique for the purification of *Cryptosporidium* oocysts in water. Experiments conducted on different types of seeded water concentrates from Bolivar (injectant, 4, and 50 m wells) gave a wide range of parasite recovery rates. Investigation on the parameters affecting this recovery was then undertaken. Several points came out of this preliminary study:

(1) The presence of significant amounts of solid particles (essentially aquifer minerals) from the 4 and 50 m wells had a significantly negative effect on oocyst recovery. A personal enquiry over the phenomenon with the R&D headquarters of Dynal in Norway (Dr A. Campbell) was undertaken. As a result, we are assisting Dynal trial a new buffer more suitable for application in environmental waters containing suspended particles. The new buffer very significantly boosted recoveries from 5 to 43%. However, both the new test buffer and the original commercially available buffer failed to improve IMS efficiency when working on water concentrates containing high levels of iron oxide.

(2) Some samples (injectant concentrates) contained polysaccharide aggregates probably formed during the first concentration step carried out in Adelaide using the tangential flow filtration (TFF) unit. These aggregates significantly interfered with the magnetic separation of the beads, leading to poor parasite recovery. Work is continuing on the optimisation of the use of the TFF unit. One highly critical parameter in this respect is the ratio of concentrate to permeate flow rate. A new pump head with larger tubing which allows a higher permeate flow rate has already given promising results.

Conclusions

Water quality changes during the injectant of the first 132 ML of reclaimed water in a calcareous aquifer at the Bolivar ASR research site have been monitored at observation wells and in short-interval piezometers. Breakthrough of injected water occurred within 1-2 days at the 4 m observation well and much later at three of eight piezometers at a 50 m radius. The observed distribution of injected water has largely been as anticipated from aquifer characterisation and groundwater modelling work.

The main reactions occurring when oxic, nutrient-rich waters are injected into the anaerobic carbonaceous aquifer are dissolution of the calcite matrix and denitrification and oxidation of organic matter, resulting in increased biomass and consumption of dissolved oxygen. The use of carbon, sulfur and nitrogen isotopes to delineate reaction pathways is currently ongoing.

The uses of NMR and HPSEC methods to examine the fate of organic matter injected into the aquifer and to characterise the injectant have largely been successful.

Low but measurable concentrations of various disinfection by-products are routinely present in the injectant. Breakthrough responses reveal that brominated compounds are removed more rapidly than chlorinated compounds, but that chloroform, the most persistent THM, is also attenuated when spatial/temporal scales are sufficiently large.

A 12 week microbial survival experiment using *in situ* diffusion chambers has been conducted for selected microorganisms. The results showed that one $\log_{10}$ removal times for these organisms were generally short and typically less than 12 days. A laboratory replication of this study confirmed these relative removal times and the removal behaviour of *E. coli*, *A. hydrophila* and the bacteriophage MS2. Other work relating to the concentration of *Cryptosporidium parvum* oocysts from water samples using the IMS technique were reported.

In summary, the Bolivar study site represents a unique opportunity to evaluate the attenuation of contaminants in an aquifer and effects on microbially mediated reactions due to the high organic loadings in injectant, at levels greater than would generally be considered acceptable as a source water for drinking water supplies. However stimulating the aquifer in this way is expected to give a clearer picture of what may be acceptable, and has the potential to challenge widely held theories.

3.3.6.3 INFILTRATION-PERCOLATION AT GREATER AGADIR (MOROCCO)

Introduction

The so-called Greater-Agadir is a rapidly growing area of Morocco with a population of over 350,000. It faces an increasing need for wastewater treatment and an increasing demand for water supplies. The two main discharges of raw sewage — one into the port area, the other into the bed of the Souss wadi within a few kilometres of its mouth — are incompatible with a valuable tourist attraction. Therefore, in a cooperative project between Morocco and France, pilot wastewater treatment through dune sand infiltration–percolation is underway at Ben Sergao, a suburb of Agadir (Bennani *et al.*, 1992).

Treatment scheme

The initial chemical oxygen demand (COD) of raw sewage is 1190 mg/l, and the first treatment is by an anaerobic stabilization pond. The anaerobic stabilization pond (1500 m^3, residence time of 1.4 days, depth of 3–4 m) is used to reduce suspended solids (40–50 %) and organic matter (50–60 %), increasing the rate of infiltration and reducing the surface area necessary for the infiltration basin.

1000 m^3/day of highly concentrated effluents are treated by infiltration–percolation using 5 infiltration basins of 1500 m^3 each. An infiltration basin consists of 2 m thick eolian sand, whilst the product water is drained from the base where a network of pipes is placed into a gravel layer. Each basin is submerged for 8 hours and remains dry for 16 hours. The wastewater is infiltrated at the rate of 1 m/day. Nearly 100% of suspended solids and 95% of COD are removed; 85% of nitrogen is in oxidized form and 56% is removed. Microbiological quality of raw sewage, pond effluent and percolated water are shown in Table 3.46; removals are satisfactory. In Table 3.47 some physisco-chemical data are presented, which show that K, P and conductivity are not significantly affected by the system, whereas COD and NTK are significantly decreased and NO_x are formed.

The percolated water will be used in growing tomatoes, public gardens and future golf courses (adapted from Aertgeerts and Angelakis, 2003).

Table 3.46: Bacterial characterization of raw sewage, pond effluent and percolated water at Ben Sergao [Bennani et al., 1992]

	Raw sewage	Pond effluent	Percolated water	Overall removal efficiency
Fecal coliforms (No./100 mL)	6x106	5x105	327	4.26 logs
Fecal streptococci (No./100 mL)	2x107	1.6x106	346	4.78 logs
Nematode ova (No./L)	139	32	0	~100%
Cestode ova (No./L)	75	18	0	~100%
Total helminths ova (No./L)	214	47	0	~100%

Table 3.47: Overall system removal of physico-chemical parameter

Variable	Raw Water	Treated water
K (mg/L)	36.7	37.1
Conductivity (mS/cm)	2075	1930
TSM (mg/L)	431.0	2.8
COD (mg/L)	1189	52
NTK (mg/L)	116	17
NO_2 (mg/L)	~0	2.3
NO_3 (mg/L)	~0	146
P (mg/L)	35.2	36.2

3.3.6.4 DIRECT INJECTION AT FRED HERVEY (CALIFORNIA, USA)

At Fred Hervey water reclamation and groundwater recharge plant, the aquifer "Bolson del Hueco" is recharged by direct injection with residual water treated at a potable level. The influent and effluent quality, as well as the quality of the aquifer that is recharged is shown in . The recharge permit requires:

- the monitoring of 23 parameters and a record of the average for 30 days
- the result of 8-hour batch analysis be less than 10 mg nitrates N/l and turbidity less than 5 NTU nephelometric

The treatment consists of a biological process in two stages, with powdered activated carbon, treatment with lime, recarbonation, sand filtration, ozonation, adsorption in granular activated carbon and storage. Water is carried to 11 injection wells and the residence time is at least two years before extraction. The reclaimed water is of very high quality (adapted from Aertgeerts and Angelakis, 2003).

Table 3.48: Water quality at Fred Hervey (Bureau of Reclamation,1993)

Parameter	Influent	Effluent	Bolson del hueco	Recharge permit limits
Alkalinity (mg/L)	250	150	129	
Ammonia N (mg/L)	25	<0.1		
Boron (mg/L)	<1	<0.8		
Calcium (mg/L)	35	50	45	
Chlorides (mg/L)	122	140	64.7	300
COD (mg/L)	400	<10		
E. coli (MPN/100mL)		0		
Electrical conductivity (dS/m)	1.20	1.00	0.51	
Fluorides (mg/L)	0.9	0.9	1	
Magnesium (mg/L)	7.9	3	10.6	
pH	7.1	7.5–8	8.1	
P-PO$_4$(mg/L)	20	0.1	<0.5	
Sodium (mg/L)	192	145	96	
Sulfates (mg/L)	125	125	53.7	300
Silica (mg/L)	38	38	38	
Total hardness (mg/L)	120	140	102	
Total nitrogen (mg/L)	36	2		
N-nitrates (mg/L)	0	1.5	<2.1	10
TOC (mg/L)		< 2		
Turbidity (mg/L)	97	<0.5	0.14	1
TSS (mg/L)	150	<1		
Cyanides (mg/L)		0.02		
Arsenic (mg/L)	0.008	0.05		0.05
Barium (mg/L)	0.46	0.1		1
Cadmium (mg/L)	<0.01	<0.01	<0.01	0.01
Chromium (mg/L)	0.01	0.01	<0.05	0.05
Copper (mg/L)	< 0.05	<0.05	<0.1	1
Iron (mg/L)	<0.31	0.05	<0.1	0.3
Lead (mg/L)	<0.05	<0.05	0.05	0.05
Manganese (mg/L)	<0.05	<0.05	0.01	0.05
Mercury (mg/L)	0.002	0.0014		0.002
Selenium (mg/L)	<0.0035	0.01		0.01
Silver (mg/L)	<0.01	<0.01		0.05
Zinc (mg/L)	<0.1	<1	0.1	5
Aluminium (mg/L)	0.28	<0.15		
Colour (mg/L)	52	<10		
MBAS (mg/L)	3.5			
Corrosion	0.2			
Hydrogen sulfide (mg/L)		Non corrosive		
Odour, TON	11	0.01		
TDS (mg/L)	770	1	391	1000
Dissolved oxygen (mg/L)		1		

2-4 D = 2,4-dichlorophenoxyacetic acid; 2,4,5-TP = 2,4,5-trichlorophenoxypropionic acid; MBAS = methylene blue active substances; TON = threshold odour number

Data correspond to the effluent and influent design data

3.3.6.5 DIRECT INJECTION AT WF 21 AND THE GROUNDWATER REPLENISHMENT SYSTEM (CALIFORNIA, USA)

Introduction

Orange County has been practicing aquifer recharge via both infiltration and direct injection for almost 30 years. The aim is to maximize the use of local water resources, as already in the early 1950s, the overexploitation of aquifers had led to saline intrusion into fresh water aquifers.

Orange County's groundwater basin (the Basin) covers 229,000 acres and currently provides potable water for over 2.3 million residents of North and Central Orange County. The Basin's primary water supply is obtained from the Santa Ana River, which is recharged into the Basin. Supplemental sources are imported from the Colorado River and State Water Project. The Orange County Water District (OCWD) currently owns over 1,000 acres of land dedicated to groundwater recharge near the Santa Ana River and sub-streams. The Basin is capable of storing up to 66 million acre-feet of water and the basin's water quality and stability are generally compromised when 500,000 acre-feet of water is withdrawn. The Basin is connected to the Pacific Ocean by a 2.5-mile stretch between the Huntington and Newport Beach mesas known as the Talbert Gap. As groundwater basin levels decrease (i.e., basin overdraft), seawater is drawn into the Basin through the Talbert Gap, and the water quality of the Basin is negatively impacted.

To address the issue of seawater intrusion, in 1976 OCWD began recycling Orange County Sanitation District (OCSD) wastewater and injecting it along the Talbert Gap via a series of injection wells to form a hydraulic barrier. The treatment facility was known as Water Factory 21 (WF-21) and was the first wastewater treatment plant of its kind. For over 25 years, WF-21 provided approximately 5-15 million gallons per day (mgd) of water for the Talbert Gap seawater intrusion barrier (the Barrier). Since early 1990s, it was evident that WF-21 was reaching the end of its useful life and that the facility should be expanded: though the Barrier was successful in reducing seawater intrusion, it was also clear from increasing chloride concentrations near the Talbert Gap that additional supplies were needed to sustain it. As it was determined that it was more cost-effective to replace WF-21 than to try and expand the existing facility, the Groundwater Replenishment System was developed (adapted from Daughtery *et al.*, 2004).

Treatment scheme

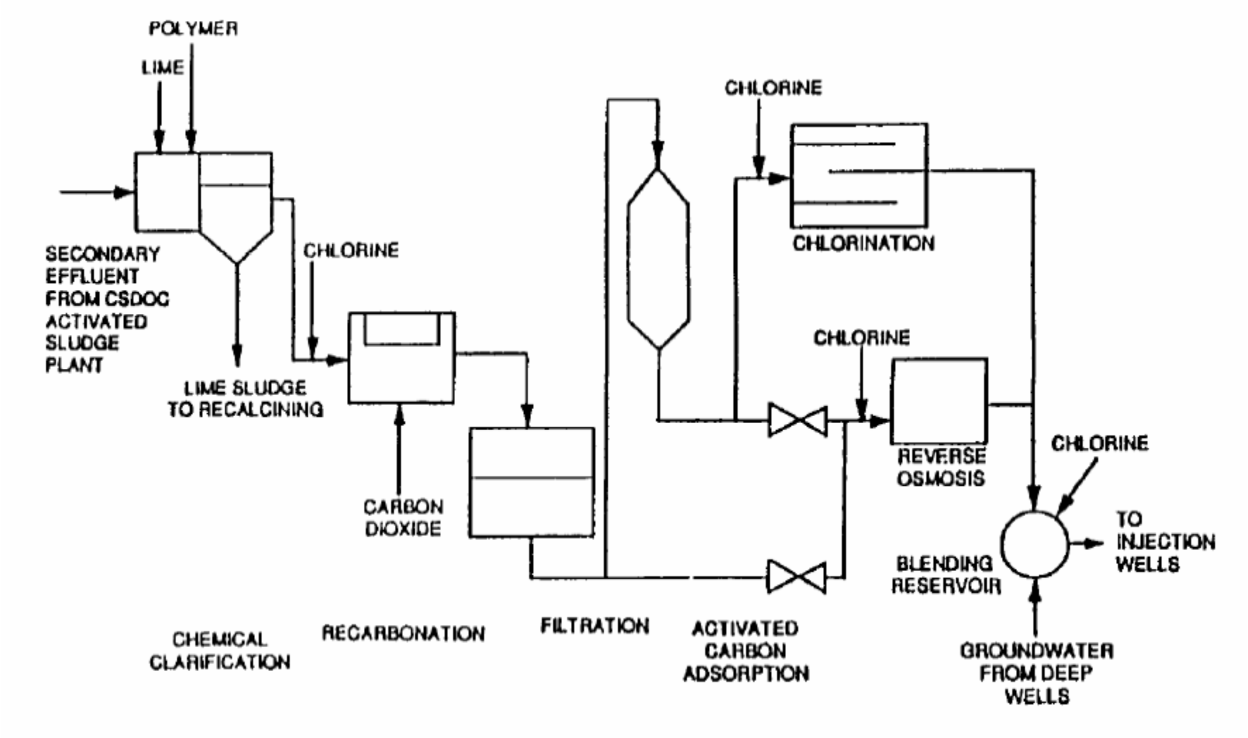
At Water Factory 21 (WF 21), a water-reclaiming project for direct advance injection into the aquifer and via infiltration ponds using natural percolation, has been successfully realised from 1976 to 2004, when the facility has been dismissed to allow further expansion.

Originally, the treatment scheme reproduced in Figure 3.26 was applied, treating secondary effluent with lime clarification, recarbonation, chlorination, mixed media filtration, granular activated carbon and reverse osmosis (using cellulose acetate membranes). 2/3 of reclaimed water was blended with 1/3 of groundwater before injection. The availability of water was increased from 6.2 x10^7 to 9.3 x 10^7 m/year (Mills *et al.*, 1994).

In the following, given the consistency of the reclaimed water quality, the Orange County Water district (OCWD) was given the permission for injection of 100% reclaimed water (Mills and Watson, 1994). However, during its latter years, WF-21 produced 5 mgd of injection water, which was blended with other potable and deep well water sources to achieve a total of 15 mgd of injection water for the Barrier. From 2000, advanced oxidation combining UV with Hydrogen peroxide was introduced.

It must be remarked that WF 21 has consistently produced water exceeding the standards for human consumption.

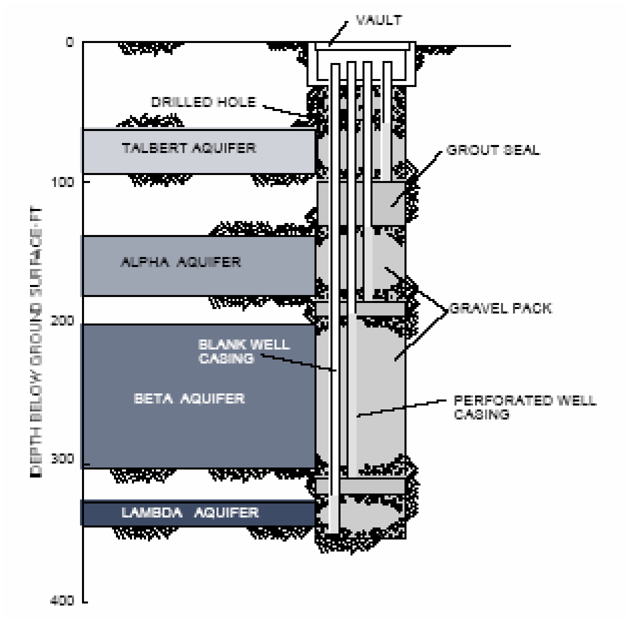
Figure 3.26: Flow diagram of Orange County Water District Water Factory 21 [Mills and Watson, 1994]



Infiltration

The purpose of Water Factory 21 was to produce a water supply for the Talbert Barrier to prevent seawater intrusion. Final plant effluent was pumped into the groundwater basin via a series of 23 multi-point injection wells with a total of 81 individual injection points. Injection wells were placed approximately every 600 feet along Ellis Avenue from the Santa Ana River to the bluffs at Beach Boulevard. These injection wells (see Figure 3.27) are still operative and will be included in the expanded groundwater recharge project (see also Figure 3.28). Once underground, some of the injected water flows toward the ocean, forming the seawater barrier. The majority of the water, however, flows into the groundwater basin to augment Orange County's domestic groundwater supply.

Figure 3.27: Injection well at WF 21[http://www.ocwd.com/_html/wf21.htm]



Water Quality

The results of effluent monitoring are shown in Table 3.49.

Table 3.49: effluent quality at WF 21[Mills et al. (1998)]

Component	Selected parameters for permitted conditions [a] (mg/L)	Average concentration in 1994 for injection water [b] (mg/L)
Boron	0.7	0.2
Chloride	120	90
Fluoride	1.0	0.5
Total nitrogen	10	3.7
Sodium	115	64
Sulfate	125	40
pH	6.5–8.5	7.4
Total dissolved solid	500	237
Hardness	180	33
Total organic carbon [c]	2.0	1.9
Aluminium	1.0	0.05
Arsenic	0.05	0.002
Barium	1.0	0.006
Cadmium	0.01	0.001
Chromium	0.05	0.001
Cobalt	0.2	0.002
Copper	1.0	0.008
Cyanide	0.2	0.04
Iron	0.3	0.054
Lead	0.05	0.006
Manganese	0.05	0.004
Mercury	0.002	0.0005
MBAS	0.5	0.06
Selenium	0.01	0.005
Silver	0.05	0.001
Zinc	5.0	0.057

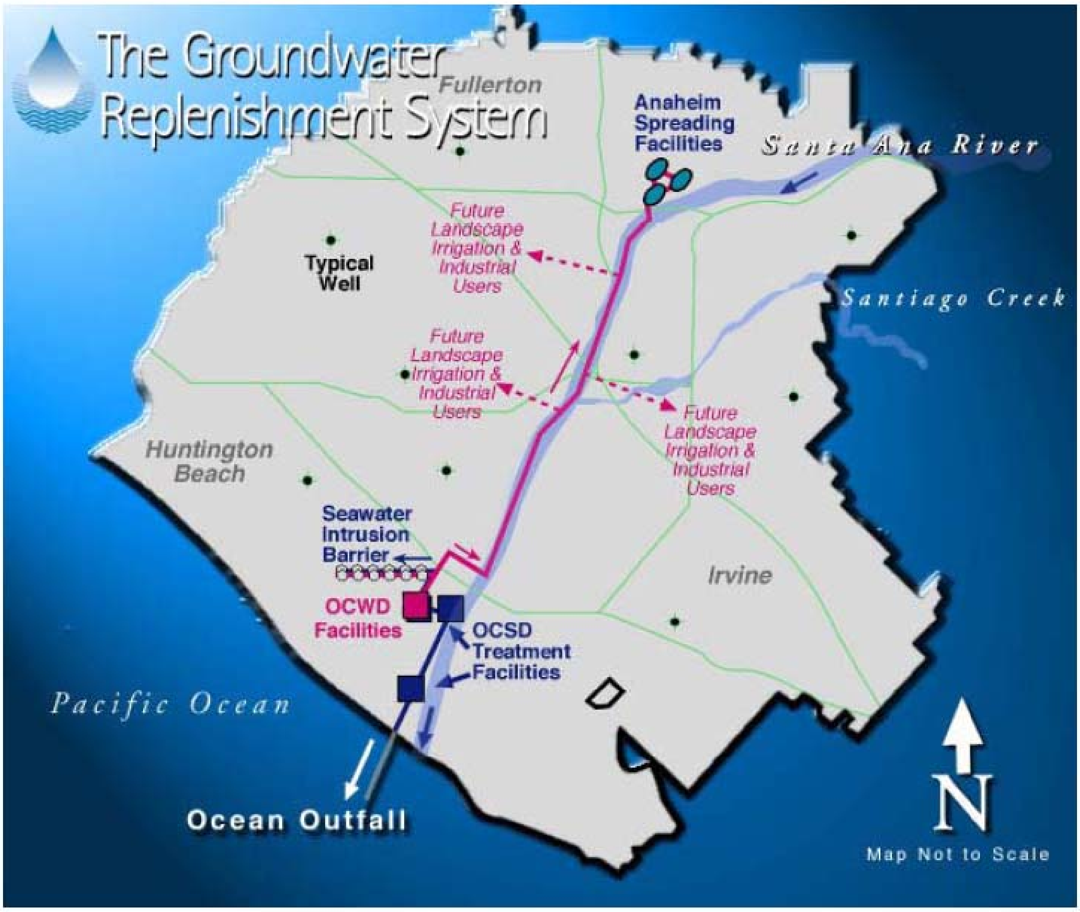
a Regional Water Quality Control Board No. 91-121, adopted November 15, 1991.

b Recycled water blended with deep well water. Averages based on values above or at the detection limit.

c Total organic carbon concentration of 2 mg/l becomes effective only when the percentage of reclaimed water injected first exceeds 67% and is based on the quarterly average of daily samples.

Groundwater Replenishment System

Figure 3.28: OCWD's Groundwater Basin and the Groundwater Replenishment System Facilities [Daughtery et al., 2004]



The GWR System is an indirect potable reuse project that will initially produce 70 mgd with an ultimate capacity of 130 mgd for groundwater recharge and groundwater basin protection from seawater intrusion. The project consists of three major components: 1) the Advanced Water Purification Facility (AWPF) and pumping stations, 2) a major pipeline connecting the treatment facilities to existing recharge basins, and 3) the addition of eight new well sites for expansion of the existing seawater intrusion barrier, currently consisting of 28 injection well sites.

The AWPF will treat clarified secondary effluent, currently discharged by OCSD into the ocean, using microfiltration (MF), reverse osmosis (RO), and advanced oxidation (ultraviolet light treatment with hydrogen peroxide). The AWPF product water will be equally distributed to the seawater intrusion barrier and recharge basins. Approximately 35 mgd will be pumped to injection wells, and the remaining 35 mgd will be piped and pumped to dedicated recharge basins, where the water will naturally pass through the ground and blend with Orange County's other sources of groundwater. The GWR System will not only provide a new, local source of water, but will also eliminate the need for an additional outfall to the ocean and improve Orange County's groundwater basin water quality.

Demolition of OCWD's renowned Water Factory 21 was necessary to allow construction of the 70 mgd treatment facility. To maintain the seawater intrusion barrier during AWPF construction, OCWD has constructed a new 6 mgd MF system, installed new RO membranes, and constructed a new ultraviolet (UV) light treatment system to produce 5 mgd of injection water until AWPF construction is complete, expected in August 2007. This project, known as GWR System Phase 1, consists of a submersible MF system, the use of polyamide RO membranes, and a low-pressure high-output (LPHO) UV light with hydrogen peroxide advanced oxidation system.

WF-21 operation was officially decommissioned on January 21, 2004. Once construction of GWR System Phase 1 was complete and prior to use for Barrier injection, a series of water quality tests was performed on the system to ensure viability. Water quality data was submitted to the California Department of Health Services and the Santa Ana Regional Water Quality Control Board (RWQCB), demonstrating that water quality produced from the 5 mgd plant met all water quality permit requirements. Some data are shown in . Exstensive tests were conducted also on the following categories, which are (not- exhaustively) presented in Daughtery *et al.*, 2004:

- VOC (Volatile Organic Compounds)
- Non-Volatile SOC (Soluble Organic Compounds)
- Disinfection by-product
- EPA Priority Pollutants
- EDC (Endocrine Disruptors) and Pharmaceutical
- Other Unregulated Chemicals among which Boron, Exavalent Chromium et others.

Table 3.50: UV effluent water quality during Phase 1 at GWR System [Daughtery et al., 2004]

Parameter	Method	Result	Reportable Detection
pH	4500H+B	7.2	NA
Electrical Conductivity	2510B	51.1 um/cm	1 um/cm
Ammonia Nitrogen	4500NH3H	1.4 mg/L	0.1 mg/L
Chloride	300.0	5.4 mg/L	0.5 mg/L
Fluoride	4500F-C	0.13 mg/L	0.1 mg/L
Nitrate Nitrogen	4500NO3F	0.31 mg/L	0.1 mg/L
Nitrite Nitrogen	4500NO3F	0.045 mg/L	0.002 mg/L
Sodium	200.7	6.1 mg/L	0.1 mg/L
Total Coliform	9221B	<2 MPN	2 MPN
Total Dissolved Solids	2540C	15 mg/L	1 mg/L
Total Hardness (as CaCO3)	200.7	<1 mg/L	1 mg/L
Total Organic Carbon	5310C	0.25 mg/L	0.05 mg/L
Turbidity	2130B	0.1 NTU	0.1 NTU
NDMA	Isotopic Dilution – GC/MS/MS-Cl	<2 ng/l	2 ng/l

Based on the data collected, five months after WF-21 was decommissioned, GWR System Phase 1 product water was blended with other sources and used for Barrier injection. OCWD is required to blend Phase 1 product water with potable and deep well sources for the remainder of GWR System Phase 1 operation. During the initial two years of the 70 mgd facility operation, OCWD will be required to blend plant product water with other sources. At the recharge basins, the blending requirement will be met using Santa Ana River water as the diluent source. At the seawater intrusion barrier, potable water will be imported to meet the blending requirement. Pending approval, OCWD plans to inject 100% recycled water into the seawater intrusion barrier for Basin protection (adapted from Daughtery *et al.*, 2004).

In some details of the various sources used for blending are compared to GWR system phase 1 product water.

Table 3.51: Blend water data [Daughtery et al., 2004]

Parameter	Deep Well No. 1	Deep Well No.3	Deep Well No.4	Deep Well No.5	Fountain Valley potable	Huntington Beach potable	GWR System Phase 1
Water Flow	7.6 m³/day total between all wells				19.3 m³/day	28.5 m³/day	18.2 m³/day
Nitrate (NO3)	<0.4 mg/L	<0.4 mg/L	<0.4 mg/L	<0.4 mg/L	4.34 mg/L	1.8 mg/L	1.6 mg/L
Nitrite Nitrogen	0.006 mg/L	0.014 mg/L	0.010 mg/L	0.004 mg/L	<0.002 mg/L	0.004 mg/L	0.045 mg/L
Nitrate + Nitrite Nitrogen	<0.1 mg/L	<0.1 mg/L	<0.1 mg/L	<0.1 mg/L	0.98 mg/L	0.4 mg/L	0.35 mg/L

3.3.7 Wetlands

3.3.7.1 WASTEWATER TREATMENT PLANT ELS HOSTALETS DE PIEROLA (SPAIN)

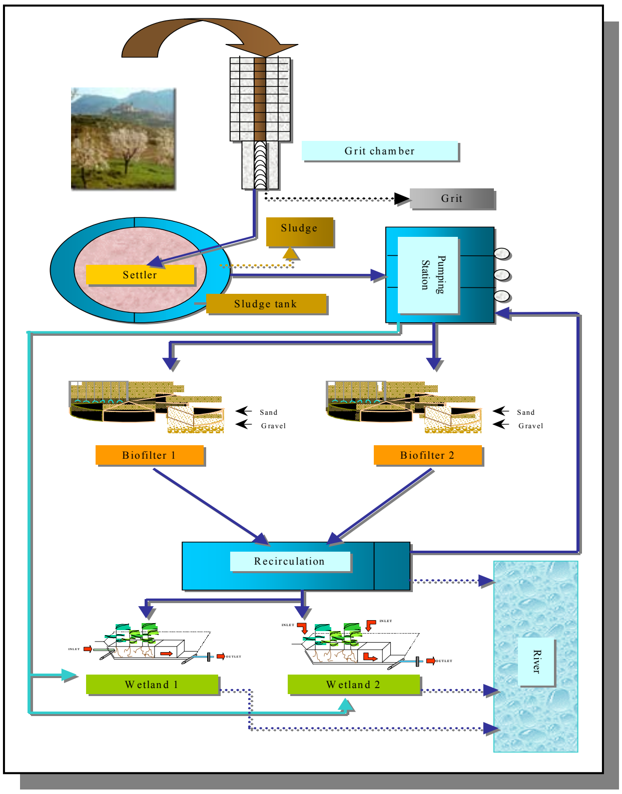
Site description

Wastewater reaches the treatment plant by gravity or by two pumping-stations. The theoretical maximum flow is 500 m3/day. Water reaches the plant (Figure 3.29) through a half cane pipe, where the wastewater is pretreated to remove grit.

After the pretreatment, readily settleable solids and floating material are removed during the sedimentation stage to reduce the suspended-solids content. The settler is a modified Imhoff tank with circular form that constitutes the central crown of a double crown.

The external crown is divided in two parts: one half of the crown is used as sludge tank while the other half is the water homogenization pond. The sludge is removed from the settler to the tank with the help of a telescopic valve. The settler has also a skimmer to collect and transport the floating material to the sludge tank.

Figure 3.29: Diagram and flows of Els Hostalets de Pierola WWTP



The settled water is transported directly to the homogenization tank where it is pumped to the biofilters (mIP) or to 2 parallel wetlands (WL) (secondary treatment). Some of the water, which is treated by biofilters, could be sent to wetlands where it is given as a tertiary treatment. Finally, the treated wastewater is disposed into a small river by gravity. Figure 3.30 gives an overview of the wastewater treatment plant.

Figure 3.30: Wwtp Els hostalets de pierola, biofilter IP (left) and constructed wetland WL (right)

Infiltration-percolation and constructed wetlands characteristics

Table 3.52 presents some of the technical characteristics of mIP and WL.

Table 3.52: Biofilters (mIP) and WL characteristics in Els Hostalets de Pierola WWTP

Characteristics	Biofilters (mIP)	Wetlands
Total surface	2 x 875 m^2	2 x 200 m^2
Surface form	Circular	Rectangular
Impervious material	Yes	Yes
Protection of impervious material	Yes with geotextile	Yes with geotextile
Depth of filtrating material layer	150 cm of sand 20 cm of gravel 8-20 cm 30 cm of gravel 20-40 cm	60 cm - slope 1% WL1 gravel 2-6 mm WL2 gravel 10-15 mm
Drainage	Yes	Yes
Additional aeration (passive)	Yes	No
Water application	Pivot with 22 shovels	Pipe/gabion
Aerosol formation	No	No
Functioning	Discontinue	Continue

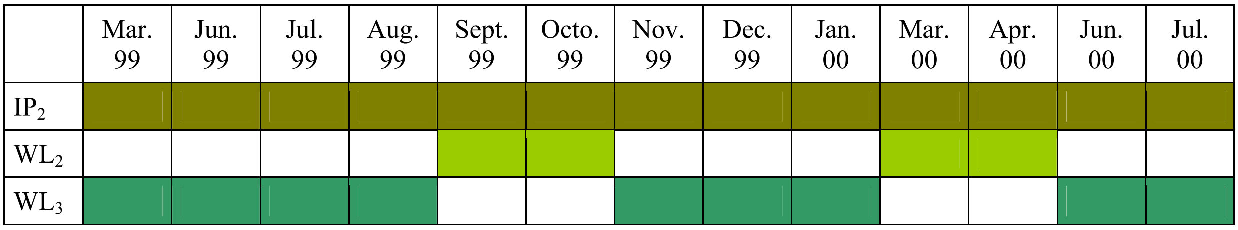
Experimental protocol

During the period between March 1999 and July 2000, WWTP performance was evaluated. Samples were taken every week. The control points were the following:

1. Inlet water in biofilters after pretreatment [iIP]
2. Outlet water in biofilters (secondary treatment) [oIP] = inlet water in wetlands [iWL]
3. Outlet water in wetlands after biofilters (tertiary treatment) [oWL]
4. Outlet water in wetlands after pretreatment (secondary treatment) [o*WL]

The schedule (time of application of every treatment technique) followed is shown in Figure 3.31.

Figure 3.31: Timetable of Els Hostalets de Pierola WWTP



	Mar. 99	Jun. 99	Jul. 99	Aug. 99	Sept. 99	Octo. 99	Nov. 99	Dec. 99	Jan. 00	Mar. 00	Apr. 00	Jun. 00	Jul. 00
IP_2	■	■	■	■	■	■	■	■	■	■	■	■	■
WL_2					■	■				■	■		
WL_3	■	■	■	■			■	■	■			■	■

IP_2: mIP as secondary treatment; WL_2: WL as secondary treatment; WL_3: WL as tertiary treatment.

Table 3.53 indicates the amount of wastewater applied to each system.

Table 3.53: Applied flows to biofilters and wetlands each studied month

Period	flow treated by mIP (m^3/day)	flow treated by WL (m^3/day)
March 1999	43.1	7.7
June 1999	52.3	20.2
July 1999	59.3	34.4
August 1999	61.8	34.0
September 1999	60.3	22.3
October 1999	68.6	7.3
November 1999	51.5	6.0
December 1999	63.1	5.6
January 2000	59.7	6.1
March 2000	48.5	14.8
April 2000	64.2	21.0
June 2000	57.9	21.2
July 2000	71.5	20.7

Results

The results of physico-chemical and microbiological parameters are shown in Table 3.54 and Table 3.55. Table 3.54 presents the minimum, average and maximum values from mIP system working as a secondary treatment (water reaches the filters from a pretreatment and a settling tank), and WL as a tertiary treatment (mIP effluent). Table 3.55 presents the results of WL and mIP systems both acting as a secondary treatment.

Table 3.54: Results related to mIP as secondary treatment and wetlands as tertiary treatment

Parameters	IP inlet			IP outlet = WL inlet			WL outlet			% IP Revomal	% WL Removal
	Min	Aver	Max	Min	Aver	Max	Min	Aver	Max	Aver	Aver
pH	6.96	7.37	8.16	6.71	6.97	7.20	6.84	7.12	7.62	-	-
Conductivity (µS/cm)	810	1891	2390	1177	1957	2440	1560	1939	2557	-	-
SS (ppm)	109	204	587	0	2.7	8.7	0	1.96	1.75	98	32.2
COD (ppm)	345	748	1797	48	98	173	33	91	143	85	57
NH_4^+-N (ppm)	29.4	54.9	70.2	0	9.3	44.2	1.13	9.42	29.01	85	31.3
NO_3^-N (ppm)	0	0.8	3.7	6.3	30.6	56.7	0	15.7	38.2	-	100
PO_4^{3-} (ppm)	12.0	23.0	36.2	0.62	9.06	28.2	0.17	4.7	11.5	66.5	30.8
FC (ulog/100mL)	6.64	7.23	7.62	1	3.66	5.13	1.2	2.33	3.11	3.57	1.25
Coliphage (ulog/100mL)	5.94	6.64	7.17	6.71	6.97	7.20	2.75	3.34	3.81	3.93	0.66
Bacteriophage (ulog/100 mL)	5.56	5.83	6.06	1.83	1.99	2.18	1.62	2.06	2.34	3.84	0.07

n.d.: not determined, ■ : Removal ulog

Table 3.55: Results related to mIP and wetlands as secondary treatment

Parameters	WL inlet			WL outlet			IP outlet			% WL Revomal	% IP Removal
	Min	Aver	Max	Min	Aver	Max	Min	Aver	Max	Aver	Aver
pH	6.96	7.31	7.66	7.01	7.25	7.46	6.71	6.97	7.20	-	-
Conductivity (µS/cm)	810	1682	2207	1450	2002	2467	1177	1957	2440	-	-
SS (ppm)	109	144	204	8	15	23	0	2.7	8.7	88	98
COD (ppm)	363	480	609	129	174	235	48	98	173	62	85
NH_4^+-N (ppm)	29.4	40.3	51.7	0	7.9	13.7	0	9.3	44.2	78.7	85
NO_3^-N (ppm)	0	0	0	0	0.05	0.17	6.3	30.6	56.7	0	-
PO_4^{3-} (ppm)	5.5	9.3	14.0	11.5	16.49	25.1	0.62	9.0	28.2	1.6	66.5
FC (ulog/100mL)	6.64	7.13	7.62	3.15	4.29	5.69	1	3.66	5.13	2.84	3.57
Coliphage (ulog/100mL)	n.d	5.94	n.d	n.d	3.78	n.d	6.71	6.97	7.20	2.16	3.93
Bacteriophage (ulog/100mL)	n.d	n.d	n.d	n.d	n.d	n.d	1.83	1.99	2.18	n.d	3.84

n.d.: not determined, ■ : Removal ulog

The graphics below present the trends of the most important parameters evaluated (*y* axis). It is to say that results correspond to the averages obtained for each studied month (*x* axis).

Results related to mIP working as a secondary treatment and wetlands as tertiary treatment are presented in the Figure 3.32 to Figure 3.37.

Figure 3.32: Suspended solids

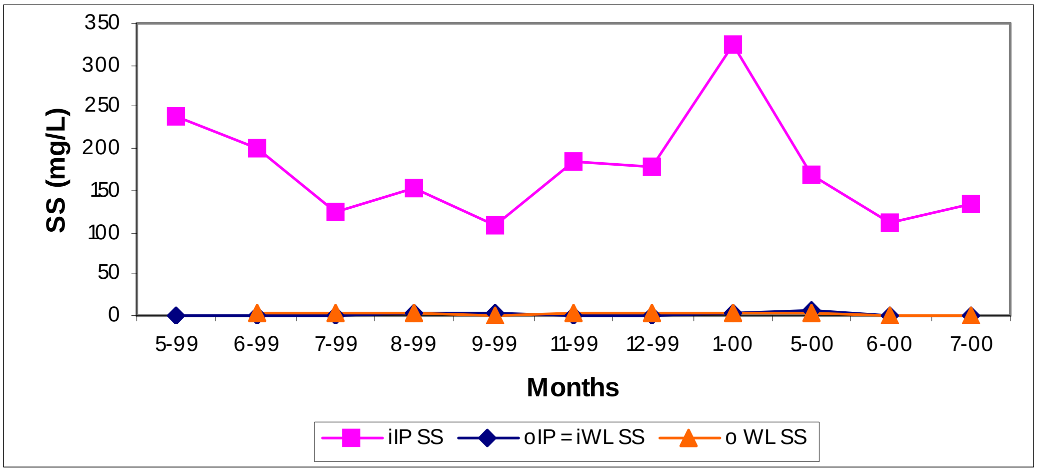


Figure 3.33: COD

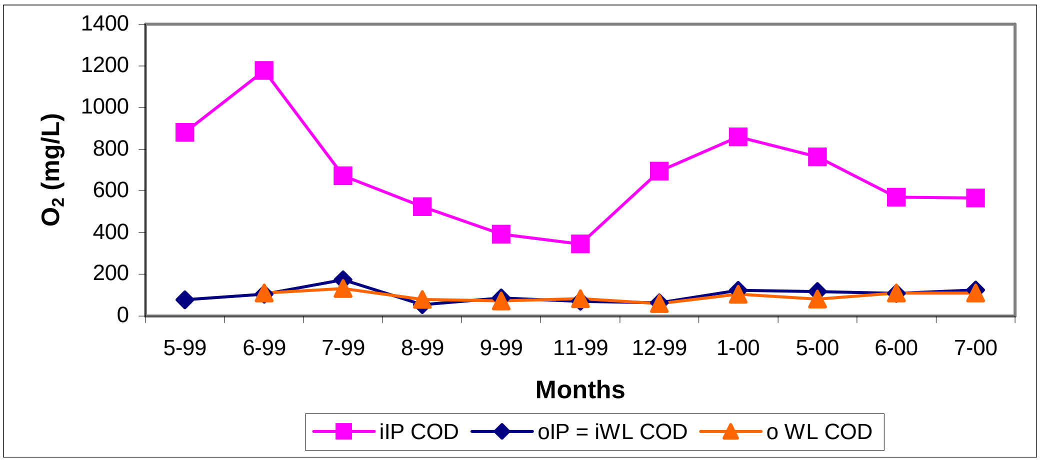


Figure 3.34: Nitrogen

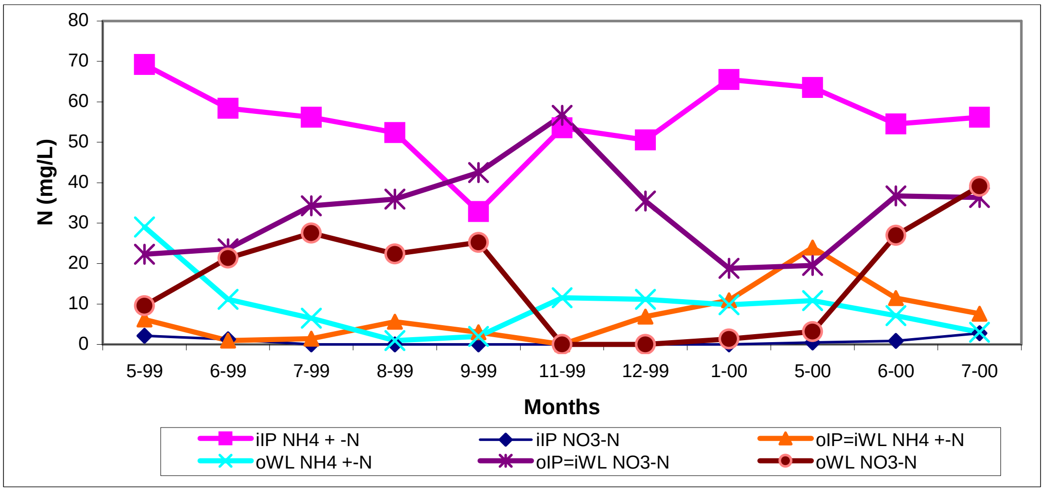


Figure 3.32 presents the trend of SS. Results show the correct performance of filtration mechanism of both systems. A reduction of almost 99% (SS) when wastewater passes through biofilters, obtaining a maximum concentration of 2.7 mg/L is shown. At the outlet of wetlands, low SS concentrations are maintained.

Figure 3.33 shows the trend of COD. The mIP system reaches a reduction between 74 and 96%, while WL maintain its value at the outlet. IP reduces COD due to filtration mechanisms and the oxidation of organic matter through biofilm's aerobic microorganisms.

Figure 3.34 presents nitrogen trend. Ammonia nitrogen is 100% nitrified during October and November, when the system is established. In relation with wetlands, two kinds of performances can be obtained: a total denitrification when the system receives low flows (< 10 m^3/day) and a denitrification reduction when the applied flows increase (> 20 m^3/day).

Figure 3.35: Fecal coliforms

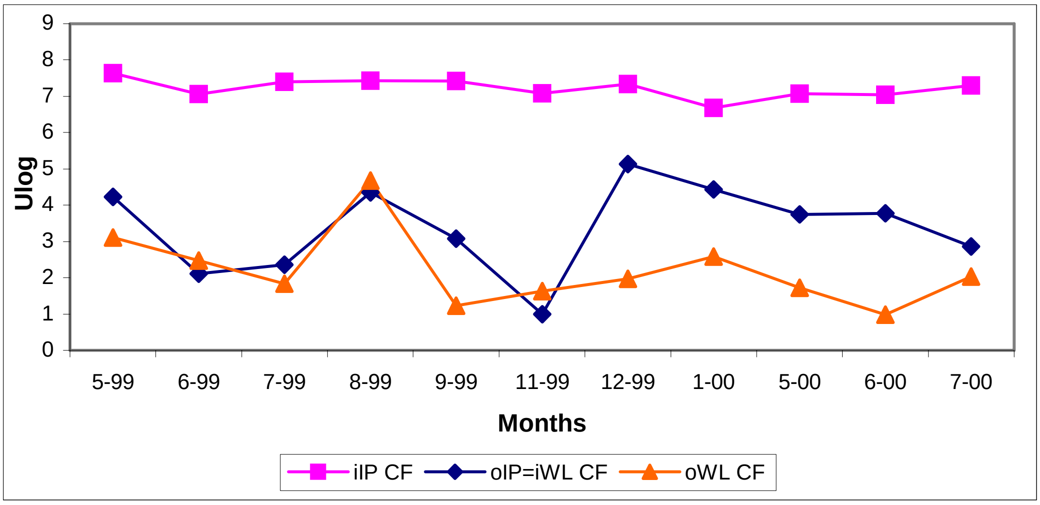


Figure 3.36:Somatoc Colidhages

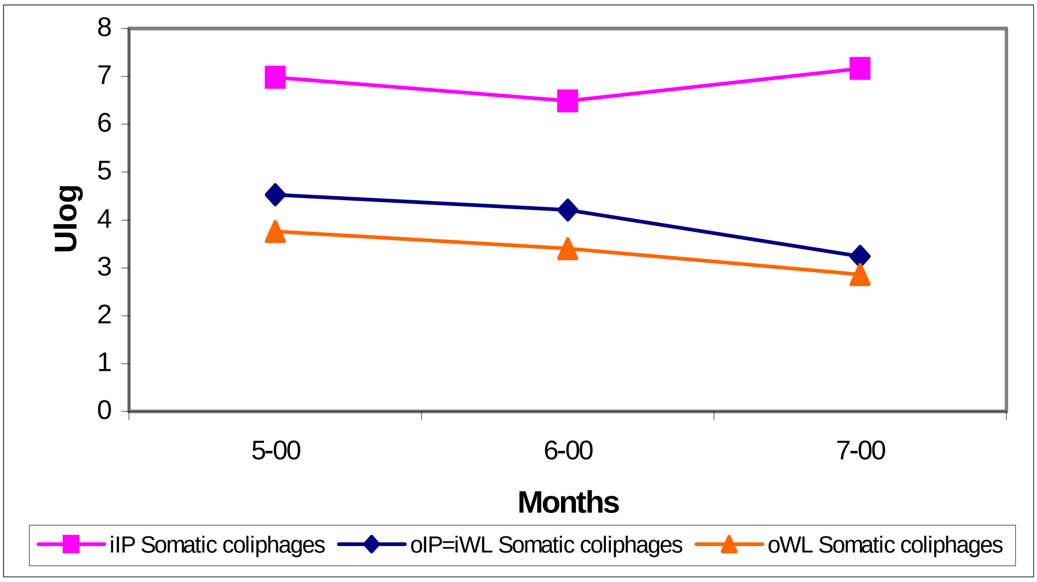


Figure 3.37: Bacteriophages RNAF-specific

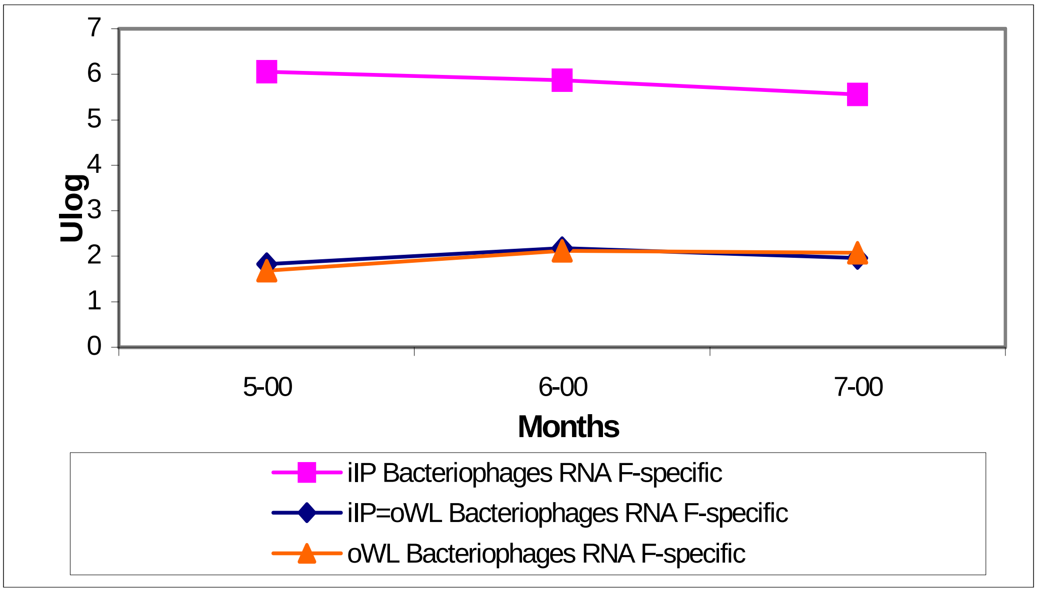


Figure 3.35 shows the trend of Fecal Coliforms. A homogeneous inlet to biofilters is observed, with reductions, which reach 4 ulog. WL improves microbiological characteristics, achieving reductions of 2 ulog.

Figure 3.36 and Figure 3.37 present the studied viral indicators. Inlet water to biofilters has a homogeneous content. A reduction of 3 ulog of somatic coliphages and 4 ulog of RNA F-specific bacteriophages was detected. WL only improves microbiological effluent in relation with somatic coliphages.

Results generated by constructed wetlands working as a secondary treatment are shown in the Figure 3.38 to Figure 3.41.

Figure 3.38: Suspended solids, WL's as secondary treatment

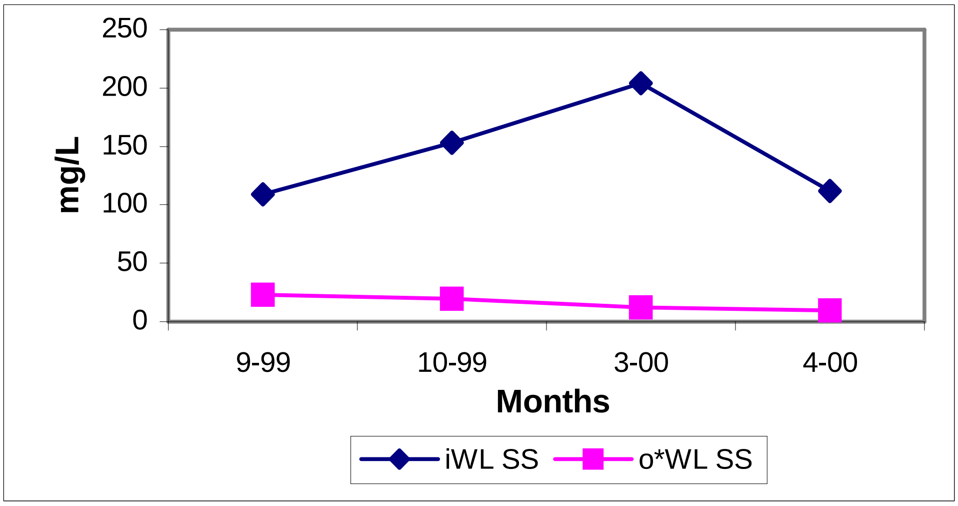


Figure 3.39: COD, WL's as secondary treatment

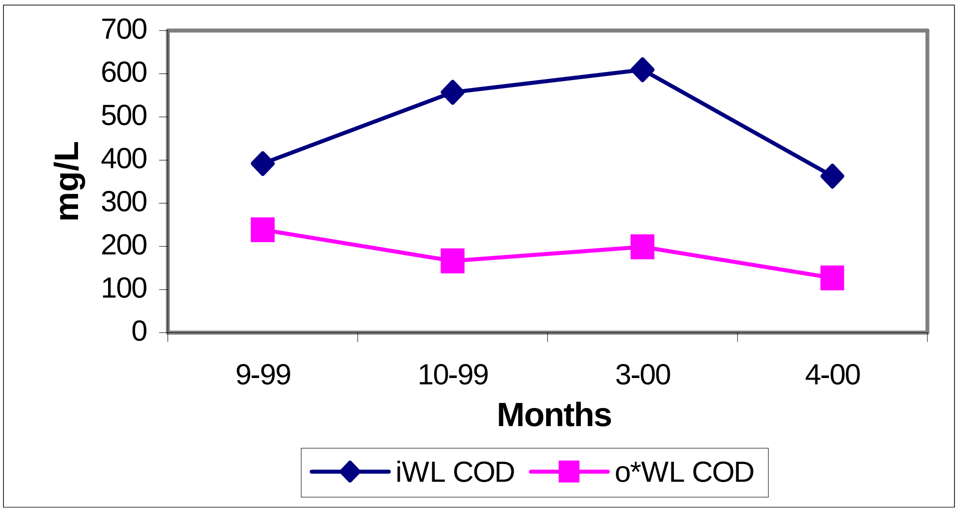


Figure 3.40: Nirtogen, WL's as secondary treatment

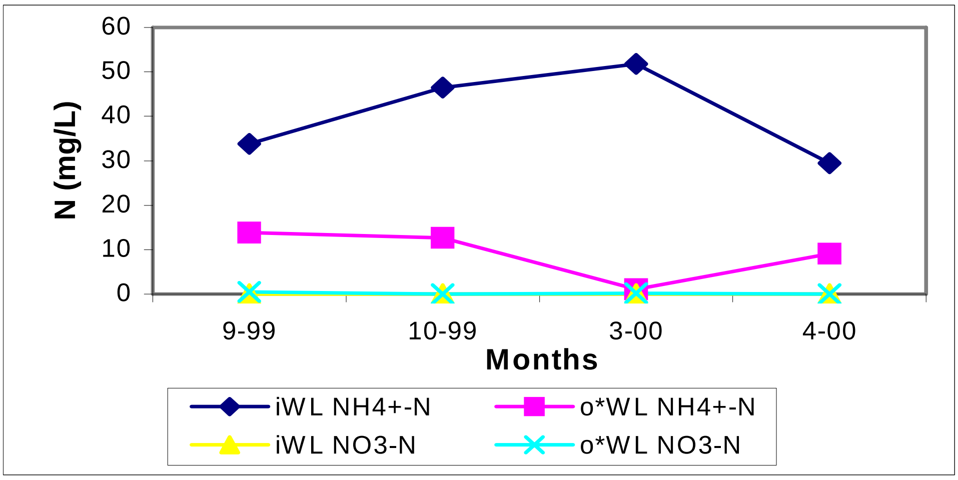


Figure 3.41: Fecal Coliforms, WL's as secondary treatment

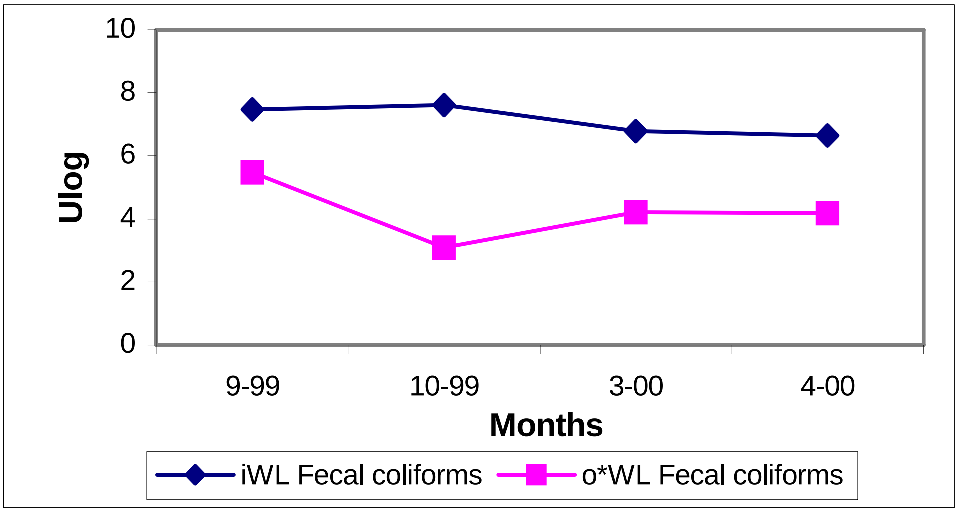


Figure 3.38 presents SS trend. The SS content in outlet is reduced drastically when WL act as secondary treatment (removal: 88%).

Figure 3.39 shows COD trend. COD decreases at the outlet of both wetlands and variations are due to raining period (March and April are rainy months). During September and October '99 a reduction of 60% was attained, while in March and April '00 it was 25%.

Figure 3.40 shows ammonia trend. Ammonia content of wetland outlet diminishes in all the months. The average reduction is 62%. On the other hand, nitrate content do not suffer any change. There is no entry of nitrate content to wetlands and there are no nitrates in the system water outlet.

Figure 3.41 presents Fecal Coliform trend. Fecal Coliform contents diminished in water outlet during September and October '99 (3.3 ulog decrease), while during March and April '00 a reduction of 2 ulog was detected. As we explained before, this is due to the rain.

Conclusions

The following conclusions were drawn from this study:

- Modified Infiltration-Percolation is an adequate secondary wastewater treatment which has shown to provide excellent quality effluent after 2 years of operation. SS decreases by 98%, PO_4^3 by 66%, and COD by 85%. Total nitrification is obtained when the process is established. Fecal Coliforms decrease has an average of 3.57 ulog, while somatic coliphage and F-specific RNA bacteriophage reductions were 3.93 ulog and 3.84 ulog respectively.
- Wetland as tertiary wastewater treatment is also capable to improve the quality of the treated wastewater. Total removal of nitrate content is achievable when low flows are applied to the system. Independently of the applied flow, phosphate content is reduced to 31%. Fecal Coliforms are reduced to an average of 1.25 ulog, while somatic coliphage to 0.66 ulog. F-specific RNA bacteriophage does not experience a noticeable reduction.
- Wetland as secondary wastewater treatment allows a very good SS reduction (88%). This system also reaches a significant reduction in COD (62%) and NH_4^+-N (79%).
- If we compare mIP and WL when they are working as a secondary treatment, we can observe that there are always better physico-chemical and microbiological parameters' reductions in mIP system.
- Els Hostalets de Pierola wastewater treatment plant has shown that the combination of two soft technologies (modified Infiltration-Percolation + Wetlands) could be considered as an alternative wastewater treatment system for small communities due to its
  - low costs of exploitation
  - integration of the system in the environment
  - reduced generation of by-products

3.3.7.2 CONSTRUCTED WETLANDS IN BESÒS RIVER BED (CATALONIA, SPAIN)

Introduction

The final section of the Besòs river (Spain) flows through a highly populated and industrial area comprising several cities (Barcelona, Montcada i Reixac, Santa Coloma de Gramanet, and Sant Adrià de Besòs) with more than two million inhabitants. The river flow varies extremely from severe flooding episodes of up to 2000 m^3/s a few times per year, to no flow but the one derived from treated wastewater disposal all around the year. There used to be a concrete channel for the low-water flows, which suffered a transformation recently to re-naturalize partially the river bed.

Although Besòs' draining basin is small (1,039 km^2), inherent factors such as

- the Mediterranean climatic conditions,
- a lot of artificially created impervious areas which made infiltration difficult and
- the presence by buildings and infrastructures in the river-related high-flow zones

make the heavy-rain episodes dangerous for the surrounding areas. Moreover, the aquifer carries usually more water than the river. For several decades, river Besòs had the most altered fluvial basin of all the hydrographic network of Catalonia and was considered the second most contaminated river of Europe, after the Rhine. During last decades, water resources quality was deteriorated due to the excessive exploitation and heavy contamination of the river.

Water demands in the basin clearly exceed the available resources. This was solved by diverting water from a northernmost river, adding around 5m^3/s to the existing groundwater resources, which is not used because of its bad quality. Until the year 1998, an aerial electricity transport infrastructure was inside the high-flow bed, which at the same time was not preserved at all, serving mainly as a disposal site, and being invaded by low-quality vegetation.

Using FEDER and local funds, a major restoration of a part of the final section of the river was undertaken. In this section, the low flow concrete channel was removed giving the river a more natural character. In the high-flow zone a tertiary wastewater treatment system was constructed existing of 10 ha of constructed wetlands. The wetlands effluent enters directly into the river, thus improving water quality. At the same time, the restoration of natural areas resulted in an improvement of the landscape and subsequently wildlife (reptiles, amphibious, birds, etc.) appeared because of the availability of habitat and nesting areas. Wetlands vegetation (reed, cattail, etc.) is typical of river beds and is capable to withstand high floods.

Usually, constructed wetlands are designed as an alternative technology to treat wastewater in small communities. Nevertheless, the system is also described as a tertiary treatment or as a way to manage runoff or industrial wastewater. Subsurface horizontal flow design was chosen for the Besòs' wetlands. This type of flow typically avoids odours problems and mosquitoes appearance. Constructed wetlands, with subsurface flow and planted with macrophytes, present a complex aerobic-anoxic-anaerobic system underground. Around substrate, roots, and rhizomes bacterial colonies – biofilms – are developped. The implied treatment mechanisms are complex and include filtration, sedimentation, chemical precipitation, and bacteriological oxidation. This technology is mainly based on the relationships between vegetation and soil saturated with water.

Material and Methods

Constructed wetlands plots were distributed along 3.2 km of the basin (see Figure 3.42). In the first 2 km the wetlands are constructed along both river banks. In the remaining 1.2 km wetlands are only constructed along the right bank. The total surface of constructed wetlands is 10 ha. It is important to note that there are four types of plots, with a total number of 60 plots, as described in Table 3.56.

Table 3.56: Typology and dimensions of Besòs River wetland plots

Type	Width (m)	Length (m)	Number of beds
1	50.4	19.1	39
2	50.4	27.6	14
3	50.4	34.6	3
4	50.4	31.5	4

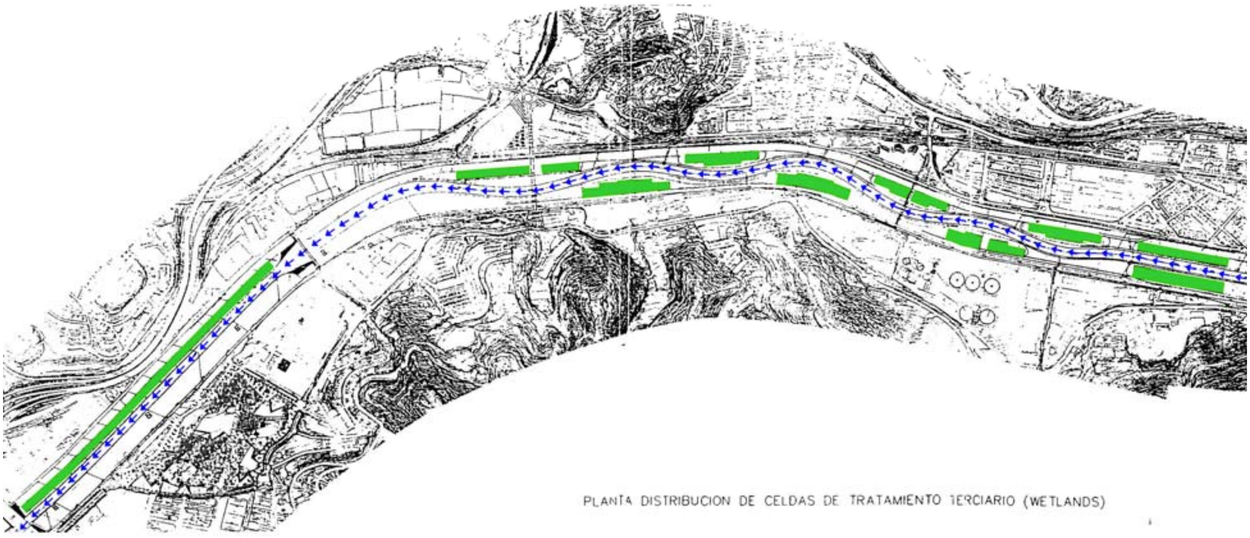
Plots are clustered in 15 groups, with each group comprising 2 to 5 plots. Each group has a valve to control the flow to each plot, and another valve to control the pressure. The average flow treated is between 0.2 and 0.4 m^3/s, depending on the hydraulic regime of the system.

Impervious (using liner protected with geotextile) plots were filled with river gravel (granulometry between 8 and 25 mm) or with granitic gravel (granulometry between 6 and 25 mm). The depth of a plot at inlet water is 0.6 m, and 0.8 m at the outlet with a slope of 0.5 %.

Each plot has an individual end tank, where treated wastewater is collected before reaching the river. To control water height inside the reed bed, an adjustable pipe was installed inside the tank. A correct management of this system avoids the appearance of wastewater on the wetland surface.

Sampling was done in each outlet tank, and the following parameters were analyzed according to the Standard Methods (1999): pH; E.C.; SS; COD; NH_4^+-N; NO_3^--N; PO_4^{3-}), as well as Fecal Coliforms.

Figure 3.42: Constructed wetlands distribution in the Besòs river



Results and discussion

The characteristics of the influent coming from an activated sludge wastewater treatment plant (WWTP) are presented in Table 3.57, as average values.

Table 3.57: Quality of wastewater entering to the constructed wetlands

Parameter	Inlet	Outlet	% Removal
pH	7.39	7.14	-
EC (dS/cm)	1.59	1.45	-
SS (mg/L)	6.90	1.10	84.0
COD (mg O_2/L)	143.55	67.65	52.9
TKN-N (mg/L)	37.52	29.12	22.4
NH_4^+-N (mg/L)	34.19	8.27	75.8
NO_3^- (mg/L)	< 2	< 2	-
PO_4^{3-} (mg/L)	8.48	7.05	16.9
Fecal Coliforms (log ufc/100 mL)	4.45	3.35	1.1*

* logU/100 mL

The obtained results for all plots are shown in Table 3.58 for the years 2001, 2002, and 2003. The performances of the constructed wetlands changed during the 3 years due to factors like wastewater quality of the WWTP (during this period of study, a high concentration of organic matter was detected in two episodes); climatology (storms, temperature, etc.) and constructions done along the river basin…

Table 3.58: Quality of wastewater to the constructed wetlands (influent)

Parameter	Year	Maximum	Average	Minimum	Standard deviation
Turbidity (NTU)	2001	100.0	5.7	0.5	13.0
	2002	45.0	5.3	0.6	5.3
	2003	49.0	5.1	0.6	7.8
pH	2001	8.3	7.5	7.0	0.2
	2002	8.1	7.5	7.0	7.5
	2003	8.2	7.5	6.8	0.3
EC (µS/cm)	2001	2167	1453	637	183.3
	2002	2930	1417	495	1417
	2003	2760	1490	659	204
NO_3^- (mg/L)	2001	79.9	8.6	< 2.0	11.6
	2002	63.6	5.4	< 2.0	5.4
	2003	78.8	6.1	< 2.0	13.1
NO_2^- (mg/L)	2001	10.1	0.6	< 0.5	0.7
	2002	10.8	0.7	< 0.5	0.7
	2003	26.6	0.9	< 0.5	2.3
NH_4^+ (mg/L)	2001	46.6	25.6	1.5	8.8
	2002	55.7	25.2	1.0	25.2
	2003	48.9	31.7	0.2	11.4
P (mg/L)	2001	12.5	4.4	1.0	1.3
	2002	6.4	3.0	1.0	3.0
	2003	7.4	3.5	1.0	1.4
TSS (mg/L)	2001	43.0	5.6	< 2.0	8.3
	2002	38.0	3.4	< 2.0	3.4
	2003	29.0	3.5	< 2.0	3.7
COD (mg/L)	2001	86.0	53.8	< 50.0	13.8
	2002	93.0	55.3	< 50.0	55.3
	2003	77.0	52.8	< 50.0	5.6

The average removal of organic matter (COD) was 62.4%. SS showed a reduction of 80%. It should be remarked that a 75% of the total samples presented a SS concentration below detection limit.

With respect to nutrients, a 20% of ammonia was removed. This reduction can be attributed to nitrogen transformation from ammonia to nitrates and nitrites. However, the results were lower than those reported in other studies (Gersberg *et al.* 1983, Huang *et al.* 2000, Cooper *et al.*, 1996). This could be explained by a low water residence time.

Phosphorus removal was 58%. Removal of phosphorus is a result of a combination of adsorption, complexation and precipitation reactions (Cooper *et al.*, 1996).

An additional sampling campaing in the year 2003 focused on the microorganisms removal using fecal coliforms as indicator. The FC average removal was 1.1 logU/100 mL, although maximum reduction was 3 logU/100 mL.

Conclusions

Constructed wetlands are usually considered as a wastewater treatment solution for small and rural settlements as well as for individual houses in suburban areas of the large cities. The experience has shown that constructed wetlands can be a good solution to recover quality of water from urban rivers.

Furthermore, the construction of reed beds contributed to the environmental restoration at the final section of the Besòs river. The reed beds result in the formation of an ecosystem which provide potential wildlife habitats for different types of fauna.

3.3.7.3 THE "WATERHARMONICA" (THE NETHERLANDS)

This section is largely based on refenrence STOWA (2005) in which expertise and results of operational constructed wetlands for post treatment of effluent of domestic sewage plants in The Netherlands are studied. Possibilities for favourable new systems scattered all over The Netherlands are also assessed and explored.

Introduction

The quality of effluent disharged from Dutch wastewater treatment plants (WWTP) has improved considerably in recent years. Still these WWTP-effluents do not resemble their receiving surface water, in particular when ecological characteristics are considered. New treatment techniques like membrane technology, ozone and UV-treatment are not capable to bridge this ecological gap. The Waterharmonica concept is developed for this purpose, aiming at the application of sustainable, energy saving and cost-effective techniques to offer a natural, ecological link between WWTP in the water chain and receiving surface water in the water system.

Well known applications of the Waterharmonica concept are constructed wetlands used as treatment wetlands to improve the quality of WWTP-effluent by removal of xenobiotic and -abiotic substances and pathogens, introducing a natural oxygen regime and (higher) organisms being characteristic for surface water. Waterharmonica systems are capable to reduce nutrients, biochemical oxygen demand (BOD), heavy metals, organic micro-pollutants, pathogens and xenobiotic organisms still present in WWTP-effluent. For the importance of achieving an ecologically sound state of surface waters is the basis of the European Water Framework Directive (WFD) it is to be expected that Waterharmonica systems might offer an important contribution in reaching WFD-objectives.

The Waterharmonica concept might be applied in many different ways. Waterharmonica systems must be designed and operated in such a way that these systems fit optimally in the local situation and resolve local environmental issues. These systems therefore will be multifunctional and take a great deal of their added value compared to more conventional and new more "high-tech" treatment techniques. Waterharmonica systems are well suited to combine effluent treatment with other functions like nature development, water storage, recreation, education and biomass production. In this respect it offers multiple use of the scarce space available in The Netherlands.

Conceivable examples of Waterharmonica systems are:

- constructed wetlands and marshes
- reed fields and ditches (surface flow systems)
- root zone systems en infiltration fields (subsurface flow systems)
- local oversized watercourses
- buffer zones and banks
- ecological connection zones
- pool and marsh shoulders
- nature and environment friendly banks

- nurse or breeding ponds (water fleas, mussels, duckweed, fish)
- cascades, flowforms and flood areas.

Water treated in a Waterharmonica system can be profitable (re)used as:
- freshwater source for abatement of salinization
- infiltrate for raising water levels (drying out abatement)
- a source for urban water level control and esthetic improvement
- cooling, rinsing or process water in industry
- water and nutrient source in agriculture
- water for recreational purposes (fishing, boating, water supply for sporting grounds and golf courses)
- supply water in nature rehabilitation and –restoration projects.

Research at Waterharmonica systems applied in The Netherlands for post treatment of WWTPeffluent revealed that treatment efficiencies for nutrients in particular vary considerably. The systems are well capable in “reshaping” these effluents in water that resembles their receiving surface waters by introduction of a natural oxygen regime and removal of active sludge particles. Also combination with nature development, recreation and education is more or less achieved, in particular with surface flow systems.

The three main reasons for applying Waterharmonica systems are the abatement of the lack of freshwater (both surface water and groundwater), reduction of pathogens in WWTP-effluent and water suppletion for nature reserve areas.

The following aspects have been indicated as important in order to stimulate large scale application of Waterharmonica systems:

- due to the implementation of the European Water Framework Directive in the near future that will set standards for both chemical and ecological quality of surface water, the possibilities for combining the Waterharmonica with advanced techniques for effluent post treatment such as dynamic sandfiltration deserve more attention.
- in short term the further development of knowledge, know-how and experience of Waterharmonica systems to cope with the many knowledge gaps that still exist. Sharing knowledge of and experience with existing and planned Waterharmonica systems between all participants at all levels involved is crucial for further successful introduction and implementation of the Waterharmonica concept.
- in medium term acceptance of the Waterharmonica as a sustainable, natural concept that offers the opportunity to combine several functions and to reach several goals.

As an example of the Waterharmonica the application at the sewage treatment plant (STP) Everstekoog and the "Kwekelbaarsjes" system is discussed.

STP Evertsekoog

Site description

One of the (touristic) Wadden islands in the Northern part of the Netherlands is Texel. The maximum length of the island is 25 km, the average width is 8 km. With a total land surface of 160 km² Texel is the largest Wadden island. The number of inhabitants is 14,000. During the peak of the touristic season the number of inhabitants is approx. 59,000.

On the island five STPs are in operation. The effluents of the STPs is discharge onto a limited number water courses. During dry periods the effluents of the STPs are an important source of fresh water. However, for getting a good surface water quality the quality of the effluents is insufficient.

In 1994 full scale wetlands are constructed at STP Everstekoog. In these wetlands the effluent of the STP is treated with reeds and water plants to improve its biological and physical/chemical quality before discharge onto the surface water.

STP Everstekoog

The STP Everstekoog is an oxidation ditch with a load of 45,000 PE in summer due to the tourism and only 10,000 PE in winter. Dry weather flow in summer is 3000-4000 m³/day; the maximum flow is 10,000 m³/day. Phosphorus removal is conducted simultaneously by dosing iron(III)chloride to the aerationbasin. Table 3.59 shows water quality parameters for the effluent of the STP.

Table 3.59: Effluent quality of STP Everstekoog (1997 and 1998) "classical" water quality parameters

Parameter	Mean Concentration	Standard deviation N >=22
NO_3-N (mg/l)	2.6	2.5
NH_4-N (mg/l)	1.1	1.6
Total N (mg/l)	6.2	4.3
Total P (mg/l)	1.1	0.7
COD (mg O_2/l)	32	6
Coli (number per ml)	590	730

The STP Everstekoog can be considered as a low loaded treatment plant. Discharge requirements for P, N, COD, BOD and SS are easily reached. Nevertheless, the oxygen demand of the effluent is such that after discharge onto the small surface water a oxygen shortage is still occurring at a distance of 2 km.

The constructed wetland

The full flow of the STP is treated in the surface-flow constructed wetland since 1994. The system consists of:

- a presettling basin
- nine parallel ditches with a length of 150 m and a width of 6.3-7.0 m
- a discharge ditch with a length of 120 m and a width of 7 m

The first part of each parallel ditch is only 0.2 m deep and has vegetation of reed (Phragmites australis) or cattail (Typha latifolia). The deeper part (design 0.5 m) has been planted with submerged aquatic plants. One ditch is a control without macrophytes (Figure 3.43 and Figure 3.44). The total water surface is 13,000 m² and the total volume is 7,143 m³. The hydraulic retention time (HRT) in the constructed wetland is 2.1 days at dry weather flow during summer and during average flow 1.8 days. During high flow rates the volume of the system can be increased with 1,000 to 1,500 m³.

During a period of four years (1995-1999) the constructed wetlands are extensively investigated. In the first research period (1995-1996) all ditches received the same flow. In 1997-1998 different flow regimes through the ditches resulted in HRTs of 1.8 up to 11 days (design retention times in separate ditches of 0.3, 1, 3 and 10 days resulted in 0.3; 0,8; 2.3 and 9.3 days).

Figure 3.43: The constructed wetland in relation with the sewage treatment plant and surface water

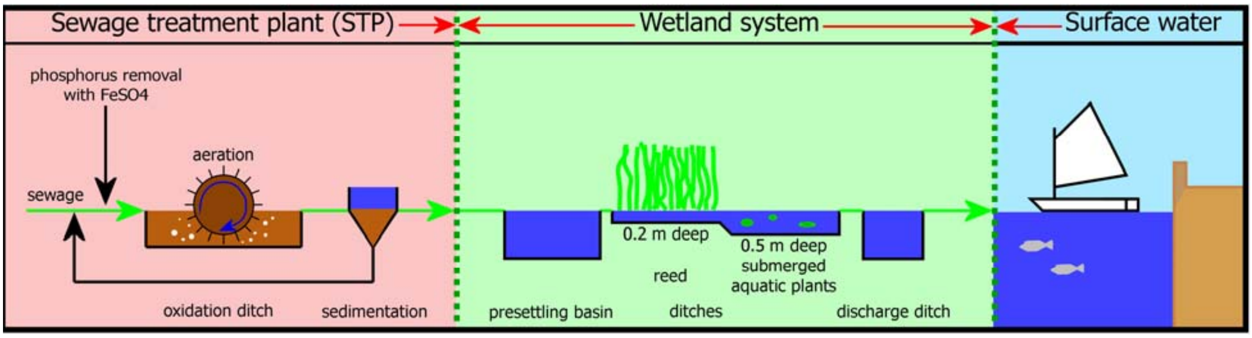


Figure 3.44: Everstekoog: Aerial View of the Everstekoog constructed wetland, on the background the STP (photo Simon Smit, Texel)

The hydraulic retention time had a profound effect on nitrogen removal (mostly due to denitrification) in the constructed wetlands. Ammonia levels in the effluent of the constructed wetlands varied, but were mostly well under 1 mg/l, nitrate concentrations went down to <0.5 mg/l at the longest hydraulic retention times, even in winter. The load of N and P with the STP effluent to the constructed wetland is 5,000 kgN/ha/year and 700 kg P/ha/year respectively. Nitrogen removal was calculated as 1,250 kg N/ha/year. This means that a surface area of at least 5,000/1,250 = 4 ha (instead of 1.3 ha) is needed for a complete nitrogen removal in the system. The needed HRT depends very much on the concentrations in the effluent of the STP. At the above mentioned N-load, an HRT of 5.5 days will be needed for a low ammonium concentration in the effluent throughout the year (Toet, 2003), 10 days hydraulic retention time will lead to more natural values in the constructed wetland. Phosphate removal in the Everstekoog constructed wetland was rather low, leading to the conclusion that when low P-concentrations in the effluent are preferred biological or chemical removal in the activated sludge plant are more appropiate.

A reasonable disinfection (10 E.coli/mL) can be achieved at a relative short HRT (2 days). HRTs of 3 days and more result in intestine bacteria levels comparable to the levels in surface water. During winter the removal of E.coli is less effective.

Kwekelbaarsjes

The basic idea of the "Kwekelbaarsjes"[1] system (see, Figure 3.45) is to build a food chain by utilizing activated sludge particles present in STP effluent to grow water fleas (Daphnia magna, Figure 3.46). Subsequently the water fleas are food for gricklebacks which are finally serve as food for spoonbills. Spoonbills are an endangered species and Texel is an important habitat for spoonbills.

The grow of water fleas can be done in the first compartment of the constructed wetland (presettling basin).

Figure 3.45: "Kwekelbaarsjes" system (STOWA, 2005)

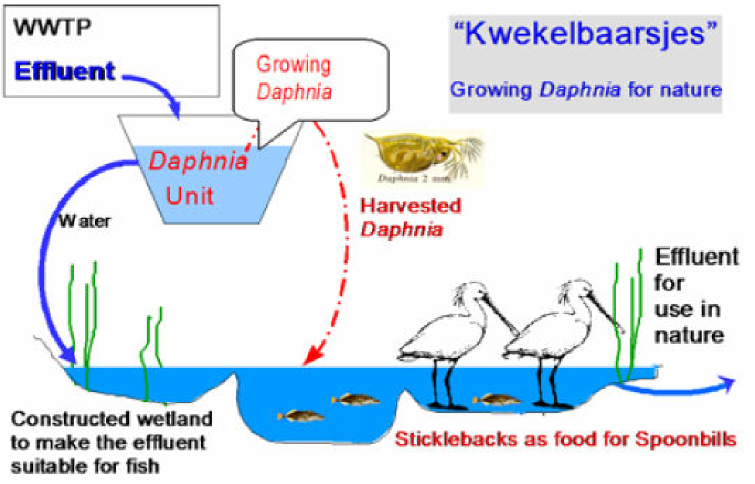


Figure 3.46: Dapnia magna, gricklebacks and spoonbill

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[1] "Kwekelbaarsjes" is an combination of the Dutch words "kweken" and "stekelbaarsjes". Or in English: "Gricklebacks"; "grow" and "sticklebacks"

Figure 3.47: "Kwekelbaarsjes" system at STP Everstekoog (pilot plant)

3.3.8 Pond systems

3.3.8.1 WASTE STABILIZATION POND SYSTEM IN ARAD (ISRAEL)

Site description

The study was performed in a full-scale advanced integrated pond and reservoir system located near the City of Arad, in the Negev Desert of Israel, at 525 m. above the sea level. The climatic conditions of this area reflect an arid or semi-arid climate, where the mean monthly temperature varies from 14.6 ^oC in winter to 23.8 ^oC during the summer. Mean annual precipitation during the rainy season (October-April) is around 150 mm. The relative humidity is low during summer, with values around 15 to 30%. Solar radiation is high during the entire yea, reaching a mean monthly maximum of approximately 1,000 W/m^2.

The treatment plant receives raw wastewater from the City of Arad, which has a stable population of around 22,000 inhabitants. The sewage is mainly domestic with a flow rate of about 5,000 m^3/day. The final effluent is used for irrigation of a variety of crops in an adjacent farm, such as almond trees, wheat, barley, sunflowers and alfalfa, under onsurface and subsurface drip irrigation systems.

This integrated pond system is in operation since 1999, and includes different treatment components (Table 3.60, Figure 3.48): (i) three anaerobic ponds operated in parallel (one of the anaerobic ponds is covered with a standard floating plastic sheet, and another one with a submerged plastic made tent, both for biogas collection); (ii) a facultative and a maturation pond in series (with an internal re-circulation); (iii) a two-stage rock filter pond with two dikes of 8-12 cm of gravel, performing like an horizontal trickling filter; (iv) three stabilization reservoirs operating in parallel under a "fill-rest-withdraw" mode, and; (v) a seasonal large storage reservoir.

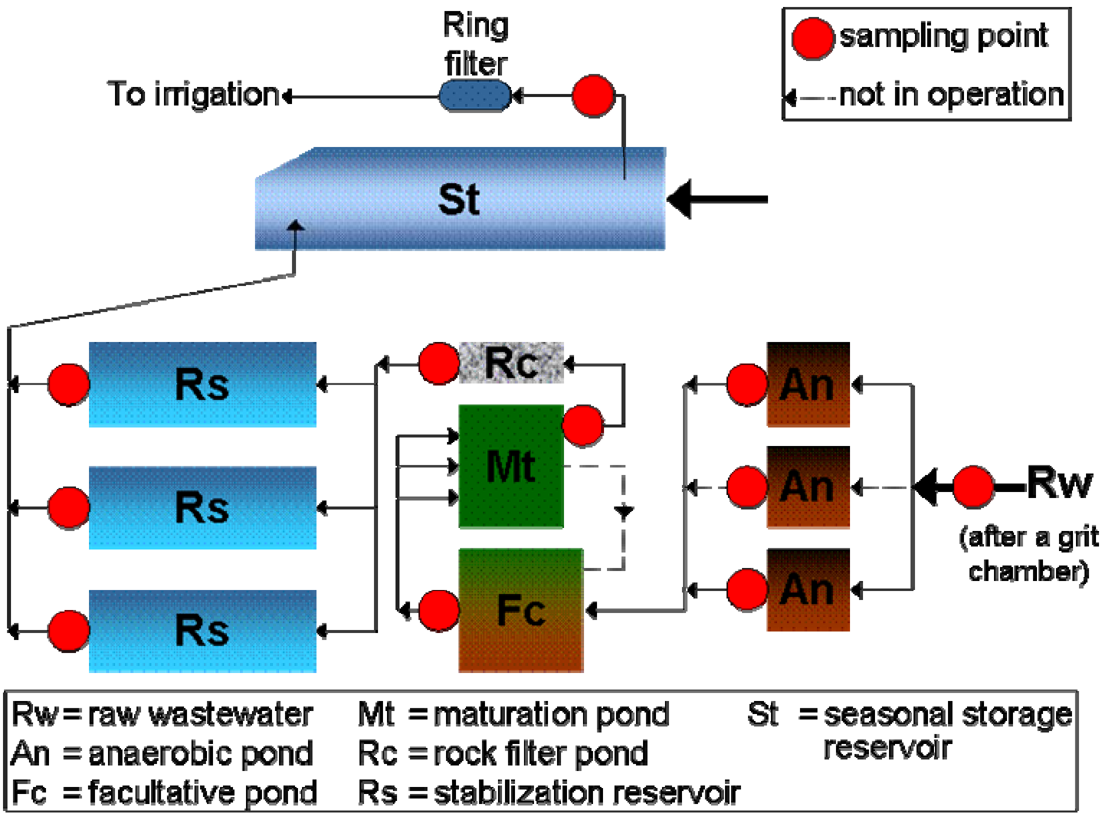
Table 3.60: Design characteristics of the water stabilization pond and reservoir system in Arad (Israel)

Components of the Waste Stabilisation Pondsystem	Volume (m^3x10^3)	Surface area (m^2x10^3)	Depth[1] (m)	HRT[2] (d)
Anaerobic pond, An	5	2.3	5	2
Facultative pond, Fc	42.5	29	2.5	8.5
Maturation pond, Mt	37.5	25.5	1.5	7.5
Rock filter, Rc	13	7.7	2	2.6
Stabilization reservoir, Rs	100	26.3	5	40
Seasonal storage reservoir, St	650	50	13	150

[1] Maximal depth of the water in the related pond/reservoir.

[2] Theoretical Hydraulic Retention Time (HRT).

Figure 3.48: Flow diagram of the stabilization pond and reservoir treatment system of Arad and sampling points



Results and Discussion

Seasonal behavior of pathogen indicator microorganims

The fecal coliform, somatic coliphage and F-specific bacteriophage content in the raw wastewater and the effluent of each system's component is presented in Figure 3.49. The numbers of the three pathogen indicators in the raw wastewater are quite similar for the two seasons with a slightly increase during summer.

The findings regarding the seasonal dynamic of the fecal coliforms content in the WSP is consistent with previous findings (Troussellier *et al*, 1986, Mezrioui *et al*, 1995). Previous studies show that for similar treatment processes under Mediterranean climate conditions (stabilization pond systems in south-east France and Marrakech, Morocco), fecal coliforms content is relatively stable in the first stages of the treatment train, whereas in the final stages, gradually larger differences between summer and winter can be identified. These changes were generated simultaneously and in the last stages of the treatment system, which is in accordance with the results of this study. This seasonal dynamic indicates that fecal coliform content is not only controlled by the incoming influent quality or by the differences in the wastewater quality of each lagoon. The bacterial populations and content probably depend on a combination of climate conditions, sewage quality, the treatment system layout and operational conditions that affect holistically the physical, chemical and biological processes.

Removal of bacterial and viral indicators through the treatment system

The average content of fecal coliforms in the final effluent of the treatment system never exceeded from 3.00 log units/100 mL along the period of study, with some of the values being below the detection limit. Therefore, it can be claimed that the final effluent of this treatment system complies with the WHO guidelines (WHO, 1989) for unrestricted irrigation regarding the fecal coliform content (≤1000 CFU/100 mL or 3 log units/100 mL), and can be applied for unrestricted irrigation of several crops during the entire year, with no need of any additional disinfection treatment.

During this study, the highest value for the average content of somatic coliphages in the final effluent was 3.67 log units/100 mL and some of the values were below the detection limit. The highest value for F-specific bacteriophages was 1.37 log units/100 mL and most of the values were below the detection limit. Although there are no guidelines issued by the WHO or other international institutions regarding maximal content of these phages in reclaimed wastewater for irrigation, it can be claimed, due to the low numbers found in this study, that the concentration of pathogenic viruses will be also low.

The capacity for fecal coliforms, somatic coliphages and F-specific bacteriophages removal of each component of the treatment system is presented in Figure 3.50. All the components have an average removal of the three indicators monitored higher during summer than during winter. These observation excludes the seasonal storage reservoir and, in the case of the F-specific bacteriophages, also the stabilization reservoirs. These exceptions are probably due to the low numbers of the three pathogen indicators found in these two last components of the system, being difficult to determine significant improvement in the removal efficiencies. It has to be noticed that those microorganisms still remaining viables are more resistant to the ambient conditions, so their elimination is more difficult.

The higher removal rates during summer for the three indicators monitored can be explained by the environmental factors effects. These include the high ambient temperature, solar radiation and pH which cause microorganisms content reduction (Saqqar *et al*, 1992, Davies-Colley, 1999).

The highest reduction rates of fecal coliforms and somatic coliphages, independently of the period of study (summer and winter) were found in all reservoirs. Mean fecal coliform removal in the stabilization reservoirs and in the seasonal storage reservoir was 1.90 log units/100 mL and 1.43 log units/100 mL, respectively, for the entire study period. These values are similar to those obtained by Liran *et al.* (1994) in a study carried out in a stabilization reservoir located in a rural settlement in Israel. The stabilization reservoirs have a theoretical hydraulic retention time of 40 days and in the seasonal storage reservoir the retention time is about 150 days (Table 3.60). The hydraulic retention time is considered the same for summer and winter due to the fact that, in this arid region irrigation also continuous during the winter. These results emphasize the major role of the hydraulic retention time in microorganism removal in reservoir systems.

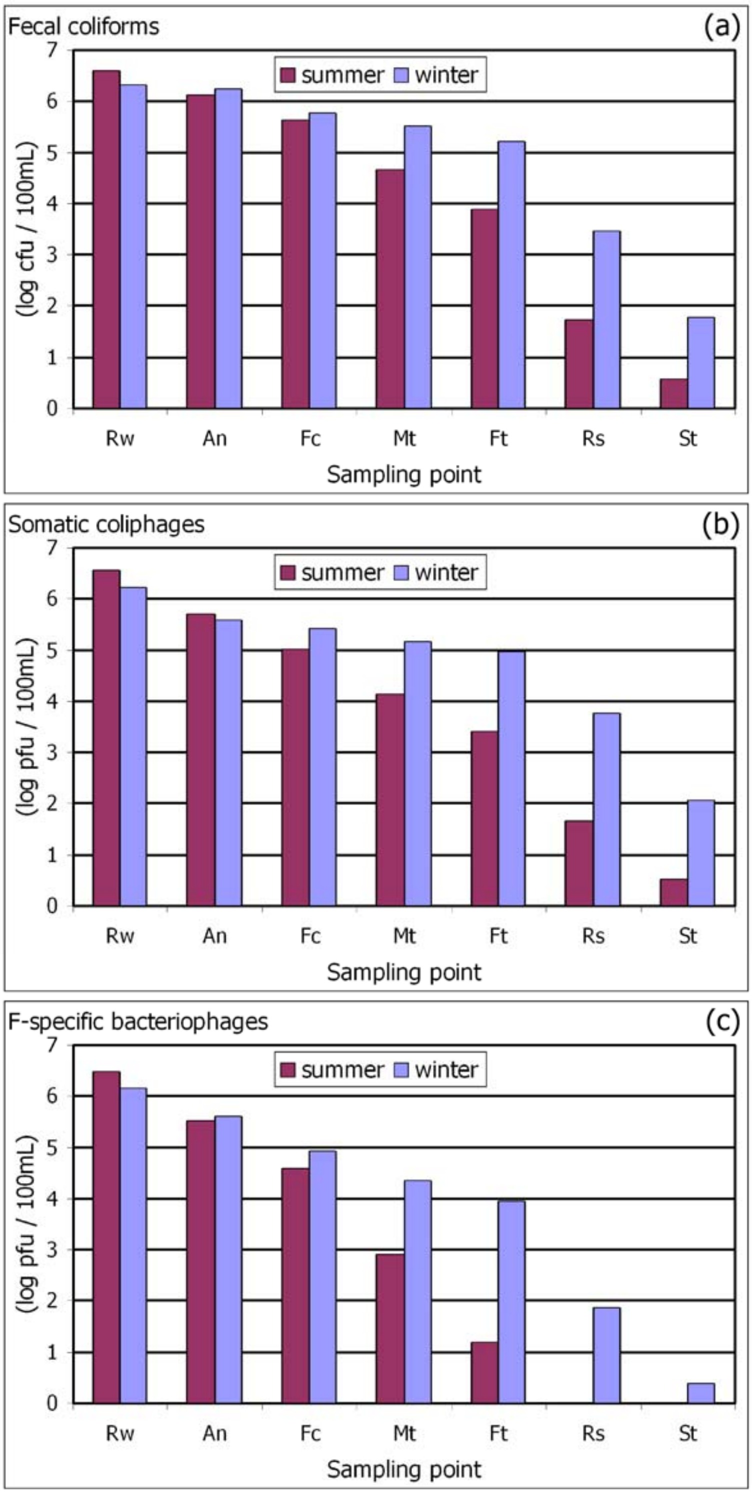
F-specific bacteriophages are removed during summer more efficiently in components of the treatment system located before the stabilization reservoirs and the seasonal storage reservoir. This behaviour differs from the one observed for fecal coliforms and somatic coliphages.

The removal rates for fecal coliforms and somatic coliphages in the different components of the treatment system are similar. However, it is noted that the removal of somatic coliphages and F-specific bacteriophages in the anaerobic ponds is higher than for fecal coliforms (Figure 3.47). This result indicates that phages are removed more efficiently than fecal coliforms in this type of ponds. The most important mechanism for microorganisms removal in anaerobic ponds is the adsorption onto settling solids (BITTON, 1975).

The rock filter pond plays an efficient role in diminishing the three-pathogen indicators content. Consequently, the reduced land requirements for the rocky pond help to offset the disadvantage of classical WSP systems.

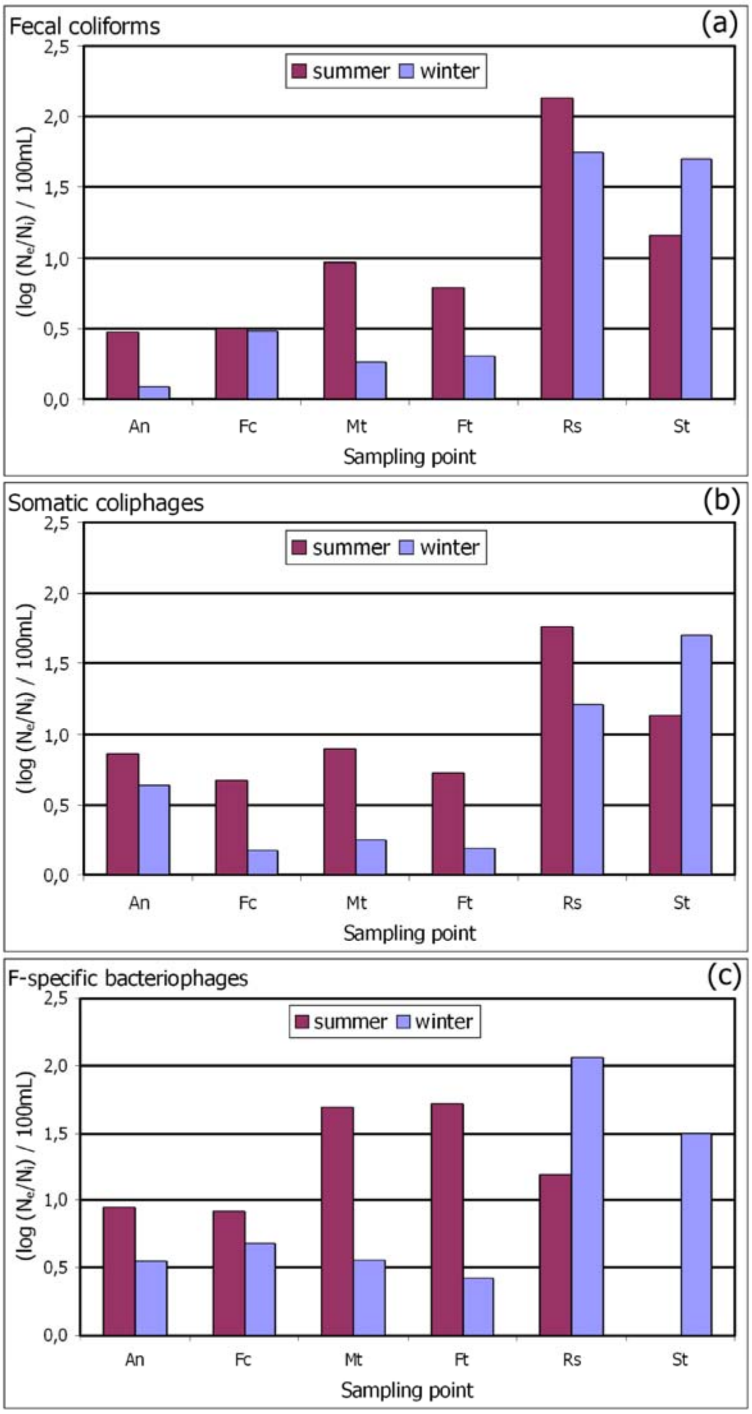
F-specific bacteriophages were removed in a higher rate than fecal coliforms and somatic coliphages in all the components of the treatment system (Figure 3.47). It can be considered that more than 90% of F-specific bacteriophages are RNA-phages, and are commonly more resistant to ultraviolet light inactivation (IAWPRC, 1991, Brion et al, 2002). Ultraviolet irradiation is one of the parameters that affect the microorganism removal and die-off in WSP treatment systems. Consequently, F-specific bacteriophages were expected to be more resistant to stabilization ponds’ disinfection than fecal coliforms and somatic coliphages. The results obtained in this study indicate that, in this case, F-specific bacteriophages were mainly DNA-phages. It is necessary to confirm this by differentiation on the basis of sensitivity to RNase in the assay of these bacteriophages. In their evaluation of a WSP treatment system in New Zealand, Turner and Lewis (1995) also found that F-specific bacteriophages were reduced at a higher rate than fecal coliforms. These results indicate that probably F-specific bacteriophages may not be adequate as viral indicators for stabilization and reservoir treatment systems, due to their rapid elimination. However, more work is needed to confirm this tendency.

Figure 3.49: Mean of fecal coliform (a), somatic coliphage (b) and F-specific bacteriophage (c) content in the raw wastewater and the effluent of each treatment step for summer and winter periods.



Rw= raw wastewater, An= anaerobic pond, Fc= facultative pond,
Mt= maturation pond, Ft= rock filter, Rs= stabilization pond,
St= seasonal storage reservoir

Figure 3.50: Average removal of fecal coliforms (a), somatic coliphages (b) and F-specific bacteriophages (c) in each treatment step for summer and winter.



Rw= raw wastewater, An= anaerobic pond, Fc= facultative pond,
Mt= maturation pond, Ft= rock filter, Rs= stabilization pond,
St= seasonal storage reservoir
Ni=concentration in influent of treatment step
Ne=concentration in effluent of treatment step

CONCLUSIONS

According to the results of this study, several conclusions can be drawn:

- Fecal coliform, somatic coliphage and F-specific bacteriophage contents follow a seasonal dynamic (summer – winter) along the entire treatment system, which emphasizes the influence of climatic conditions.

- The fecal coliform content of the final effluent of the treatment system complies with the WHO guidelines (1989) for unrestricted irrigation with reclaimed wastewater.

- The stabilization reservoirs and the seasonal storage reservoir allow several orders of reduction in fecal coliform, somatic coliphage and F-specific bacteriophage concentrations in the final effluent, confirming that the extra hydraulic retention time of these treatment components improves the microbial quality of the effluent.

- The rock filter pond performance is associated with a reduction of the three-pathogen indicators. The lower land requirements of the rock filter pond can diminish the disadvantages of classical WSP systems and make the rock filter pond an upgrading effluent quality phase.

- Anaerobic ponds seem to be more efficient for the removal of somatic coliphages and F-specific bacteriophages than for fecal coliforms.

- F-specific bacteriophages are removed more efficiently than fecal coliforms and somatic coliphages in this treatment system. This finding implies that F-specific bacteriophages would not be a reliable indicator for pathogenic viruses behaviour in this kind of treatment systems due to their rapid elimination. However, more work is needed to confirm this tendency. Also a differenciation between RNA and DNA phages could supply valuable information.

4 INNOVATIVE TECHNOLOGIES

4.1 Introduction

On the long term, schemes alternative to the traditional chain (i.e. secondary treatment including nutrient removal) can become feasible options. One of the innovating technologies is Direct Membrane Filtration (DMF) of raw wastewater. This is a purely physical process by which particles (including micro organisms) are removed from the wastewater by membrane filtration (UF). To remove large particles from the wastewater simple pre-treatments such as screening, sedimentation or Dissolved Air Flotation (DAF) can be applied. The effluent of this process is particle free water rich in dissolved components (among other things nutrients). Possible applications of this new concept can be found in agriculture. DMF is investigated in several places (Netherlands, China, Israel).

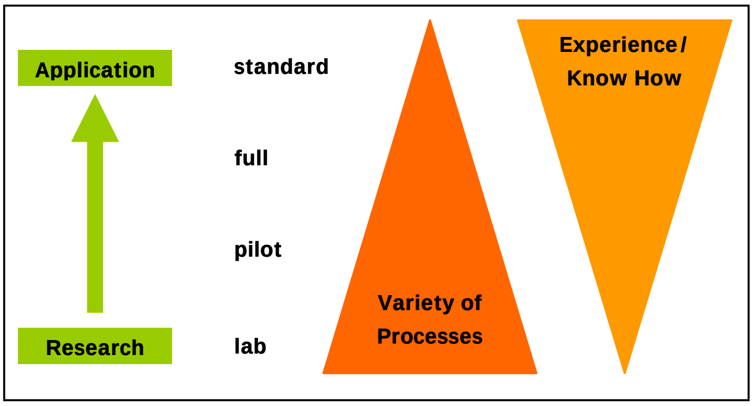
Other innovating technologies are advanced oxidation processes. These processes become more and more important since substances such as pesticides, endocrine disrupters, etc. are given priority. These substances cannot be degraded biologically. Advanced oxidation processes are capable to destoy these organic compounds.

Besides the development of new technologies the regulations for the discharge of treated wastewater become more and more stringent. This means that measuring the standard group of parameters (BOD, COD, nitrate-N, nitrite-N Kjeldahl-N, total-N, ortho-P, total-P, suspended solids) will be not longer sufficient. Up to now heavy metals and organic micro pollutants, the so-called non-standard parameters, are only measured occasionally. From literature some information is available regarding the removal of non-standard substances in traditional and advanced (wastewater) treatment processes. An overview is given in section 4.4.

4.2 Approach

The innovation of technologies is characterised in Figure 4.1. Usually innovation starts with ideas for research. At that stage a variety of processes is subject of research on lab scale whilst the level of knowledge regarding the processes and their application is still limited. During the process of development to a standard technology the number of processes investigated decreases and the level of knowledge increases.

Figure 4.1: Technical innovation management



Two approaches can be applied for the innovation of wastewater treatment technologies; the top-down approach (see Figure 4.2) and the bottom-up approach (see Figure 4.3). The top-down approach is a more practical approach which starts with an inventory of existing problems and future challenges. The objective is to solve these problems and challenges.

The bottom-up approach is a more scientific and fundamental approach. It starts with the development of new technologies on lab scale without considering possible applications. The objective to develop the technology to a practical level and propose applications (niches) to solve existing problems and future challenges.

Figure 4.2: Top-down approach

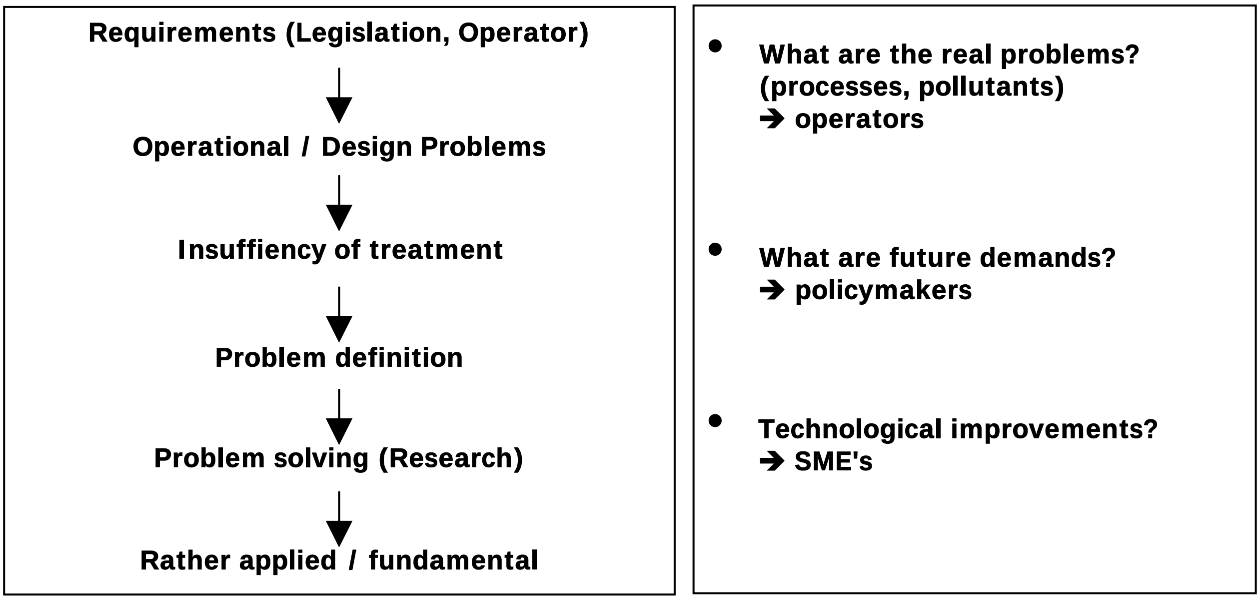
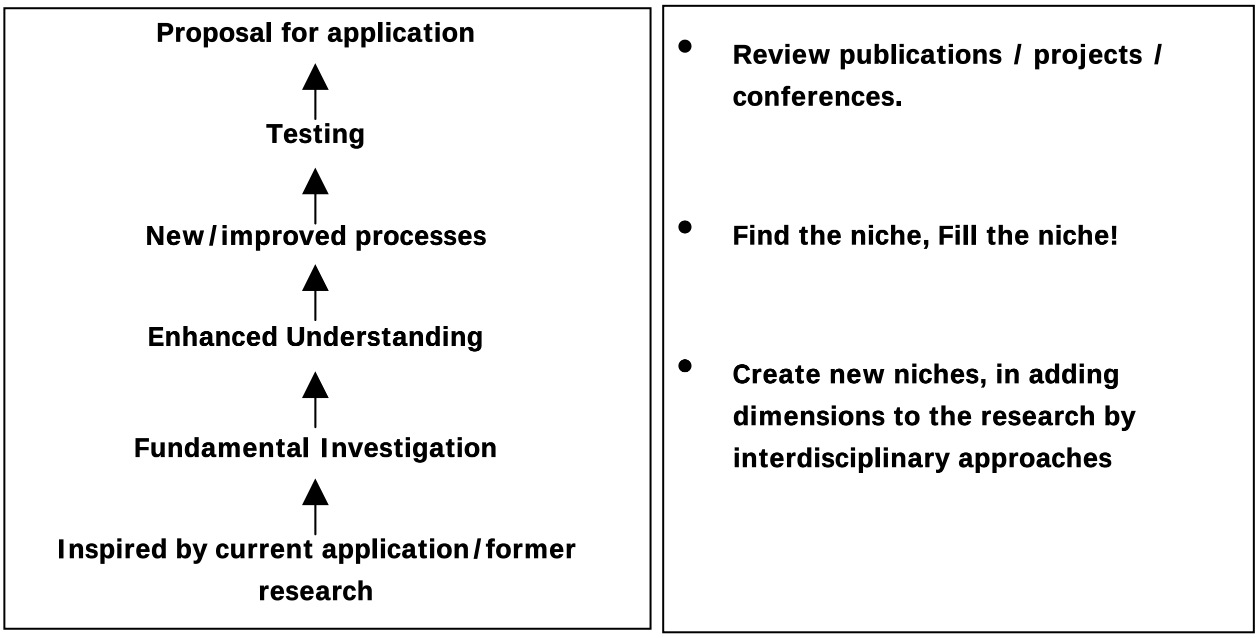


Figure 4.3: Bottom-up approach



4.3 Innovating Technologies

4.3.1 Direct Membrane Filtration

4.3.1.1 DEFINITION

During treatment of municipal wastewater, membranes are currently applied in two types of application. The first is the refinement of secondary or tertiary effluent from a conventional treatment plant; the second is membrane bioreactors (MBR) (Wintgens et al, 2005). In both cases membranes are applied after a biological treatment, which represents the core-step for the removal of bulk parameters such as COD (chemical oxygen demand), BOD (biological oxygen demand), and nutrients (Nitrogen and Phosphorous). When the wastewater is directly filtrated on the membrane, the process is usually called Direct Membrane Filtration (DMF) or Direct Membrane Separation. In this case the main removal mechanism is the mechanical separation operated by the membrane, therefore a purely physical process.

4.3.1.2 PROCESS DESCRIPTION

The feed water is wastewater directly from the collection/transport system; therefore it is most likely anaerobic. Simple mechanical pre-treatments, such as screening, sedimentation or DAF, remove large particles prior to membrane filtration. The membrane separates two phases: the filtrate (or permeate) and the retentate, where all the retained material accumulates. In principle, if a membrane system is operated in complete dead-end mode, the only retentate woud be the back-flush water, but this is unlikely during the filtration of roughly pre-screened sewage with high content of suspended solids. Therefore, during DMF, there will always be a consistent volume of retentate to treat.

For the treatment of retentate the following options can be considered:

- if the concentration is sufficient, it might be directly treated/disposed as (anaerobic) sludge;
- it might undergo further concentration with membrane;
- it might be returned to the feed tank, eventually after thickening (from where suspended solids purging must be somehow operated);
- it might be returned to the sewer, i.e. it is biologically treated downstream.

The quality of the permeate depends upon the characteristics of the feed water and the membrane pore size, but in general:

- Suspended solids and associated contaminants are completely removed, independently from the pore-size of the membrane in use (MF, UF, NF or RO);
- Harmful pathogens are significantly rejected: protozoan cysts and bacteria are removed already by MF and UF membranes, while viruses are completely removed by NF and RO;
- The permeate is clear (turbidity < 1 NTU).

According to its quality, the permeate can be considered for direct reuse or might undergo further treatment. The use of flocculants and powdered activated carbon (PAC) prior to the membrane filtration may also improve the permeate quality or the filtration performances.

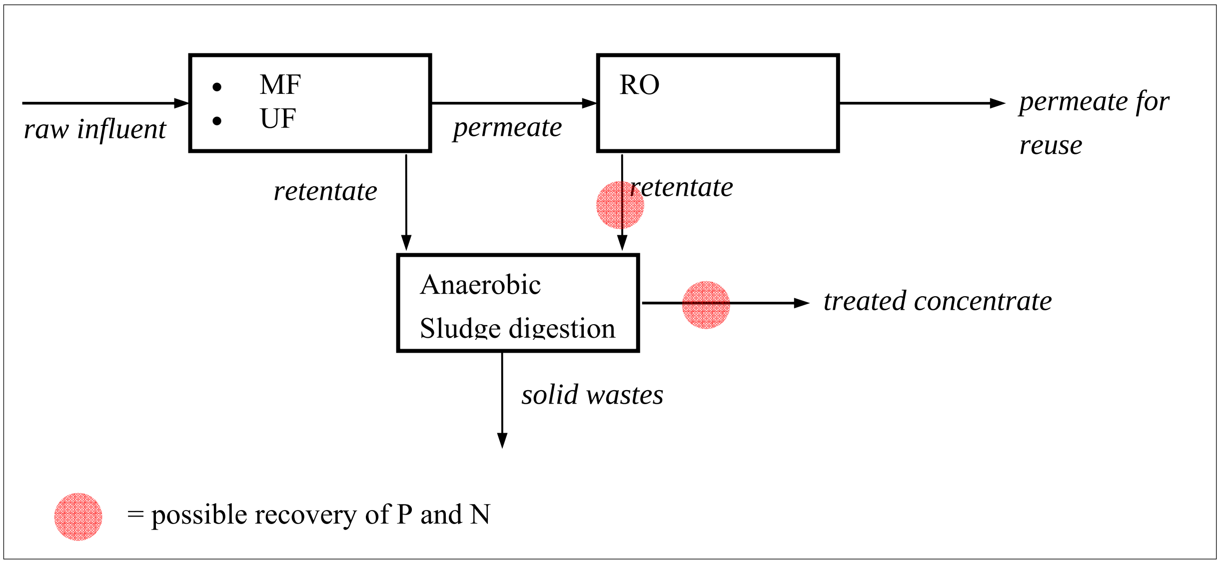
When applied as a single-step process, DMF guarantees a partial treatment only, as many substances usually regarded as pollutants may be not removed. However, it may generate water of such quality to enable reuse options. In Table 4.1 the permeate quality obtained during different researches with various feed-water is shown (for the references, please refer to Chapter 5).

Table 4.1: Average permeate quality during Direct Membrane Filtration of various feedwaters [mg/L]

Feed wastewater	**References**	**Membrane type**	**COD**	**BOD**	**TOC**	**N_{tot}**	**NH_4^+**	**P_{tot}**	**PO_4^{3-}**
Municipal raw	Ravazzini	UF	138				39		4.0
Municipal primary effluent	Ravazzini	UF	78				30		3.4
	Sethi	MF		65					
	Abdessemed	$FeCl_3$+PAC +UF	7-20						
From dormitory	Hao	MF	95-140			80-86		5.2-5.6	
	Hao	UF	67			80		5.4	
Low strength	Ahn	MF	9-20		3-5	11-27	10-27		
	Ahn, Ramon	UF	5.5-80		2				
	Ramon, Sayed	NF	15-16		6		31		0.6

When followed by further treatment, DMF can be considered a very advanced pre-treatment for the removal of particles, bacteria and turbidity. The membrane step can be followed by traditional schemes, but the most innovative option would be to realise a complete chemical-physical treatment. For instance, the combination with processes such as coagulation, adsorption and further membrane filtration could produce water of sufficient quality. When a double membrane system is realised, coupling MF/UF and RO, it may also favour the recovering of the nutrients N and P, as opposed to traditional schemes where they are simply removed. MF and UF membranes in facts are permeable to ammonia and dissolved phosphates, which are largely rejected by the RO membrane. In such a system them, N and P would be found in high concentration in the RO permeate, from where they can be recovered. A concept scheme could be as indicated in Figure 4.4.

Figure 4.4: Double membrane system with DMF and nutrients recovery



Finally, it is remarked that the application of direct membrane filtration to "sewer mining" seems particularly attractive to generate new reuse possibilities. The concept of sewer mining implies that water is reclaimed from sewage with a reduced treatment effort by simply returning the generated wastes to the sewer instead of handling them on-site (Butler and MacCormick, 1995). DMF would allow the extraction of good-quality and hygienically safe water from sewage:

- in a single-step, automated and remotely controlled treatment
- requiring very low foot-print
- producing water on demand (it can be shut down when not needed)

4.3.1.3 LITERATURE REVIEW

A literature review on DMF may show the potential of the process to wastewater reuse and the actual status of development. Several researches are indeed currently ongoing in several parts of the world, including all the different membrane technologies used in wastewater treatment, microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). Different kinds of wastewaters have been used as source: greywater, blackwater, manure wastewater and finally municipal wastewater, either raw or after primary sedimentation.

The only application developed at full-scale is the treatment of pre-settled manure with UF and/or RO membrane in VSEP (Vibratory Shear Enhanced Process) configuration. In this case UF is used to: a) concentrate the manure before digestion and b) to produce a permeate that after chemical cleaning is recycled for irrigation, wash-down or cooling water. Alternatively, pre-settled manure is passed through a wire screen and fed to RO, so as to produce drinking-water quality for the livestock, wash-water for the barns and irrigation (Johson et al, 2004).

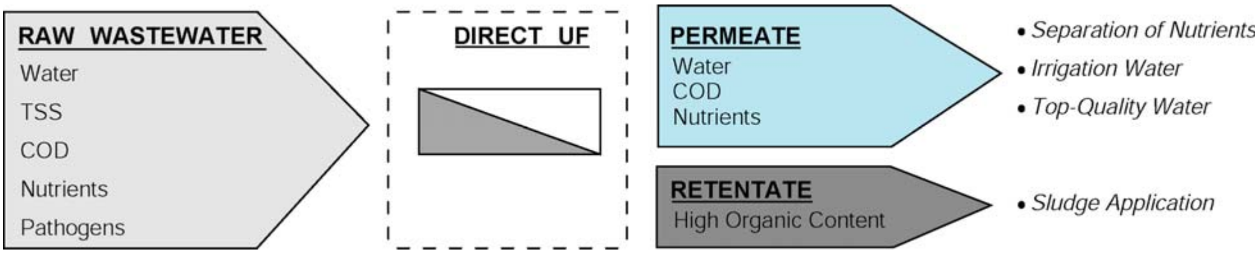
All other researches have been limited to lab-scale or pilot scale. Kyu-Hong Ahn *et al.* treated pre-screened low loaded greywater from a resort and hotel complex with MF and UF tubular ceramic membranes and hollow fibers. They obtained an effluent satisfactory for Korean standard for secondary reuse (i.e. toilet flushing and landscape irrigation) (Kyu Hong Ahn et al, 1998, 1999 and 2000). In a later work, they used effluent from the septic tank of a dormitory to compare DMF with a MBR (Kyu Hong Ahn et al, 2001).

In California, on account of Orange County Water and Sanitation District, a capillary crossflow MF pilot was tested for one year with primary clarifier effluent. The focus was on clarification and microbial removal, aiming to directly discharge to the ocean or further RO. Results were defined “promising” for both the applications (Sethi et al, 2002).

In China, direct MF and UF of highly loaded wastewater from university apartments were tested with ceramic and organic membranes (Hao et al, 2005). The effluent was used to irrigate winter wheat in small laboratory test fields. The membranes were able to guarantee “health-safe” irrigation and the wheat production increased of 7.5% in weight in comparison with the crops irrigated with tap water and fertilisers.

A similar concept is developed in the Netherlands, were some current studies focus on the feasibility of crossflow UF of municipal wastewater either as a tool for advanced particle removal or for irrigation purposes (van Nieuwenhuijzen et al, 2000, Ravazzini et al 2004 and 2005). The concept is illustrated in Figure 4.5

Figure 4.5: The concept of direct ultrafiltration of municipal wastewater



Always in Holland research is undergoing to obtain process water by capillary NF of municipal wastewater (Sayed et al, 2005), whereas in Sweden, direct RO of black water is investigated to regain the nutrients in the waste water.

Regardless of the process conditions, and focusing only on the achievable permeate quality, Abdessemed and Nezzal (2002) showed that it is possible to obtain filtrate suitable for industrial applications by treating primary effluent with a combination of coagulation, adsorption and UF. In Israel, Ramon *et al.* (2004) demonstrated that direct NF of graywater from a sport centre may produce water for reuse on-site.

4.3.1.4 PROS AND CONS

PROs:

- It’s a treatment in a single step;
- It’s purely physical, therefore it can operate discontinuously (extracting water on demand) and in difficult climates;
- It can be fully automated and remotely controlled, which is favourable to realize decentralised systems;

- Different permeate quality can be achieved using different membrane pore sizes or auxiliary coagulants/PAC dosing;
- In absence of additional chemical dosage the produced sludge can be treated as primary sludge with high organic content (high rate anaerobic digestion with energy production);
- It provides excellent pathogens removal;
- The permeate is clear and particle free, therefore it is visually appreciable and is suitable for UV disinfection (interesting in case of irrigational reuse) or AOP treatment for reduction of organic micropollutants;
- Nutrients (P and N) are isolated: using MF and UF they will be found in the permeate, as ortophosphates and ammonia, whilst during RO they will be mostly found in the concentrate. This aspect might lead to efficient nutrients recovery or utilization.

CONs:

- Contaminants are not removed, but only separated;
- Fouling problems still need to be solved and differ from case to case;
- High content of ammonia is likely to be found in the permeate, when it is present in the feed water;
- The “sanitizing” effect might require a back-up disinfection system to protect form membrane or sealing leakages;
- Costs are unknown yet.

4.3.1.5 REUSE POSSIBILITIES AND OTHER APPLICATIONS

As mentioned in the literature review, several reuse options have been considered in different researches, some of which were proved to be technically feasible. In the following a list of possibilities is given with some comments:

- Irrigation: irrigation is a large water-consuming activity and requires lower water quality, therefore MF and UF seems more appropriate while NF and RO are too expensive. A remarkable advantage would be the possibility to directly reuse the nutrients in the permeate (N, P and K) reducing the needs for additional fertilization. A number of national regulations exist for irrigation reuse, with great differences in terms of included parameters and limiting values. In general, the filtrate of Direct MF/UF may accomplish the values for pH (6.0-8.5), TSS (<10mg/l), turbidity (<2-5NTU), Electroconductivity (<3000µS/cm) and microbiological parameters (eventually in combination with another disinfecting technique). About organic (COD, BOD) and nutrients content (especially for ammonium), the situation may differ from case to case and it is difficult to generalise. Irrigation deals also with soil modifications with time and crops needs and uptakes. Direct use of permeate from municipal wastewater can be considered for urban irrigation as well as for irrigation of fruit trees, forested areas and not-eaten-raw crops. If in some cases some values are not matched, partial blending with the traditional water sources can be sufficient for the accomplishment. In this case the water saving would be just as much as a fraction of the total. Selected areas and selected crops or vegetation can probably be irrigated when the contact of irrigation water with surface water and groundwater is avoided. Other applications may regard green-houses, confined open-air crops and urban-landscape irrigation.

- Ocean discharge: it has already been proved possible, showing the main advantages in total suspended solids removal and disinfection without chlorination. Taking advantage of the process flexibility, it could be considered for treating seasonal flow peaks or combined sewer overflow.
- Industrial reuse: for direct reuse, the most probable application regards internal reuse of industrial effluent. Municipal wastewater is indeed a difficult source with respect to membrane fouling, especially because of the variable composition with time: operating with constant-quality industrial effluent might be easier. Furthermore, starting from municipal wastewater, water for such purpose can be retrieved also with Title22-alike technologies. However, it might be that DMF become interesting when using other water sources (e.g. graywater, combined sewer overflow), or for discontinuous needs.
- Advanced pre-treatment: direct UF/MF could be considered as highly advanced pre-treatment for (seasonally) overloaded treatment plants. Thinking of tourist areas where high wastewater flows are generated in limited period of the year, it would take advantage of the small footprint and the possibility to work intermittently. The excess flow could be filtrated retaining primary sludge and delivering the permeate to the biological process. In this case, the biological process would receive almost the same flow but smaller load, with an increase in the soluble fraction. The low COD/N ratio in the UF filtrate (~3.5 in van Nieuwenhuijzen *et al.* (2000)) will not constitute a problem when mixed with the “traditional” flow from the primary clarifier. The concentrate from the membrane process could be thickened and the sludge be separated from the surnatant, which is returned to the membrane filtration. From another point of view, UF/MF filtrate may result suitable for further membrane filtration (RO), or for enhanced biological treatment on attached biomasses or MBR (eventually after AOP to effectively control the removal of organic micropollutants).
- Urban reuse: NF and RO may be suitable for local reuse of graywater or black water in applications such as toilet flushing, service/washing water, park irrigation. It would be especially appreciable in decentralised system for isolated communities, hotel and resorts, large shopping/office buildings.

4.3.1.6 KNOWLEDGE GAPS

The development of the technique with respect to wastewater of municipal origin is still at a research stage. Several answers still need to be answered:

- Fouling: membrane processes are always prone to fouling. Nevertheless, in every membrane application and even more for the novel DMF, there is little knowledge about what compounds or properties are responsible for it. Until now, there is no experience to predict the effect of fouling over a period longer than one year

- Permeate reuse: starting from selected wastewater source, it has been shown that requirement for reuse options can be fullfilled. However, there is no experience about practical applications which could start in the fields of agriculture and process water.
- Waste streams treatment: before DMF is realised in practice, also the quality of the produced wastes (sludge and concentrate) and their treatment must be evaluated
- Costs: fouling can be tackled by means of energy expenditure (cross-flow velocity ad backflush) or by chemical cleaning, which is also a direct cost.

Given the improvements in the use of membranes for wastewater treatment, it can be expected that technical issues will be overcome. Fouling problems and costs are expected to be the most important factors that will set the limits to the applicability of the technique.

4.3.2 Advanced oxidation processes

4.3.2.1 DEFINITION

The production of various new compounds to meet the ever increasing demands of human beings has led to the occurrence of a variety of pollutants in wastewater that can not be degraded by conventional wastewater treatment techniques. Typical examples are textile dyes, Personal Care Products (PCP), hormones, pharmaceuticals, pesticides, etc. To remove these types of compounds, more advanced techniques are needed, such as for instance Advanced Oxidation Processes (AOP’s).

The main characteristic of Advanced Oxidation Processes is that free (hydroxyl) radicals are involved in the oxidation reactions. Free radicals -especially the hydroxyl radical- are amongst the most powerfull oxidising species known. The hydroxyl radical is highly reactive and able to oxidise a wide range of species at a fast rate. Most AOP’s therefor aim at the production of hydroxyl radicals.

Radical formation can be induced by photolysis, ozone, H_2O_2, … Once a radical is formed, a series of complicated reactions is initiated in which new radicals are formed, radicals are recombined or scavenged, or organic/inorganic species are oxidized.

Advanced oxidation processes may be used to treat wastewater, drinking water, contaminated soils or sludges for the following purposes:

- Organic pollutant destruction
- Toxicity reduction
- Biodegradability improvement
- BOD/COD removal
- Odor and color removal
- Destruction of resin in radioactive contaminated sludge
- Desinfection
- …

Literature covers a wide variety of AOP’s. This paragraph highlights the most common techniques. It would be impossible to make a complete overview of all existing processes. Not only are there numerous varieties and combinations of AOP's, there is also some discussion on whether or not some applications belong to the AOP's. Ozone e.g. is not included in this review because it was considered that the reaction mechanism is (partly) based on the direct attack of ozone molecules to the target compounds and not necessarily on radical reactions.

Techniques which are highlighted in this section are:

- Cavitation: ultrasound
- Fenton
- Photocatalysis:
  - UV
  - UV + H_2O_2
  - semiconductor photocatalysis
  - photo-assisted Fenton
- Emerging techniques:
  - Pulsed Plasma
  - Electrolysis
  - Catalytic ozonation
  - Ionising irradiation

Wet air oxidation is not discussed in this section as this technology is only suitable for highly concentrated waste streams.

4.3.2.2 ULTRASOUND

Ultrasound is the term used to describe sound energy at frequencies above the range that is normally audible to human beings.

Sound is composed from longitudianl waves comprising rarefactions (negative pressures) and compressions (positive pressures). It is these alternating cycles of compression and rarefaction that, in high power ultrasonic applications, can produce a phenomenon known as "cavitation". Caviation is the formation, growth and collapse through implosion of micro bubbles. The collapsing bubbles generate local hot spots of extreme high temperatures and pressures. The rapid bubble collapse induces high mechanical shear forces in the bulk liquid surrounding the bubble. When water is sonicated, the extreme conditions generated upon collapse of the cavitation bubbles are sufficient to cause rupture of the O-H bond itself. This results in the formation of radical species , oxygen gas and hydrogen peroxide.

Applications of ultrasound for advanced oxidation processes are limited to laboratory experience. Especially the combinations with other AOP's seem to be attractive. When ultrasound is combined with oher AOP's, the combination would lead to faster degradation rates when compared to either method alone.

The use of sonochemical reactors for oxidation processes in water is illustrated in literature for the destruction and removal of trihalomethanes (Shemer *et al.*, 2005), the decomposition of volatile and non-volatile organic compounds (Goel *et al.*, 2004) and the degradation of azo dyes (Teczanli-Güyer *et al.*, 2004). Combinations techniques under investigation are the use of ultrasound together with H2O2, UV, photoelectrocatalysis or electrochemistry (Mason *et al.*, 2004). The use of ultrasound in combination with semiconductor photocatalytic oxidation for the purpose of cleaning the catalyst surface was reported by Gogate *et al.* (2004).

4.3.2.3 ULTRAVIOLET / UV/H_2O_2

Photolysis

UV radiation is usually defined as the electromagnetic radiation of wavelength between 4 and 400 nm (Koller 1965), the spectral domain that covers the gap between X-ray and visible light. Photolysis applications in wastewater treatment can be distinguished into direct photolysis and vacuum-UV-photolysis (VUV).

In direct photolysis, the component to be destroyed must absorb the ultraviolet radiation to reach its excited state and to dissociate into radicals that undergo further reduction or oxidation. Industrial applications of direct photolysis are limited because of the low efficiency: the components are usually present in low concentrations and the probabilty that absorption leads to a further chemical reaction (the quantum yield) is low. Only when target pollutants are strong UV absorbers and have a relatively high quantum yield, oxidation by direct photolysis might be significant (e.g. NDMA, PCE, certain pesticides, …, Stefan, 2004). The UV spectral of interest for the UV-photolysis applications in water is the UVC (200-280 nm) where both the pollutants and the water constituents (dissolved organic and inorganic compounds) absorb the radiation.

In VUV applications (100-200 nm), the radiations are absorbed by water, thereby generating highly reactive hydroxyl radicals that further induce oxidative degradation of the dissolved organic compounds. Organic compounds also absorb in the VUV spectral range, but when dissolved in aquaous solution, water is the main absorber as it is present at concentrations a million times or more the concentration of any contaminant present. Vacuum UV applications are described in literature for mineralisation of model compounds (1-heptanol, benzoic acid, potassium hydrogen phtalate, Oppenländer *et al.*, 2005).

Lamp selection for a particular photolysis application is governed by several factors, such as the absorption spectrum of the pollutant, the spectrum of the water background (dissolved organic matter may exert an inner filter effect), lamp geometry and the manufacturing and operating costs. Monochromatic light sources such as the low pressure Hg-lamps or excimer lamps emit radiation of one certain wavelength, whereas polychromatic light sources, like medium pressure Hg-lamps, emit a wide wavelength range.

Upscaling of photochemical reactors is often complicated due to the different phenomena involved in photo-catalytic reactions (geometrical effects, absorption of radiation, …). Furthermore, kinetic modelling of the degradation process is the key point in the effective design of the reactors.

UV/H_20_2

The principal behind the beneficial effects observed using UV-light in combination with H_2O_2 as compared to the individual application, lies in the fact that the rate of generation of free radicals is significantly enhanced in the combination technique.

The ultraviolet/hydrogen peroxide proces is based on the photochemical cleavage of H_2O_2 for the generation of highly reactive hydroxyl radicals. The combination of hydrogen peroxide and UV can create very fast and efficient oxidation reactions. The efficiency depends on several factors (Gogate *et al.*, 2004b):

- UV source: the maximum absorbance of H_2O_2 is at 220 nm; commonly used low-pressure mercury vapor lamps have a maximum peak emission at 254 nm. Therefore, a high concentration of H_2O_2 is needed to generate sufficient hydroxyl radicals when using a conventional UV source, although the quantum yield is high. To overcome this limitation, medium-pressure, high-intensity broadband UV-lamps may be used.
- The concentration of H_2O_2 needs to be properly selected. Usually there is an optimum concentration beyond which the presence of hydrogen peroxide becomes detrimental to the degradation reaction due to scavenging reaction of the hydrogen peroxide itself.
- Presence of hydroxyl scavengers, such as carbonate and bicarbonate. Hydroxyl scavengers consume hydroxyl radicals and limit further oxidation reactions. Also humic acids, benzene, toluene, xylene can scavenge radicals.
- Operating pH: lower pH is usually favourable. The intrinsic rates of the UV/H_2O_2 are not affected much, but there will be a lower effect of radical scavengers.
- Optical path length of the medium, presence of compounds absorbing the UV light, such as suspended solids, high turbidity, …
- Lamp cleanliness: mineral deposits etc… prevent light emission

UV/oxidation can economically treat a broad range of contaminants in concentrations ranging from several hundred parts per billion (ppb) to several hundred parts per million (ppm). UV/oxidation is particularly effective for chloroalkenes such as trichloroethene (TCE) and vinyl chloride, and for aromatic compounds such as toluene and benzene. Experience and cost comparisons have shown that for contaminants such as 1,4-dioxane, vinyl chloride, nitrosodimethylamine (NDMA) and iron cyanide, UV/oxidation is the only practical choice. UV/peroxide can treat saturated compounds such as trichloroethane (TCA) and chloroform, but reaction rates are much slower (http://waternet.com, 2005)

UV applications are studied in drinking water treatment for the removal of NOM and DOC. The optimal H_2O_2 dose for NOM removal was found to be 0.01% (Wang *et al.*, 2000). A demonstration project in San Jose, California evaluated a UV/oxidation technology for groundwater treatment (removal of VOC’s). H_2O_2 concentration was 200 ppm. At bench scale, removal efficiencies were excellent (99.99%), but during the test period in the field the efficiency deteriorated dramatically due to precipitation of chemicals and minerals on the quartz tubes (Tuhkanen, 2004)

In general, ground water treatment costs for UV/oxidation range from 30 cents to $3 per 1,000 gallons (http://www.watertechonline.com/article.asp?IndexID=5190913).

4.3.2.4 FENTON

Fenton reactions in wastewater treatment processes are known to be very effective in the removal of many hazardous organic pollutants from water.

Fenton's reagent was discovered about one hundred years ago (Fenton, 1894), but its application as an oxidizing agent for destroying toxic and recalcitrant organics was not applied until the late sixties (Huang *et al.*, 1993). The conventional Fenton process involves the use of H_2O_2 and an iron catalyst.

The Fenton process is based on the following so-called Fenton reaction:

$$Fe^{II} + H_2O_2 \rightarrow Fe^{III} + {}^{\circ}OH + OH^{-} \qquad (1)$$

$$(Fe^{III} + H_2O_2 \rightarrow Fe^{II} + HO_2{}^{\circ} + H^{+}) \qquad (2)$$

Iron is continuously cycled between the ferric and the ferrous state. But since Fe^{II} oxidation is a much faster reaction than Fe^{III} reduction, iron is mainly present in the Fe^{III} form. By irradiation of light with wavelenghts below 580 nm the generated Fe^{III} is reduced to Fe^{II} together with the formation of a hydroxyl radical, this is called the photo Fenton process.

Fe acts as a catalyst, but loss of iron can occur, e.g. by precipitation of FeO(OH). Therefore, pH should be maintained < 3-4 (optimal pH is 2,8). It has been found that addition of certain organic ligands that can complex Fe^{III}, enables the process to be carried out at higher pH. This occurs because complexation limits the loss of Fe^{III} through precipitation. This is an important modification of the process because the addition of large amounts of acid to achieve the optimum process efficiency, followed by base to neutralise the water after the oxidation is complete, makes the process unsuitable for many applications due to the increased salinity. Suitable ligands should be biodegradable, should bind Fe^{III} strongly, but allow transformation of Fe^{III} to Fe^{II} as a result of reductants (e.g. superoxide) produced in the process. Common ligands used for this process are oxalic and citric acids. At lower pH, acetic acid/acetate buffer can be used to maintain pH. Phosphate and sulphate buffers give lower oxidation efficiencies. This can be attributed to the formation of stable Fe^{3+} complexes that are formed under these conditions (Pignatello, 1992).

A batch Fenton reactor essentially consists of a completely stirred reactor, equiped with addition of acid, base, ferrous sulfate catalyst and industrial strength (35-55%) hydrogen peroxide. Corrosion resistant materials should be used because the Fenton reagent is very aggressive. The optimum catalyst to peroxide ratio is 1:5 (wt/wt). Addition of reactants are done in the following sequence: wastewater followed by dilute sulfuric acid, catalyst, acid or base for pH-adjustment (+/- 3). Finally, hydrogen peroxide is added slowly (maintaining ambient temperature). The discharge of the Fenton reactor is fed into a neutralizing tank, followed by a flocculation tank and a liquid-solid separation step (Gogate *et al.*, 2004b).

Use of Fenton processes can lead to complete mineralisation of some organic compounds, but this would often involve a large excess of chemicals preventing the process from being cost effective. Hence, only partial degradation occurs in order to reduce toxicity and increase biodegradability of the residue.

A major drawback of the conventional homogeneous Fenton proces, are the enormous amounts of sludge produced upon iron addition. Heterogeneous processes make use of a solid surface containing iron, e.g. iron coated sand, iron adsorbed onto zeolites or ion exchange membranes. When treating contaminated groundwater with Fenton's oxidation, autochtonous iron can be used (Bergendahl *et al.*, 2003).

There are several full scale plants in South Africa that use Fenton's reagent to treat wastewater from the textile industry (Vandevivere *et al.*, 1998) and commercial scale Photo-Fenton installation exist in the USA for treatment of water contaminated with VOC's and semivolatile organic compounds (USEPA, 1998) Patented technologies involving the Fenton reaction used in industry are (Wadley *et al.*, 2004):

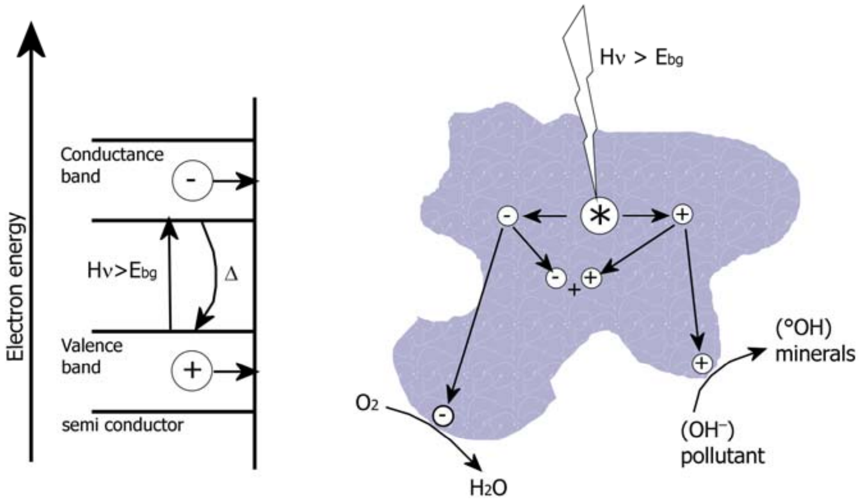
- The Geo-Cleanse process® (in situ treatment of subsurface environmetns) by Geo-Cleanse international, Inc. (http://www.geocleanse.com/).
- The CleanOX process (in situ chemical oxidation) by ManTec, Inc (MECx) (http://www.mecx.net/).
- ISOTECH^{SM} Modified Fenton's Process by In-Situ Oxidative Technologies Inc. (http://www.insituoxidation.com/).
- The BIOX® Process (in-situ coupled chemical oxidation-enhanced biodegradation) by BioManagemnt Services, Inc. (BMS)
- The On-Contact Remediation Process® by Environmental Business Solutions International, Inc. (EBSI) (http://www.ebsi-inc.com/).

4.3.2.5 SEMICONDUCTOR PHOTOCATALYSIS / PHOTOELECTROCATALYSIS

A semiconductor material consists of a highest occupied band full of electrons (valence band, VB) and a lowest unoccupied band (conductance band, CB). The two bands are at a different energy level, the difference in energy between the two bands is called the bandgap energy (E_{bg}). When the material is illuminated with a wavelength ν such that the energy $h*\nu > E_{bg}$, an electron is transferred from the valence band to the conductance band, leaving a hole h^+ in the valence band. The electrons/holes can either recombine or find their way to the surface. Generally, the efficiency of most processes involving semi-conductor photosenstizers is low because the usual fate of photogenerated electron-holes is recombination before the surface of the solid is reached. The electron-hole pairs that can make it to the surface react with oxygen, respectively surface hydroxyl groups (or pollutant) to form H_2O, resp. OH• radicals (or mineralised pollutant).

Ideally, a semiconductor photocatalyst for the purification of water should be chemically and biologically inert, photocatalytically active, easy to produce and use, and activated by sunlight. The semiconductor TiO_2 comes close to this demanding list of requirements, but it needs to be illuminated by UV-light. (Mills *et al.*, 2004). At first sight, ZnO is an obvious competitor to TiO_2, but it is not used for water treatment because it slowly dissolves under practical conditions.

Figure 4.6: Schematic Illustration of the energetics and major processes occurring in semiconductor photocatalysis (after Mills et al., 2004)



The semiconductor photocatalyst can be used as a powder dispersion or as a fixed film. Powder dispersion is usually very efficient in terms of photons and easy to make and maintain. A major disadvantage is that the catalyst must be separated from the treated wastewater and be recycled to the reactor. This often involves an additional filtration step. Catalyst separation is much easier in a fixed film system. However, these systems are low in efficiency and complicated for catalyst replacement (e.g. upon desactivation).

The most common problem associated with photocatalytic oxidation seems to be the reduced efficiency associated with the adsorption of contaminants at the surface and the blocking of the UV-activated sites. Gogate *et al.* (2004) advised ultrasonic treatment of the catalyst surface during the photocatalytic operation as a proper continuous cleaning technique.

Although numerous research projects have been devoted to photocatalytic treatment, commercial applications stay well behind. It seems that the low overall efficiency prevents adoption by the big water treatment companies.

There are however several commercial TiO_2 photocatalyst systems available (Mills *et al.*, 2004): ISK (Japan, www.iskweb.co.jp), Hyosung Ebara (Korea, www.heec.co.kr), Clearwater Industries (USA, www.cwirfc.com), Photox Bradford Ltd (UK, www.vcb.co.uk/photox/), Lynntech Inc. (USA, www.lynntech.com), Purifics® Environmental Technologies Inc. (Canada, www.purifics.com).

4.3.2.6 RECOMMENDATIONS AND FUTURE RESEARCH

Mineralisation of organic compounds by AOP's is seldom complete. Smaller molecules tend to be less susceptible to hydroxyl radical attack. Even if conditions exist under which complete mineralisation would be possible, it would consume too much reagents/energy. Advanced oxidation treatment should therefore aim at a reduction of toxicity, more than complete oxidation. If complete oxidation is the ultimate goal, AOP's are to be combined with subsequent bioloigcal treatment.

In AOP's the wide range of reactions occurring upon radical formation, leads to a wide variety of degradation products that in some cases are more toxic than their parent compounds. It is therefore vital to determine the degradation products, e.g. by means of GS_MS, HPLC-MS and HPLC-DAD (Wadley *et al.*, 2004).

Upscaling of AOP's involving irradiation is often complicated due to the different phenomena involved in photo-catalytic reactions (geometrical effects, absorption of radiation, …). Future research should pay attention to methods for upscaling laboratory set-ups. Zalazar *et al.* (2003) showed that with a detailed modelling of laboratory reactors, it is possible to obtain reaction kinetic models and the corresponding kinetic parameters than can be used to design a large scale reactor.

Radical scavenging is a major problem in advanced oxidation techniques. Several authors state that pretreatment should remove radical scavengers before an AOP is used. There is however little or no information available on removal techniques for radical scavengers.

4.3.2.7 REUSE APPLICATIONS

In re-use applications in textile industry, decolourization of wastewater by AOP's is frequently studied. Besides decolourization, also toxicity reduction and enhanced biodegradability are aimed for. Because of the absorption of radiation, high concentations of oxidants are needed when applying photochemical processes. El Dein *et al.* (2002) found that chemical oxidation alone was not feasible, but combined to biological stages it may offer an economical alternative.

Currently, an European research project is conducted which focusses on the optimisation of a hybrid technology combining solar photocatalysis, ozone and bioprocesses to the treatment of wastewaters containing Priority Hazardous Substances for permitting the reuse of this water. The expected result would be a new technology (CADOX) with market possibilities and suitable to be applied for the remediation of wastewaters with organic contaminants (http://www.psa.es/webeng/projects/cadox/index.html).

Furthermore, AOP's may prove effective in any re-use project where emerging contaminants as endocrine disruptors, pharmaceuticals, surfactants, PCP's or other organic micropollutants pose an ecotoxicological risk. Typical exmaples are groundwater recharge or drinking water projects. However, full scale applications of AOP's in this type of projects are limited because of the high costs associated with AOP's and the lack of regulations on the above mentioned compounds.

4.4 Non-standard parameters

4.4.1 Introduction

Conventional wastewater and drinking water treatment plants throughout the world are designed to remove or significantly reduce the concentration of a limited number of targeted contaminants. National authorities and international organizations specify effluent water criteria and drinking water standards for such targeted contaminants, which in turn are used to develop appropriate treatment processes. In recent years, research tends to document, with increasing frequency, that many chemical and microbial constituents that have not historically been considered as contaminants are present in the environment on a global scale. These "emerging contaminants" usually originate from municipal, agricultural, and industrial wastewater sources and pathways. The extent to which existing water treatment processes can reduce the concentration of emerging contaminants is an active research area.

Several emerging contaminants, including a range of anthropogenic compounds such as endocrine disrupting chemicals (EDCs), pharmaceuticals and personal care products (PPCPs), hormones, and persistent pesticides, have been found in wastewater treatment plant effluents and in surface waters.

Emerging contaminants are compounds of evolving regulatory interest— a term used to describe contaminants that are currently unregulated or may be subject to new or revised regulatory standards in the near future (Wastewater Framework Directive). That is why emerging contaminants could be characterised as “non-standard” contaminants, since they are not included yet in any regulation. Table 4.2 lists examples of compounds that have emerged recently as particularly relevant. Those “non-standard” compounds are candidates for future regulation, depending on research results on their potential health effects and on monitoring data regarding their occurrence.

Besides recognized pollutants, numerous new chemicals are synthesized each year and released to the environment with unforeseen consequences. This group is mainly composed of products used in everyday life, such as surfactants and surfactant residues, PPCPs, gasoline additives, fire retardants, plasticizers, pesticides, etc. A notable feature of these contaminants is that they do not need to be persistent in the environment to have negative effects since their high rates of transformation/removal can be compensated by their continuous release to the environment (Barceló *et al.*, 2005).

Table 4.2: Non-regulated compound classes (Barceló et al., 2005)

Compound class	Examples
Pharmaceuticals	
Veterinary and human antibiotics	Penicillins, tetracyclines, sulfonamides, macrolides, fluoroquinolones
Analgesics/antiinflamatory drugs	Ibuprofen, diclofenac, naproxen, acetaminophen, acetylsalicilyc acid fenoprofen
Psychiatric drugs	Diazepham, carbamezapine
Blood-lipid regulating agents	Bezafibrate, clofibric acid, fenofibric acid, atorvastatin, simavastatin
β-blockers	Metoprolol, propanolol, timolol
X-ray contrast agents	Iopromide, iopamidol, diatrizoate
Steroids and hormones (contraceptives)	
Personal care products	
Fragrances	Nitro, polycyclic and macrocyclic musks
Sun-screen agents	Benzophenone, methylbenzylidene, camphor
Insect repellents	N,N-diethyltoluamide
Antiseptics	Triclosan, Chlorophene
Surfactants and surfactant metabolites	Alkylphenol ethoxylates, alkylphenol carboxylates and dicarboxylates
Flame retardants	Tetrabromo bisphenol A, hexabromocyclododecane (HBCD), Tris(2-chloroethyl)phosphate
Industrial additives and agents	Chelating agents (EDTA), benzene and naphthalene sulfonates
Gasoline additives	Dialkyl ethers, Methyl-*t*-butyl ether (MTBE) and related compounds
Disinfection by-products	Iodo-THMs, bromoacids, bromoacetonitriles, bromoaldehydes, cyanoformaldehyde, bromate, NDMA

4.4.1.1 EU PRIORITY SUBSTANCES

As part of the Water Framework Directive, a European 'priority list' of substances posing a threat to or via the aquatic environment has been established. In this list 33 priority substances (Annex X of the Directive) has been identified by the European Commission based on their toxicity, persistence and liability to bio-accumulate in the environment. This list will be reviewed by the Commission every four years and is divided into two categories (depending on the level of concern):

- Priority Substances
- Priority Hazardous Substances

This includes 14 heavy metals and cyanide, 28 volatile organic compounds, 58 semi-volatile organic compounds and 25 pesticides and polychlorinated biphenyls (PCB’s).

The Commission DG Environment has engaged the Frauenhofer Institute (FHI) to propose quality standards in water, sediment and biota for the priority substances. The list of priority substances and their quality standards are shown in the Table 4.3.

Table 4.3: List of priority (hazardous) substances (European Commission, 2000), dissolved and total concentrations (Toetsnorm, 2004)

No.	Name of priority substance	Identified as priority hazardous substance	Concentration dissolved $^{2)}$ [ug/l]	Concentration total $^{2)}$ [ug/l]
(1)	Alachlor			0,035
(2)	Anthracene	(X)***		0,063
(3)	Atrazine	(X)***		0,34
(4)	Benzene			16
(5)	Brominated diphenylethers (**)	X****		0,0005
(6)	Cadmium and its compounds	X	0,16	0,8
(7)	C_{10}-$_{13}$-chloroalkanes (**)	X		0,41
(8)	Chlorfenvinphos			0,01
(9)	Chlorpyrifos	(X)***		0,00046
(10)	1,2-Dichloroethane			10
(11)	Dichloromethane			8,2
(12)	Di(2-ethylhexyl)phthalate (DEHP)	(X)***		0,33
(13)	Diuron	(X)***		0,046
(14)	Endosulfan (alpha-endosulfan)	(X)***		0,004
(15)	Fluoranthene (*****)			0,12
(16)	Hexachlorobenzene	X		0,03
(17)	Hexachlorobutadiene	X		0,003
(18)	Hexachlorocyclohexane (gamma-isomer, Lindane)	X		0,042
(19)	Isoproturon	(X)***		0,32
(20)	Lead and its compounds	(X)***	1,3	26
(21)	Mercury and its compounds	X	Anorg: 0,2, methyl: 0,02 $^{1)}$	Anorg: 1,2; methyl: 0,1 $^{1)}$
(22)	Naphthalene	(X)***		2,4
(23)	Nickel and its compounds		3,9	4,8
(24)	Nonylphenols (4-(para)-nonylphenol)	X		0,33
(25)	Octylphenols (para-tert-octylphenol)	(X)***		0,1
(26)	Pentachlorobenzene	X		0,05
(27)	Pentachlorophenol	(X)***		0,1
(28)	Polyaromatic hydrocarbons (PAK)	X		
	(Benzo(a)pyrene),			0,05
	(Benzo(b)fluoroanthene),			0,0054
	(Benzo(g,h,i)perylene),		0,031	0,51
	(Benzo(k)fluoroanthene),			0,0054
	(Indeno(1,2,3-cd)pyrene)		0,041	0,41
(29)	Simazine	(X)***		1
(30)	Tributyltin compounds (Tributyltin-cation)	X		0,0001
(31)	Trichlorobenzenes (1,2,4-Trichlorobenzene)	(X)***		1,8
(32)	Trichloromethane (Chloroform)			3,85
(33)	Trifluralin	(X)***		0,03

* Where groups of substances have been selected, typical individual representatives are listed as indicative parameters (in brackets and without number). The establishment of controls will be targeted to these individual substances, without prejudicing the inclusion of other individual representatives, where appropriate.

** These groups of substances normally include a considerable number of individual compounds. At present, appropriate indicative parameters cannot be given.

*** This priority substance is subject to a review for identification as possible "priority hazardous substance". The Commission will make a proposal to the European Parliament and Council for its final classification not later than 12 months after adoption of this list. The timetable laid down in Article 16 of Directive 2000/60/EC for the Commission's proposals of controls is not affected by this review.

**** Only Pentabromobiphenylether

***** Fluoranthene is on the list as an indicator of other, more dangerous Polyaromatic Hydrocarbons

$^{1)}$ not yearly average but 90%

$^{2)}$ quality standards by Frauenhofer Institut (Toetsnorm, 2004)

From these 33 priority substances, are:

- 11 priority hazardous substances:
  Emissions, discharges and losses should be ceased not later than in 20 years(5, 6, 7, 16, 17, 18, 21, 24, 26, 28, 30)
- 14 priority substances under review:
  Proposal by EU-Commission by latest December 2002 which ones are priority hazardous (2, 3, 9, 12, 13, 14, 19, 20, 22, 25, 27, 29, 31, 33)
- 8 priority substances:
  Progressively reduce the discharges, emissions and losses
  (1, 4, 8, 10, 11, 15, 23, 32)

4.4.1.2 ENDOCRINE DISRUPTORS (EDC'S)

An endocrine disruptor is a synthetic chemical that when absorbed into the body either mimics or blocks hormones and disrupts the body's normal functions. This disruption can happen through altering normal hormone levels, halting or stimulating the production of hormones, or changing the way hormones travel through the body, thus affecting the functions that these hormones control. Chemicals that are known human endocrine disruptors include diethylstilbesterol (the drug DES), dioxin, PCBs, DDT, and some other pesticides. Many chemicals, particularly pesticides and plasticizers, are suspected endocrine disruptors based on limited animal studies. But also some heavy metals might belong to this group. The necessity for research is obvious to specify the target substances.

A comprehensive Austrian study with risk assessment on EDCs showed no threat to human health from consumption of drinking water or fish from neither the steroid hormones nor the 4-nonylphenols (NP), NP-ethoxylates and bisphenol A. In other countries, like Japan where fish diets are more prevailing, a similar assessment may show other results. Japan officially designated NP as an endocrine disrupting chemical.

Significantly, studies on the effect of the alkylphenol polyethoxylates (APEOs) on fish (Danio Rerio) reproduction suggest, that there is an environmental health risk problem. There is also a report that Bisphenol A is metabolised to be another stronger female hormone binding product (Jacobsen *et al.*, 2003).

Table shows an EDC priority list as agreed by members of the Global Water Research Coalition (GWRC). The list is considered to be dynamic and compounds may be added or deleted as more information becomes available (GWRC, 2003).

Table 4.4: Priority list of EDC's (GWRC, 2003)

Hormones	**Heavy metals**
17β-estradiol	Cadmium
Estriol	
Estrone	
17α-Ethinylestradiol	
Pesticides and herbicides	**Industrial Chemicals**
DDT, DDE, DDD	PCB (total)
Dieldrin, Aldrin, Endrin, Isodrin	
α-Endosulphan, β-Endosulphan	Glycol ethers
Endosulphan-sulphate	ρ-Nonylphenol
Heptachlor, Heptachlor epoxide	
Lindane (γ-BHC)	ρ-Octylphenol
Vinclozolin	Phthalates: DEPH, DBP
Parathion	
Atrazine	Bisphenol A
Simazine	
Terbutylazine	
2.4-D	
Metoxychlor	
Tributyltin	
Cyhexitin	

Furthermore a number of chemicals were listed as possible candidates:

Glyphosate
Amitrole

2,4-dichlorophenol
Kepone

DPCP (1,2-dibromo-3-chloropropane)

Chlordecone
β-BHC

Arsenic
Chrome VI

These substances are all reported to have shown endocrine disrupting properties, but it remains uncertain whether they meet all the criteria for inclusion.

4.4.2 Presence of non-standard parameters in wwtp-effluent

4.4.2.1 INTRODUCTION OF THE LOES PROJECT IN THE NETHERLANDS

The Health Council of the Netherlands shares the concern about these endocrine-disrupting compounds, and addresses the issue in its recommendations ‘Hormoonontregelaars in ecosystemen’ (Endocrine-disrupters in ecosystems, in Dutch).

An initial start towards monitoring the effects has been carried out for a limited group of endocrine-disrupting compounds. This concerned (xeno-)estrogens and their effects on fish as target animals in the period 1999 – 2001 in the largescale baseline study ‘National investigation into the occurrence and effects of estrogenic compounds in the aquatic environment’ (Dutch acronym, LOES).

The LOES project indicated that the selected (xeno-) estrogens were generally found in those wastewater streams in which they had been expected. All selected (xeno-) estrogens were found to lesser or greater degrees in both treated and untreated municipal wastewater. In industrial wastewater, the compounds selected occurred as expected on the basis of the production process or application. In manure, high concentrations of natural hormones were found. Remarkable were the relatively high concentrations of phthalates found in rainwater. The concentration ranges are summarized briefly in the following paragraphs and in the following tables by chemical group and source of emission (Vethaak *et al.*, 2002).

Estrogen and xeno-Estrogen

Natural and synthetic hormons

In untreated municipal wastewater, natural hormones were found in all aquatic samples. Estrone and 17β-estradiol were found in the highest concentrations (15-150 ng/L), with 17α-estradiol found at levels up to 15 ng/L. The synthetic hormone 17〈-ethynylestradiol used in the contraceptive pill was found in one third of untreated wastewater samples. The hormones were found almost exclusively in the dissolved fraction of wastewater. After biological treatment, 17α-estradiol and 17β-estradiol were not found in the effluent of a municipal sewage treatment plant (STP) (limit of detection < 0.8 ng/L). On average, 94% of estrone was removed in the STP to a concentration below 11 ng/L. This removal is shown in figure 0.1. The compound 17〈-ethynylestradiol was found only once (2.6 ng/L) in the effluent of a stp; the concentration in the other effluent samples was below the limit of detection (< 0.3 ng/L).

In municipal wastewater, the concentration of estrogenic compounds was generally higher than in industrial wastewater with the exception of a number of specific types of industry where this was to be expected on the basis of the production process. The concentration of natural hormones in two manure samples taken from a manure storage for cows varied as follows: 17α-estradiol 120 – 190 ng/g dry weight; 17β-oestradiol 46 – 50 ng/g dry weight; estrone 28 – 72 ng/g dry weight. Hormones were not found in rainwater above the limit of detection (Vethaak *et al.*, 2002).

Table 4.5: Concentration ranges of hormones in rainwater, untreated municipal wastewater, STP effluent, industrial wastewater and manure (**Vethaak **et al.**, 2002**).

Source of emission	17α-estradiol	17β-estradiol	Estrone	17α-ethinyl estradiol
Rainwater (ng/l)	< 0.3	< 1.5	< 0.6	< 0.3
Raw municipal wastewater (ng/l)	< 0.7 – 4.9	17 – 150	20 – 130	< 0.3 – 5.9
STP effluent (ng/l)	< 0.4	< 0.8	< 0.3 – 11	< 0.3 – 2.6
Industrial wastewater (ng/l)	< 0.3 – 7.1	< 0.8 – 54	13 – 120	< 0.3 – 3.9
Manure (ng/g ds)	120 – 190	46 – 50	28 – 72	< 1

Alkylphenol (ethoxylate)

Alkylphenols and alkylphenol ethoxylates were not found in regular patterns of occurrence. In untreated municipal wastewater, nonylphenol ethoxylates and nonylphenols were sometimes found in high concentrations on occasion and in low concentrations on others. For nonylphenol ethoxylates in untreated municipal wastewater, the range was < 0.8-125 µg/L, with a median value of 37 µg/L. For nonylphenols, the range was < 0.2-19 µg/L with a median value of 3.0 µg/L. The other compounds investigated, octylphenols and octylphenol ethoxylates, were found only in a few wastewater samples. In the biologically-treated effluent of a STP, the concentrations of alkylphenol ethoxylates were generally below the limit of detection of 0.7 µg/L. The suspended matter obtained after centrifuging the effluent contained nonylphenol ethoxylates in concentrations up to 70 µg/g dry weight and up to 12 µg/g dry weight of nonylphenol.

In industrial wastewater, the variations in the concentration of alkylphenol (ethoxylate)s were even greater than in municipal wastewater. The concentrations of nonylphenol ethoxylates varied from 520 – 22,500 µg/L and between <0.4 – 39 µg/L for nonylphenols. The biologically treated effluent of one industrial wastewater treatment plant contained no demonstrable concentrations of alkylphenol (ethoxylate)s. In general no detectable concentrations of alkylphenol (ethoxylate)s were found in rainwater (Vethaak *et al.*, 2002).

Table 4.6: Concentration ranges of alkylphenol(ethoxylates) in rainwater, untreated municipal wastewater, STP effluents and industrial wastewater (**Vethaak **et al.**, 2002**).

Source of emission	Octyl-phenols	Octylphenol-ethoxylates	Nonyl-phenoles	Nonylphenol-ethoxylates
Rainwater (µg/l)	< 0.08 – 0.28	< 0.48	< 0.41	< 0.36 – 0,99
Raw municipal wastewater (µg/l)	< 0.27 – 13	< 1.1 – 24	< 0.24 – 19	< 0.82 – 125
STP effluent (µg/l)	< 0.45 – 1.3	< 0.65	< 0.55 – 1.5	< 1.9 – 2.2
Industrial wastewater (µg/l)	< 0.16 – 0.53	< 0.42 – 12	< 0.44 – 39	< 0.26 – 22,500

4.4.2.2 BISPHENOL-A

Bisphenol-A was found in each sample of untreated municipal wastewater. The concentration of bisphenol-A was shown to increase as the proportion of industrial wastewater increased. In municipal sewage of domestic origin, bisphenol-A was found in the range of 250-1,000 ng/L. In areas with more industrial activity, bisphenol-A concentrations over 5,000 ng/L were found.

Bisphenol-A concentrations in the specific industrial wastewaters sampled in the LOES project were in the range of < 20-800 ng/L. This relates to both untreated and biologically-treated industrial wastewater. The percentage of removal in sewage treatment plants varied greatly per location.

In rainwater, bisphenol-A was found in only a few samples in concentrations just above the limit of detection (Vethaak *et al.*, 2002).

Table 4.7: Concentration ranges of bisfenol-A in rainwater, untreated municipal wastewater, STP effluent and industrial wastewater (*Vethaak *et al.*, 2002*).

Source of emission	Bisfenol-A
Rainwater (ng/l)	< 15 – 57
Raw municipal wastewater (ng/l)	250 – 5,620
STP effluent (ng/l)	< 3 – 4,090
Industrial wastewater (ng/l)	< 19 – 800

4.4.2.3 PHTHALATES

The two most common phthalates in untreated sewage effluent were DEP (< 4.1 – 44 µg/L; median 13 µg/L) and DEHP (< 13 – 101 µg/L; median 32 µg/L). High concentrations of DEP and DEHP were mainly found in domestic wastewater from a residential area. Of the phthalates measured during LOES, DEP and DEHP have the lowest estrogenic potency. DMP and BBP with highest estrogenic potency, were found in far lower concentrations. The other phthalates were generally found in concentrations below 10 µg/L (DMPP, DBP, BBP) or below 1 µg/L (DMP, DPP, DCHP, DOP). After treatment by a STP, all phthalates with the exception of DEHP were removed to concentrations (far) below 1 µg/L. DEHP was still found in the effluent at concentrations to 2.5 µg/L. In addition to DEHP (30-60 µg/kg dry weight) and DEP (a factor 100 lower), DOP was also found (0.3 – 2.5 µg/kg dry weight) in the suspended matter in of the effluent. In the sewage sludge, DMPP and DBP were found in addition to DEP and DEHP. Generally speaking, the concentration of phthalates (such as with DEP and DEHP) in

untreated industrial wastewater was lower than in municipal wastewater. In a number of industrial (untreated) wastewaters streams, a few high peak values were found for DEHP and DMPP that were specific for the manufacturing process of the companies in question. In contrast, at one company that produces phthalates, very low concentrations were found in the treated effluent.

A remarkable finding in LOES was the concentrations of phthalates found in rainwater. Almost all phthalates (with the exception of DPP and DCHP) were found on several occasions in the three rainwater samples. The concentrations were comparable to those found in surface water samples. The maximum measured DEHP concentration was 1.7 µg/L, with a median value of 0.77 µg/L (Vethaak *et al.*, 2002).

4.4.2.4 BROMINATED FLAME RETARDANTS

Polybromobiphenyls (PBBs) were found in almost none of the municipal or industrial wastewater samples. Of the polybromodiphenyl ethers, the congeners BDE 47, BDE 99 and BDE 209 were found in all samples of untreated municipal wastewater. The highest measured concentrations in untreated wastewater were those of BDE 209 found in a range of 20 – 140 ng/g dry weight, with a median value of 24 ng/g dry weight. In the suspended matter derived from centrifuging the effluent, the concentrations of the PBDE congeners BDE 47, BDE 99 and BDE 209 were a factor 10 higher. BDE 209 was found in the range of 310 – 920 ng/g dry weight, with a median value of 350 ng/g dry weight. This difference is most likely attributable to the fact that the percentage of small particles in the suspended matter derived from centrifuging the effluent is much more than those in the filtered suspended matter from the influent.

Only these three PBDE congeners (BDE 47, BDE 99 and BDE 209) were also found in greater concentrations in the selected industrial wastewaters (Vethaak *et al.*, 2002).

Table 4.8: Concentration ranges of the four most common brominated flame retardants in suspended matter of untreated municipal wastewater, STP effluents and industrial wastewater** (Vethaak **et al.**, 2002)**.

Source of emission	BDE 47	BDE 99	BDE 153	BDE 209
Untreated municipal wastewater (ng/g dw)	0.70 – 13	0.50 – 14	< 5.3 – 1.0	< 20 – 140
STP effluent (ng/g dw)	14–35	18–29	< 4.0–7.1	310–920
Industrial wastewater (ng/g dw)	< 0.14 – 68	0.273 – 33	< 2.6	< 0.52 – 200

4.5 Removal of non-standard parameters

In general, different classes of emerging contaminants, mainly surfactant degradates, PPCPs and polar pesticides were found to have the smallest elimination rates and have been detected in WWTP effluents and in the receiving surface waters. This fact has led to the adoption of advanced treatment processes, such as activated carbon adsorption, ozonation and membrane technology, as well as the use of advanced oxidation processes, including a combination of ozone with other oxidation agents (UV radiation, hydrogen peroxide, TiO_2).

In general a wide variety of factors should be taken into account in order to assess the impact of drinking water treatment on the levels of different pesticides in drinking water. For treated drinking water sources, available survey information establishes that there are many distinct types of water treatment processes (and many more combinations of processes) in use that show different removal efficiencies. Pesticides may potentially be removed by a variety of conventional and developing technologies including biological wastewater treatment, adsorption on porous media (including deep bed filters and subsurface aquifer material), coagulant and activated carbon addition, oxidation (including advanced oxidation) processes, UV degradation and membrane separation. It should be recognized, however, that pesticides possess a wide range of chemical properties and the ease of removal by any specific technology may vary greatly depending upon the particular properties.

4.5.1 Conventional water and wastewater treatment

The present state-of-the-art of wastewater treatment involves the activated sludge treatment (AST) preceded by conventional physico-chemical pre-treatment steps. Removal mechanisms and biotransformation pathways are different for each group of compounds, which are determined by their physical and chemical properties. Data regarding the occurrence and removal of various "non-standard" contaminants in a WWTP have been reviewed by several researchers (e.g. Petrovic *et al.*, 2003). Table 4.9 summarizes data on the elimination of emerging contaminants in WWTPs.

Table 4.9: Elimination at WWTPs (Table retrieved from Petrovic et al., 2003)

Compound	Average elimination (%)[a]	Effluent concentrations (µg/L)	Observation
Non-ionic surfactants			
Alkylphenol ethoxylates	90-99	<0,1-350	Primary degradation fast; ultimate degradation less than 40%, with metabolites being potential EDCs
Pharmaceuticals			
Ibuprofen	65-90	0,37-0,60 (3,4)[b]	Rapid photodegradation Degradation product of lipid-regulating agents
Diclofenac	69-75	0,06-0,81 (2,1)	
Clofibric Acid	34-51	0,12-0,36 (1,6)	
Benzafibrate	83	1,1-2,2 (4,6)	
Naproxen	45-66	0,27-0,61 (2,6)	
Ketoprofen	69	0,02-0,38 (0,87)	
Gemfibrozil	46-69	0,31-0,40 (1,9)	
Carbamazepine	7	0,30-2,1 (6,3)	Low removal rate
Antiseptics			
Triclosan	44-92	0,070-0,650	Possible photodegradation
Pesticides			
MCPP and MCPA	-	20-400	Application period
2,4-D	-	<20	
2,4,5-T	-	<20	

[a] Primary elimination of the parent compound

[b] Range of average values detected (in parentheses: maximum concentration detected)

Experimental works at urban WWTPs reported the positive influence of long sludge retention time (SRT) on the removal of endocrine disruptors. Positive influences were also associated with increased nitrification. This is typically practiced in WWTP with biological nutrient removal and shows a positive side-effect from these – now conventional – treatment processes. Primary and secondary sludges from urban WWTPs may exhibit different sorption characteristics for natural steroid hormones (Jacobsen *et al.*, 2003).

The removal of EDCs and PPCPs from raw drinking water supplies with conventional water treatment processes had been investigated with treatability studies in Westerhoff, 2003. From there, some important conclusions for the removal during conventional treatment were drawn:

- Conventional treatments such as coagulation, sedimentation, and filtration will remove less than 25 percent of most EDCs and PPCPs.
- If chlorine is used during conventional treatment, then approximately one-third of the EDCs and PPCPs examined will have greater than 90 percent removal for compounds with aromatic carbon and amine or hydroxyl functional groups; less than 20 percent removal of other compounds can be expected. The byproducts of EDCs and PPCPs reactive with chlorine have not been identified and may be of concern. Preliminary work using bioassays suggests that chlorination byproducts of 7ß-estradiol may exhibit estrogenic activity.
- The addition of PAC to conventional water treatment plants, similarly to what is currently used seasonally to control odor and taste, may be effective in removing more than 75 percent of EDCs and PPCPs (Westerhoff, 2003).
- Ultraviolet (UV) irradiation is capable of oxidizing aromatic EDCs and PPCPs, but requires approximately 100 times higher UV dosages (greater than 5000 mJ/cm$_2$) than those required for microbial disinfection (5 to 50 mJ/cm$_2$). UV irradiation is unlikely to be used for EDC or PPCP removal in surface water treatment plants, but may be appropriate for smaller well head treatment systems.
- Advanced treatment processes such as membranes and AOPs can be very effective at removing EDCs and PPCPs.

Byproducts of oxidation and metabolites of biodegradation of EDCs and PPCPs are important future research topics, to identify the daughter products and determine whether they pose any health risks. Upgrading conventional treatment plants to include ozone and biofiltration on granular-activated carbon media together should be very effective at removing EDCs and PPCPs. Many EDCs and PPCPs that are not oxidized well by ozone were reduced during biofiltration and/or adsorption. Biofiltration should aid in reducing oxidation byproducts of EDCs and PPCPs (Westerhoff, 2003).

In general, the conventional water treatment, specifically coagulation-flocculation, sedimentation and conventional filtration, does not remove and transform pesticides in finished drinking water. Disinfection and water softening, however, lead to pesticide transformation and, in some cases, pesticide removal or degradation (OPP, 2001). According to previous studies, clarification plants are far from efficient and offer efficiency levels that rarely exceed 10-20% for *atrazine* and 40% for *simazine* (Miltner *et al.*, 1989). The use of slow filtration in plants offers little more than a 25% reduction in *atrazine* (Richard et al., 1991; cited in Agbekodo *et al.*, 1996). Negligible removal of *lindane* in the primary clarification stage has been found by Hannah *et al.* (1986), while 50–75% removals in this stage have been reported by McIntyre *et al.* (1986) for total chlorinated pesticides.

Pesticides may enter also a wastewater treatment plant either due to the contribution of industrial discharge or as a component of urban runoff or drainage into the sewerage system (Petrasek *et al.*, 1983 and Katsoyiannis *et al.*, 2002). The fate of these organic compounds in wastewater treatment plants will be governed both by the physico-chemical properties of the compounds and the process design and operating conditions of the treatment system (Bhattachatya *et al.*, 1996, Jacobsen *et al.*, 1996 and Byrns, 2001). Pesticides have been determined among other organic priority pollutants in the influents and the effluents of several municipal wastewater treatment plants (USEPA, 1982). According to USEPA, the removal of pesticides in these conventional treatment plants was very low, while higher concentrations in the effluent compared to the influent, for various types of pesticides (like *lindane*), were observed in the cases where a chlorination stage was employed in the end of the treatment process (USEPA, 1982).

Generally, there are few publications dealing with the behaviour of pesticides in real WWTPs, but there is a fair amount of work on their degradation under laboratory conditions. Activated Sludge Treatment (AST) was found to be ineffective in removing chlorinated phenoxy acid herbicides from settled sewage. However, under laboratory conditions MCPP (a chlorinated phenoxy acid herbicide) proved to be biodegradable (nearly 100%). Nevertheless, this requires a long adaptation time (lag-phase) of activated sludge (Nitscheke *et al.*, 1999). In real WWTPs, this presents a major difficulty since, like the majority of herbicides, MCPP is applied only during a short growth period of plants, which means that WWTPs that contain a non-adapted activated sludge, receive shock-loads of herbicides which will not be eliminated. A long acclimatization period (about 4 months) was also observed in a bench-scale study using sequencing batch reactors before 2,4-D biodegradation was established (Mangat *et al.*, 1999). Subsequently, at steady-state operation, all reactors achieved practically complete removal (>99%) of 2,4-D.

The effectiveness of chemical and physical wastewater treatment processes, in removing selected organic pesticides from domestic wastewater, was also studied in a water reclamation pilot plant by Saleh et al (1982). The pilot consisted of biological, chemical and physical units. More specifically, biologically treated wastewater was subjected to chemical coagulation, multimedia filtration and activated carbon adsorption. Thirteen compounds were confirmed in the biologically treated wastewater. These included DDT and its metabolites, aldrin, dieldrin, and 2,4-D alkyl esters and salts. Concentration levels of these compounds in wastewaters were at the ng/L level. Chemical coagulanon with alum-lime or lime-ferric chloride was found to effect slight reduction of the organic residues detected. Quantitatively only DDT compounds were more completely removed by chemical treatment. Multimedia filters had no discernible effect in removing organic residues from biologically and chemically treated wastewater. Activated carbon columns were found to be the most effective means for removing the refractory organic residues detected. However, breakthrough of some organic residues was noted after usage of the carbon for over one year. The overall results of the study showed that application of several sequences of treatment processes on domestic wastewater can produce a high quality effluent.

4.5.2 Advanced methods of treatment

4.5.2.1 MEMBRANE TECHNOLOGY

It has become evident that the application of more enhanced and advanced technologies is crucial to fulfil the requirements for the production of drinking water. In recent years, there have been studies of new technologies not only for wastewater treatment but also production of drinking water. Among them membrane treatment, using both biological (MBRs) and non-biological processes (reverse osmosis, nanofiltration) and advanced oxidation processes are considered, since they may be appropriate for removing trace concentrations of emerging contaminants such as pesticides (Petrović *et al.*, 2003).

Over the last few years, membrane technologies, especially reverse osmosis and nanofiltration, have emerged as suitable processes for drinking water treatment and sea water demineralization.

Most organic EDC/PPCP compounds are in the molecular size range of 150 to 500 Dalton. Therefore, only those compounds associated with particles or colloidal organic matter can be removed by microfiltration (MF) and ultrafiltration (UF). Most EDCs and PPCPs can be removed by reverse osmosis (RO) and tight nanofiltration (NF) systems (i.e., those with a low molecular weight cutoff). For example, RO can achieve greater than 90% removal of steroid hormones. Experience with other organic/inorganic compounds suggests that polar compounds and charged ones that interact with membrane surfaces, can be better removed than the less polar or neutral compounds. For example, the removal efficiency of several low molecular weight compounds (150 Dalton) tends to increase at higher pH due to electrostatic repulsion between RO membranes and dissociated organic compounds. RO, NF, and charged UF membranes can remove inorganic EDCs. Overall, membranes provide an excellent barrier for most EDCs and PPCPs, except for the lower molecular weight uncharged compounds (Snyder *et al.*, 2003). Hormones can be removed by adsorption by hydrophobic microfiltration hollow fibre membranes (Chang *et al.*, 2001).

Considering that the molecular weight of almost all pesticides is in the range of 200 to 400 Dalton (Da), nanofiltration membranes are potentially useful for pesticide removal. Regarding the pesticides, a literature survey shows that there are key solute parameters that primarily affect their rejection, such as molecular weight (MW), molecular size and shape (length and width), acid disassociation constant (pKa), hydrophobicity/hydrophilicity ($\log K_{ow}$) and diffusion coefficient (Dp). There are also key membrane properties affecting rejection, including molecular weight cut-off, pore size, surface charge, surface morphology and hydrophobicity/hydrophilicity (Berg *et al.*, 1997, van der Bruggen *et al.*, 1998, Kiso *et al.*, 2001, Chen *et al.*, 2004 and Košutić *et al.*, 2005). Additionally, feed water properties such as pH, ionic strength, hardness and the presence of organic matter are identified as having an influence on solute rejection (Agbekodo *et al.*, 1996, Boussahel *et al.*, 2000, Devitt *et al.*, 1998 and Zhang *et al.*, 2004).

One great example of nanofiltration for the removal of organic residues during the production of drinking water is the Méry-sur-Oise Plant in the northern part of the Paris region, France. The Méry-sur-Oise Plant has been producing water from the river Oise, using nanofiltration technology for a production capacity of 140.000 m^3/d, since 1999. This plant is a world premiere on surface water. Performances are very satisfactory, especially for the two main objectives: elimination of organic matters and of pesticides, which make the use of nanofiltration technology a complete success (Cyna *et al.*, 2002).

Despite the high removal capacity of pesticides by membranes, it should be taken into account that a relatively large concentrated fraction is obtained (up to 20% of the feed volume), where the initial pollutants are present in elevated concentrations. Easy methods for concentrate disposal are discharge to salt water bodies, transport to wastewater treatment plants, the use of deep injection wells, and blending for use as irrigation water (possibly after purification of the concentrate with UF). More complex applications may require the implementation of a hybrid system, e.g. in combination with adsorption or biodegradation. The environmental fate of the pollutants in the concentrate is usually unclear; research and practical applications should, therefore, focus on the further treatment of the concentrated fraction, which is inextricably bound up with the application of NF (van der Bruggen *et al.*, 2003).

Reverse osmosis can be applied for the removal of heavy metals (Metcalf & Eddy, 2003).

4.5.2.2 ADSORPTION

Activated carbon adsorption

Activated carbon can be used to remove many different pesticides, pharmaceuticals, and estrogenic compounds. The performance of activated carbon depends on the physicochemical properties of the sorbent (surface area, pore size distribution, surface charge, oxygen content) as well as of the solute (shape, size, charge, and hydrophobicity). Hydrophobic interactions are the dominant mechanism for removal of most organic compounds in activated carbon adsorption systems, although ion exchange interactions can result in removal of polar solutes (Snyder *et al.*, 2003 and Crittenden *et al.*, 1999). As a result of the hydrophobic interactions, activated carbon can efficiently remove most nonpolar organic compounds (i.e., those compounds with $\log K_{ow} > 2$). The capability of activated carbon to remove more polar compounds will depend on the strength of the polar interactions, though prediction of the strength of these interactions is difficult (Snyder *et al*,, 2003).

The presence of natural organic matter (NOM) or wastewater organics (such as bacterial exudates) may lower the extent of trace contaminant removal by activated carbon as a result of competition for surface sites (Wu *et al.*, 2001) and/or pore blocking resulting in a reduction of the activated carbon capacity for adsorbing micropollutants. For example, addition of 10 to 20 mg/L of powdered activated carbon (PAC) to distilled and river water spiked with seven antibiotics has shown to achieve between 50% and more than 99% removal. However, when the same experiments were repeated with river water containing 10,7 mg/L of NOM, removal decreased by 10 to 20%.

The rate of adsorption of the trace contaminant to the activated carbon and the contact time provided will be important determinants of extent of contaminant removal. The rate of adsorption of contaminants to the activated carbon will be determined by the nature of the activated carbon used (the smaller the size, the more rapid will be the uptake kinetics), by the presence of competing solutes and, at least in GAC where systems may operate for some months, by how long the GAC has been in operation since more strongly adsorbable constituents can displace previously adsorbed compounds.

Under the conditions encountered in drinking water treatment plants, removal of micropollutants by PAC tends to be independent of initial contaminant concentration. The use of granular activated carbon GAC leads to very high removal of micropollutants during the first weeks/months but, with time, more strongly adsorbable constituents can displace previously adsorbed compounds (Snyder *et al.*, 2003).

The review paper of Snyder *et al.* (2003) provides a generalized summary of the potential for removal of EDCs and PPCPs by various processes and operations used for this purpose.

Westerhoff (2003) concluded more than 90 percent removal of many of the studied EDC and PPCP compounds for using PAC added with a 4 hour contact time in a 5 milligram per liter (mg/L); some compounds were removed to below detection levels. Other compounds had lower removals (40 to 60 percent); these included ibuprofen, sulfamethoxazole, meprobamate, and iopromide. A trend in removal capability was observed, with hydrophobic compounds (octanol-water partition coefficient ($\log K_{ow}>5$) having better removal than more polar compounds (deprotonated acids). Removal was dependent upon the PAC brand, PAC dose, and the presence of DOC in the water.

Filtration through activated carbon has been demonstrated to be highly effective process at removing organic chemicals, including **certain** pesticides (primarily acetanilide herbicides), but specific data on removal of most pesticides are not available. Although adsorption on activated carbon offers an efficiency of 30~60% with *atrazine* (Baker *et al.*, 1986), this process is limited by the competition between different absorbable molecules and, more generally, by the organic matter naturally present in raw waters (Li *et al.*, 2003). The carbon filters are saturated rapidly and their efficiency to eliminate pesticides decreases with a high presence of natural organic matter (NOM) due to a competitive adsorption. Organic micropollutants such as pesticides may be present at the mg/l level, whereas NOM concentrations may be 10,000 times higher. Furthermore, the cost is increased by the frequent regeneration of the carbon. The adsorption columns have to be regenerated rapidly because the column capacity is mainly used for NOM adsorption instead of pesticides adsorption.

Adsorption to other components

Hormones can be removed through adsorption on particles of activated sludge, bentonite, hematite and cellulose (Jensen *et al.*, 2001).

Biofiltration

Biofiltration was simulated using biological acclimated sand. Some compounds appeared to biodegrade; these included acetaminophen, caffeine, DEET, estrone, estradiol, naproxen, ibuprofen, and gemfibrozil. Almost all showed some partitioning into the biofilm, but lab-scale tests left unclear whether the sorption mechanism is sustainable. Other compounds were persistent, such as iopromide and meprobamate, and were not biodegraded (Westerhoff, 2003).

4.5.2.3 CHEMICAL PRECIPITATION, COAGULATION/FLOCCULATION

Coagulation (alum or ferric) removed less than 20 percent of the compound concentration in drinking water supplies, investigated in Westerhoff (2003). Slightly higher removal rates were observed in the presence of a hydrophobic dissolved organic carbon (DOC) material, indicating some partitioning of hydrophobic EDC and PPCP compounds with the DOC and concurrent removal. EDCs or PPCPs associated with particulate matter (i.e., that were adsorbed) were effectively removed during coagulation, sedimentation, and nonbiological filtration.

Heavy metals are removed by chemical precipitation under the formation of hydroxide- and sulfide-precipitates (Metcalf & Eddy, 2003).

4.5.2.4 LIME SOFTENING

Lime softening at pH 9 or pH 11 removed less than 20 percent of the compound concentration (Westerhoff, 2003).

4.5.2.5 ION EXCHANGE

Ion exchange can be applied for the removal of pollutants dissolved as ions, like heavy metals. Treatment of wastewaters with widely fluctuating metal concentrations requires often flow equalization (Metcalf & Eddy, 2003).

4.5.2.6 CONVENTIONAL AND ADVANCED OXIDATION PROCESSES

A range of oxidants including chlorine, chloramines, chlorine dioxide and ozone are used in water and wastewater treatment for disinfection purposes. These oxidants may also induce the transformation of organic compounds present in the aqueous streams to which they are applied.

Chlorination

Chlorine dioxide (ClO_2) is a relatively stable free radical, which is applied either as an oxidant or a disinfectant in wastewater and drinking water treatment processes. Its use is attractive, in part, because of its apparent lower tendency to produce chlorinated byproducts than chlorine.

Chlorination (1 to 6 mgCl_2/L dose to achieve 1 mgCl_2/L residual after 24 hours) either removed compounds by more than 90 percent or led to less than 20 percent removal. More reactive compounds contained aromatic structures with hydroxide functional groups, while less reactive compounds had carboxyl groups or lacked aromatic structures. The use of some chlorine residual-quenching agents such as thiosulfate appeared to react with EDCs and PPCPs, and should be avoided in monitoring studies (Westerhoff, 2003).

While there have been no reports of investigations of the reactivity of ClO_2 specifically with pesticide compounds, chlorine dioxide is recognized to react selectively with phenols. Hoigne and Bader (1994) have investigated the reaction of chlorine dioxide with a wide range of phenols. Since it is the phenoxide anion which reacts rapidly (up to 106 times as quickly as the non-dissociated species), the apparent total reaction rate constant increases for most types of phenols by a factor of 10 per pH increment over most of the pH range of interest in water treatment.

Ozonation

Ozone is a powerful oxidant and can oxidize substrates either directly or by producing hydroxyl radicals that then react with other entities (organic compounds, bicarbonate anions, bromide, etc). The two pathways compete for oxidizable substrates. Although the activation barrier for the direct oxidation of organics by aqueous ozone is much larger than that for oxidation by hydroxyl radicals, the concentration of molecular ozone is much larger than that of the radicals. Because the production of hydroxyl radicals is facilitated at high pH, the hydroxyl radical-mediated oxidation pathways tend to dominate under those conditions, while direct oxidation with molecular ozone dominates under acidic conditions. In some processes referred to as advanced oxidation processes (AOPs), the formation of hydroxyl radicals from ozone is enhanced by exposure of the solution to UV light, addition of hydrogen peroxide, or other measures.

Ozonation (1 to 8 mgO_3/L for 3 to 5 minutes) oxidized similar compounds as chlorination but achieved slightly higher removal percentages. Compounds that were less reactive, including progesterone, testosterone, iopromide, musk ketone, meprobamate, and TCEP, lacked aromatic carbon with attached hydroxyl functional groups. Addition of hydrogen peroxide during ozone addition is an advanced oxidation process (AOP) which forms hydroxyl radicals that slightly increased the removal of most EDCs and PPCPs compared to ozone addition only (Westerhoff, 2003).

While pesticides would be expected to be prone to attack by hydroxyl radicals (and to react at diffusion controlled rates), a wide range of reactivities would be expected in direct attack by ozone. If these trace organic compounds are present in a matrix of natural organic matter or bacterial exudates, the "bulk" organics would be expected to be attacked in preference to the trace species, though longer lived peroxy radicals generated by hydroxyl radical attack on the bulk material may be effective in inducing degradation of the trace contaminants. Ozone and AOPs in general would be expected to be particularly effective in degrading pesticides in low DOC matrices such as groundwaters or tertiary treated effluents.

Additionally, Welte et al. (1996, cited in Boussahel, 2000) point out that with ozonation, the formation of small molecules after the breakage of pesticide molecules can cause bacterial regrowth in water distribution systems and also the formation of by-products (peroxides, ozonides, organobromine and bromate).

Photodegradation

Andreozzi *et al.* (2003) present an evaluation of the persistence towards abiotic photodegradation for six selected pharmaceuticals (carbamazepine, diclofenac, clofibric acid, ofloxacin, sulfamethoxazole and propranolol) present in STP effluents. The effluents had been submitted to solar experiments at 40° N latitude during spring and summer. Based on experimentally measured quantum yields for the direct photolysis in bi-distilled water, half-life times ($t_{1/2}$) at varying seasons and latitude were predicted for each substance. In salt- and organic-free (bi-distilled) water carbamazepine and clofibric acid are characterized by calculated half-life times of the order of 100 days at the highest latitudes (50° N) in winter, whereas under the same conditions sulphamethoxazole, diclofenac, ofloxacin and propranolol undergo fast degradation with $t_{1/2}$ respectively of 2.4, 5.0, 10.6 and 16.8 days. For almost all studied compounds, except propranolol the presence of nitrate ions in aqueous solutions results in a reduction of $t_{1/2}$. When present, humic acids act as inner filters towards carbamazepine and diclofenac, and as photosensitizers towards sulphamethoxazole, clofibric acid, oflaxocin and propranolol (Andreozzi *et al.*, 2003).

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6 ANNEXES

6.1 Global wastewater treatment matrix

In Table 6.1, Table 6.2 and Table 6.3, an outline of the global wastewater treatment matrix is given. In this matrix all conceivable treatment schemes are mentioned (the numbers refer to the list in Table 6.4).

Table 6.1 Global wastewater treatment matrix for raw wastewater

/ = or, + = and		**Raw Wastewater**
Suggested Treatment Train for End Use	Industry (A)	001/003,002,101,212(,304),305/306,401/405 or 001/003,002,102/103/104/106,202/204/205/206(,316+301/302),316+303/304,305/306,401/405 or 001/003,002,102/103/104/106,202/204/205/206,316+301/302,307/308,310/311(,309)(,401/405) or 001/003,002,102/103/104/106,203+214(,316+301/302),(316+)303/304,305/306,401/405 or 001/003,002,102/103/104/106,213(,316+301/302),(316+)303/304,305/306,401/405 or 001/003,002,101/102,105,(316+)304,305/306,401/405
	Potable (B+)	001/003,002,101,212(,304),305/306,401/405 or 001/003,002,102/103/104/106,202/204/205/206(,316+301/302),316+303/304,305/306,401/405 or 001/003,002,102/103/104/106,202/204/205/206,316+301/302,307/308,310/311(,309)(,401/405) or 001/003,002,102/103/104/106,203+214(,316+301/302),(316+)303/304,305/306,401/405 or 001/003,002,102/103/104/106,213(,316+301/302),(316+)303/304,305/306,401/405 or 001/003,002,101/102,105,(316+)304,305/306,401/405 or all above
	Urban(B&C)	B: C with 212(,304),305/306,401/405 or C w/o 212(,316+301/302)(,316+)303/304,305/306,401/405 or all above C: 001/003,002,102/103/104/106,202/203(+214)/204/205/206/213(,401/402/403/404/405) or 001/003,002,101,212(,401/402/403/404/405) or 001/003,107,208/(209+)207(,401/402/403/404/405) or 001/003,210/211(,401/402/403/404/405) or all above
	Groundwater recharge (B (direct) or C (indirect))	Direct: Indirect with 212(,304),305/306,401/405 or Indirect w/o 212(,316,301/302)(,316+)303/304,305/306,401/405 or all above Indirect: 001/003,002,102/103/104/106,202/203(+214)/204/205/206/213(,401/402/403/404/405) or 001/003,002,101,212(,401/402/403/404/405) or 001/003,107,208/(209+)207(,401/402/403/404/405) or 001/003,210/211(,401/402/403/404/405) or all above
	Environmental and recreational (C&D)	001/003,002,102/103/104/106,202/203(+214)/204/205/206/213(,313/314/315)(,401/402/403/404/405) or 001/003,002,101,212(,401/402/403/404/405) or 001/003,107,208/(209+)207(,313/314/315)(,401/402/403/404/405) or 001/003,210/211 or all above
	Agriculture (E)	none or 001/003 or 001/003,002 or 001/003,002,101 or 001/003,002,102/103/104/106/107 or 001/003,002,101/102,105 or all above

Table 6.2 Global wastewater treatment matrix for primary effluent

/ = or, + = and		Primary Effluent
Suggested Treatment Train for End Use	Industry (A)	212(,304),305/306,401/405 or 202/204/205/206(,316+301/302),316+303/304,305/306,401/405 or 202/204/205/206,316+301/302,307/308,310/311(,309)(,401/405) or 203+214(,316+301/302),(316+)303/304,305/306,401/405 or 213(,316+301/302),(316+)303/304,305/306,401/405 or 105,(316+)304,305/306,401/405
	Potable (B+)	212(,304),305/306,401/405 or 202/204/205/206(,316+301/302),316+303/304,305/306,401/405 or 202/204/205/206,316+301/302,307/308,310/311(,309)(,401/405) or 203+214(,316+301/302),(316+)303/304,305/306,401/405 or 213(,316+301/302),(316+)303/304,305/306,401/405 or 105,(316+)304,305/306,401/405 or all above
	Urban(B&C)	B: C with 212(,304),305/306,401/405 or C w/o 212(,316+301/302)(,316+)303/304,305/306,401/405 or all above C: 202/203(+214)/204/205/206/213(,401/402/403/404/405) or 212(,401/402/403/404/405) or 107,208/(209+)207(,401/402/403/404/405) or 210/211(,401/402/403/404/405) or all above
	Groundwater recharge (B (direct) or C (indirect))	Direct: Indirect with 212(,304),305/306,401/405 or Indirect w/o 212(,316,301/302)(,316+)303/304,305/306,401/405 or all above Indirect: 202/203(+214)/204/205/206/213(,401/402/403/404/405) or 212(,401/402/403/404/405) or 107,208/(209+)207(,401/402/403/404/405) or 210/211(,401/402/403/404/405) or all above
	Environmental and recreational (C&D)	202/203(+214)/204/205/206/213(,313/314/315)(,401/402/403/404/405) or 212(,401/402/403/404/405) or 107,208/(209+)207(,313/314/315)(,401/402/403/404/405) or 210/211 or all above
	Agriculture (E)	none or 107 or 105 or all above

Table 6.3 Global wastewater treatment matrix for secondary effluent

/ = or, + = and		Secondary Effluent
Suggested Treatment Train for End Use	Industry (A)	(304),305/306,401/405 or (316+301/302),316+303/304,305/306,401/405 or 316+301/302,307/308,310/311(,309)(,401/405) or (316+301/302),(316+)303/304,305/306,401/405 or (316+301/302),(316+)303/304,305/306,401/405 or (316+)304,305/306,401/405
	Potable (B+)	(304),305/306,401/405 or (316+301/302),316+303/304,305/306,401/405 or 316+301/302,307/308,310/311(,309)(,401/405) or (316+301/302),(316+)303/304,305/306,401/405 or (316+)304,305/306,401/405 or all above
	Urban(B&C)	B: (304),305/306,401/405 or (316+301/302)(,316+)303/304,305/306,401/405 or all above C: (401/402/403/404/405) or all above
	Groundwater recharge (B (direct) or C (indirect))	Direct: (304),305/306,401/405 or (316+301/302)(,316+)303/304,305/306,401/405 or all above Indirect: (401/402/403/404/405) or all above
	Environmental and recreational (C&D)	(313/314/315)(,401/402/403/404/405) or (401/402/403/404/405) or (313/314/315)(,401/402/403/404/405) all above
	Agriculture (E)	none or all above

Table 6.4 Unit Process Operations

Preliminary	
001	Bar screen
002	Grit chamber
003	Coarse screen
Primary	
101	Fine Screen
102	Sedimentation w/o Coagulant
103	Sedimentation w/ Coagulant
104	DAF w/ Coagulant
105	Membrane Filtration
106	Actiflo®
107	Stabilization Pond : Anaerobic ponds
Secondary	
201	High Loaded Activated Sludge + Sec. Sedim.
202	Low Loaded Activated Sludge w/o de-N + Sec. Sedim.
203	Low Loaded Activated Sludge w/ de-N + Sec. Sedim.
204	Trickling Filter + Secondary Sedimentation
205	RBC
206	Submerged Aerated Filter
207	Stabilization Pond : Aerobic ponds
208	Stabilization Pond : Aerated ponds
209	Stabilization Pond : Facultative ponds
210	Constructed wetland: Free-Water-Surface Flow
211	Constructed wetland: Subsurface Water Flow
212	Membrane bioreactor
213	EBPR
214	P-Precipitation
Tertiary	
301	Filtration over fine porously media
302	Surface filtration
303	Micro filtration
304	Ultra filtration
305	Nano filtration
306	Reverse osmosis
307	GAC
308	PAC
309	Ion exchange
310	Advanced oxidation - UV/O3
311	Advanced oxidation - UV/H2O2
313	SAT
314	Maturation pond
315	Constructed wetland - polishing
316	Flocculation
Disinfection	
401	Ozone
402	Paracetic acid
403	Chlorine dioxide
404	Chlorine gas
405	UV radiation

6.2 Development of indirect potable reuse in impacted of the United States

MSc thesis by H.P. Jansen, Delft University of Technology and University of California Los Angeles.

Development of Indirect Potable Reuse in Impacted Areas of the United States

UCLA/DUT Harm Jansen 2005

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Disclaimer

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Table of contents

0.0 Table of contents 3

0.1 Table of figures........8
0.2 Table of tables........9

1.0 Executive summary 11

1.1 Key Words........11
1.2 Problem statement........11
1.3 Abstract........11
1.4 Approach........12

2.0 Indirect Potable Reuse: an overview 13

2.1 Introduction........13
2.2 Types of IPR........15
2.3 IPR in California........16
2.4 Exhausted alternatives to IPR........17
2.5 Desalination: a viable alternative to IPR........18

3.0 Water rights 20

3.1 Introduction 20
3.2 Water rights basics.. 20
  3.2.1 Water rights cases 21
  3.2.2 Reclaimed water rights cases 22
  3.2.3 Water rights and Indian tribes.. 23

4.0 Legislative and executive hurdles 24

4.1 Introduction 24
4.2 International Institutions 25
4.3 Federal executive and legislative hurdles 26
  4.3.1 Reclaimed water and the federal legislative branch.. 27
4.4 State executive and legislative hurdles.. 33
  4.4.1 IPR and the California state executive branch.. 33
  4.4.2 Reclaimed water and the California legislative branch 35
  4.4.3 Laws and regulations in California: a schematic overview 39
4.5 State executive and legislative barriers for other states: Florida and Arizona.. 41
  4.5.1 The Florida and Arizona executive departments involving water reclamation.. 41
  4.5.2 Florida and Arizona legislative branch: key water reclamation laws and regulations.......... 43

5.0 Public’s relation to IPR 44

5.1 Introduction 44
5.2 Why humans react the way they react: law of contagion 44
5.3 Acceptance and perception issues in IPR 45
5.4 Implementing IPR projects 49
5.5 Public’s concerns in California 50

6.0 Constituents of concern 52

6.1 Introduction 52
6.2 Current detection methods 52
6.3 Constituents of concern and the need to remove 52
6.4 Inorganic compounds of concern: heavy metals 53
6.5 Emerging trace organic compounds 54

7.0 Advanced Treatment 58

7.1 Introduction 58
7.2 Categories of constituents removal 58
7.3 Encountered configurations 60
7.4 Advanced treatment types 61
7.5 Membrane filtration 66
  7.5.1 Micro filtration 69
  7.5.2 Submerged Micro Filtration 69
  7.5.3 Ultra filtration 70
  7.5.4 Nano Filtration 70
  7.5.5 Reverse Osmosis 70
7.6 Concentrate Disposal 74

8.0 Conducted survey for IPR projects 75

8.1 Introduction 75
8.2 IPR projects in Southern California 76
  8.2.1 Orange County, California: Water Factory 21 76
  8.2.2 Los Angeles County, California: West Basin Water Reclamation Project 81
  8.2.3 Los Angeles County, California: Montebello Forebay Groundwater Recharge Project 82

8.2.4 San Bernardino County, California: Chino Valley Basin 84
8.2.5 Victorville, California: Victor Valley Water Reclamation Authority 85
8.3 Failed IPR projects in Southern California 88
8.3.1 Los Angeles County, California: East Valley Water Reclamation Project 88
8.3.2 San Diego, California: San Diego Water Re-purification Project 89
8.4 IPR projects in Arizona and Florida 92
8.4.1 Scottsdale, Arizona: City of Scottsdale Water Campus 92
8.4.2 Tucson, Arizona: Roger Road Wastewater Plant & Tucson Water's Filtration Plant 93
8.4.3 Mesa, Arizona: Northwest Water Reclamation Plant (NWWRP) 94
8.4.4 West Palm Beach, FL: Wetlands Demonstration Project 95
8.5 Failed IPR project in Florida 97
8.5.1 Tampa Water Resource Recovery Project 97
8.6 Established Non Potable Reuse projects in the United States 100
8.6.1 San Diego, California: San Diego's North City Water Reclamation Plant 100
8.6.2 San Jose, California: San Jose/Santa Clara Water Pollution Control Plant 100
8.6.3 Malibu, California: Tapia Water Reclamation Facility 100
8.6.4 St Petersburg, Florida: Water Reclamation System 101
8.6.5 APRICOT Project, Florida: Regional Water Reclamation Facility 101
8.6.6 Orange County, Florida: Eastern Water Reclamation Facility 102

9.0 Established non-surveyed IPR and DPR Projects 105

9.1 United States 105
9.1.1 Chanute, Kansas 105
9.1.2 El Paso, Texas: Hueco Bolson Recharge Project 105
9.1.3 Denver Potable Water Reuse Project 106
9.1.4 Fairfax, Virginia: Upper Occoquan Sewage Authority (UOSA) Reclamation Plant 106
9.1.5 More IPR projects operating successfully throughout the United States 106
9.2 Established IPR and DPR project outside the US 109
9.2.1 Singapore: NEWater Project 109
9.2.2 Namibia: Windhoek 109

10.0 Results and discussions 111

10.1 Introduction 111
10.2 Trends in water reclamation and IPR 111
10.3 Legislative response 112
10.4 Public response 113
10.5 Technological response 113
10.6 Plants and how well they performed 115

11.0 Conclusion 118

12.0 Addendums 119

12.1 References 119
12.2 Additional references and information 122

13.0 Appendix 124

13.1 IPR facilities in Southern California 125
13.2 Failed IPR projects 136
13.3 IPR projects in Arizona 139
13.4 IPR projects in Florida 142
13.5 Established NPR facility 145

Table of figures

Figure 1: unplanned IPR......13
Figure 2: planned IPR......14
Figure 3: Types of groundwater recharge. 16
Figure 4: Mono Lake 21
Figure 5: Inter-relations between branches on international, federal, and state (California) level......24
Figure 6: International organizations involved in wastewater......25
Figure 7: federal executive departments concerning wastewater 27
Figure 8: relationships between Federal law, regulations and departments. 28
Figure 9 Contaminants Regulated by the SDWA 32
Figure 10: California state executive agencies (top) and departments (bottom) dealing with wastewater......34
Figure 11: California’s legislative and executive branch 36
Figure 12: laws and regulations and its inter-relations with IPR in California......39
Figure 13: reclaimed water use and its acceptability 47
Figure 14: Possible advanced wastewater treatment configurations as encountered during survey......60
Figure 15: schematic overview of filtration characteristics 67
Figure 16: types of membrane fouling 68
Figure 17: MegaMagnum® RO Element (picture by Harm Jansen)......73
Figure 18: Traditional secondary (left) and tertiary (right) treatment......75
Figure 19: Traditional RO pretreatment 76
Figure 20: Contemporary advanced treatment......76
Figure 21: Process flow diagram of Water Factory 21 77
Figure 22: Inactive submerged MF modules at GWR System (picture by Harm Jansen) 80
Figure 23: Process flow diagram of West Basin Water Reclamation Project......81
Figure 24: Montebello Forebay spreading basins (Rio Hondo)......84
Figure 25: Schematic overview of the SDWRP......89
Figure 26: Trickling Bio towers at Roger Road WWTP (picture by Harm Jansen) 94
Figure 27: Wetlands Demonstration Project 95
Figure 28: Process flow diagram Tampa Water Resource Recovery Project......97

Table of tables

Table 1: Overview of change in focus of the treatment of wastewater (after Ødegaard, 2000) 15
Table 2: Characteristics of the types of groundwater recharge for IPR 16
Table 3: abbreviations for Figure 5 25
Table 4: abbreviations for figure 12 40
Table 5: IPR in the United States 41
Table 6: The percentage of respondents opposed to specific uses of recycled water* 49
Table 7: Residual organic and inorganic colloidal and suspended solids 59
Table 8: Dissolved organic constituents 59
Table 9: Dissolved inorganic constituents 59
Table 10: Biological constituents 59
Table 11: Advanced treatment types and the targeted category of constituents* 61
Table 12: advantages and disadvantages of the most commonly used advanced oxidation processes 66
Table 13: overview of filtration characteristics 69
Table 14: Membrane characteristics 73
Table 15: MF and RO data WF 21 77
Table 16: CMF-S filtrate 78
Table 17: Pall filtrate 78
Table 18: Zenon filtrate 79
Table 19: Test results WF 21 MF pilot testing 79
Table 20: 2003 average NMDA concentrations at Water Factory 21 80
Table 21: MF and RO data GWR System 80
Table 22: Reverse Osmosis Membrane data West Basin 82
Table 23: NDMA levels for Montabello Forebay WWTPs 83
Table 24: NDMA levels for Montabello Forebay production and monitoring wells 83
Table 25: NDMA levels for Chino Valley basin WWTPs, 2002 85
Table 26: NDMA levels for Chino Valley basin WWTPs, 2003 85
Table 27: overview of current indirect potable projects in Southern California 86
Table 28: overview of proposed IPR projects in Southern California 91
Table 29: MF and RO configuration Scottsdale Water Campus. 93
Table 30: overview of IPR projects in the remainder of the United States 96
Table 31: Overview of established non potable reuse projects in the United States 103
Table 32: Overview of other non surveyed IPR projects 108
Table 33: Inventoried plants performing IPR through direct injection and surface water augmentation 116

Table 34: Inventoried Plants Performing IPR Through Recharge Basins 117
Table 35: Water Factory (WF) 21, Fountain Valley, CA* 125
Table 36: Ground Water Replenishment (GWR) System, Fountain Valley, CA* 127
Table 37: West Basin Reclamation Project, El Segundo, CA 128
Table 38: Pomona Valley, CA 130
Table 39: San Jose East, CA 131
Table 40: San Jose West, CA 132
Table 41: Whittier Narrows WRP, CA 133
Table 42: Chino Valley Basin, Chino Hills CA* 134
Table 43: Victor Valley Water Reclamation Authority, Victorville CA * 135
Table 44 East Valley Water Recycling Project (EVWRP), Los Angeles, CA* 136
Table 45 San Diego Water Re-purification Project (SDWRP), CA 138
Table 47: Pima Roger Road Wastewater Plant Tucson, AZ........ 139
Table 48: Mesa Northwest Water Reclamation Plant, AZ 141
Table 49: East Central Region WWTP* West Palm Beach, FL........ 142
Table 50: Tampa Water Recourse Recovery Project (TWRRP), Tampa, FL 143
Table 51: San Diego North City Water Reclamation Plant, CA * 145
Table 53: Tapia Water Reclamation Facility, Malibu, CA 146
Table 55: Apricot Project, Altamonte Springs, FL 147
Table 56: Eastern Water Reclamation Facility (SW and SE), Orange County, FL 148

Executive summary

Key Words

California, Indirect Potable Reuse (IPR), institutional barriers, membranes, water policy, water reclamation

Problem statement

What is the future for water reclamation related to Indirect Potable Reuse (IPR) in impacted areas in the United States and which technologies will be prevail?

Abstract

Water resources are in short supply in many areas of the United States. Water supply is impacted by the increasing risk of periodic droughts and on-going development. In response to both concerns, additional water supplies are being developed. Water reclamation is viewed as a new source of water and is being rapidly developed in many areas, particularly in Southern California, Arizona, and Florida. Despite the need for additional water and the promise of water reclamation, there are technical and institutional barriers that challenge its implementation and development.

In order to quantify the amount of reclamation and the problems associated with its development, a survey of both successful and failed projects in California, Arizona and Florida was performed. These three states were selected because of the need for reclamation due to arid conditions and rapid development, as well as previously attempted successful and unsuccessful projects. Affiliation with Indirect Potable Reuse (IPR) was the main criterion for selecting projects. IPR is a method of reusing treated waters and wastewaters for potable use through at least one environmental barrier that serves to isolate, as well as protect consumers. Examples of barriers include a groundwater basin or reservoir providing more than one-year retention time. Projects involving IPR are much harder to implement because of the public's concern and there are many noteworthy examples.

A survey was conducted by collecting historical data on each plant as well as visiting the plant. Current records were obtained including assessments of their evolving water treatment technologies. Twenty-six

projects were reviewed and nineteen of the projects were visited. The relevant laws and regulations that governed the project were also reviewed. The various projects were categorized by size, technology, goals, successes and failures. The results are presented in tabular form and patterns of successes and failures are identified. Relative costs are presented.

Technological barriers were not a limiting factor. Institutional barriers and challenges, such as public perception, local politics, risk communication, and impacts of confusing or partially developed regulations were most often limiting. The most successful projects involved the public and other stakeholders before the conception of the project. Lower water reuse objectives (Non-Potable Reuse (NPR)) were more easily implemented than higher use projects (IPR). There were no examples of successfully implemented Direct Potable Reuse (DPR) found in the United States. In some cases, projects that began with IPR goals were converted to or augmented with lower use goals by displacing potable water with reclaimed water.

A review of the technologies of successful projects reveals a declining use of traditional water treatment technologies, such as granular media filtration, carbon adsorption, lime clarification, ammonia stripping and chlorination with membrane-based technologies, such as (submerged) Micro Filtration (MF), Nano Filtration (NF), Reverse Osmosis (RO), disinfection with Ultra Violet (UV) light, and advanced oxidation with hydrogen peroxide.

Approach

This thesis begins with an introduction to IPR in Chapter 0, which gives an impression of the history, types and the presence of IPR, particularly in California. After the introduction, three categories are considered to determine the institutional hurdles IPR faces. The first is water rights, which are covered in Chapter 0. The second category covers legislative and executive hurdles of which the areas of international and national will be covered in Chapter 0 and 0. California and other state legislative and executive hurdles follow in Chapter 0. A final challenge and third category of institutional hurdles is the acceptance of the general public and detailed attention is paid to this subject in the Chapter 0.

After this broad institutional approach, the remainder of this thesis presents a more detailed approach to quantify the development of IPR in the US by covering newly emerging constituents, up to date technology, and relevant facilities. Constituents of concern are discussed in Chapter 0. Current available technologies for IPR are covered in Chapter 0 for an up-to-date status, while the relevant facilities are examined in Chapter 0. Chapter 0 covers a variety of facilities that have not been visited, but have been reviewed to complete the survey. Analyses of all findings are presented in Chapter 0 with its conclusion in Chapter 11. Relevant addendums can be found in chapter 0.

Indirect Potable Reuse: an overview

Introduction

The hydrological cycle, the continuous transfer of water from ocean to air and land then back to the ocean, designates nature as the ultimate water recycler. The simple underlying principle is that all water is recycled and that true fresh water does not exist. For many years, people have augmented the hydrological cycle with treated wastewater. Where a large population is situated near a water stream, wastewater is treated for discharge to the environment. This treated wastewater augments water streams and is treated further by nature. When people use the water, it is withdrawn from that same stream and purified again for use as drinking water. There are numerous examples of wastewater being discharged into waters that are used as drinking water sources, thus resulting in unplanned IPR (Figure 1). More than 25 major water utilities in the US use water from rivers that receive wastewater discharges that amount up to 50 percent of the stream flow during low flow conditions[1].

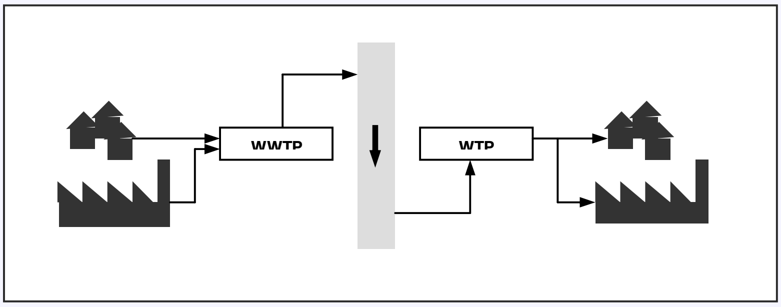

Figure 1: unplanned IPR

On the other hand, planned IPR is the purposeful augmentation of a water supply source with tertiary or advanced treated wastewater (Figure 2). While drinking water obtained from the best available source should be the guiding principle for water supply development, in some cases the only feasible source of complementary water is reclaimed water. A growing number of communities have implemented or are planning IPR projects. Before it can be retrieved for drinking water treatment, the water has a certain residence time after it is purposely augmented during which time many viruses and bacteria decay.

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[1] Issues in Potable Reuse: The Viability of Augmenting Drinking Water Supplies with Reclaimed Water, 1998, page 2.

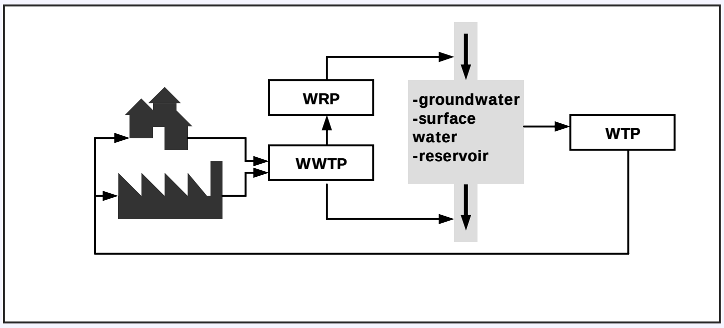

Figure 2: planned IPR

Planned IPR is widely implemented in today's hydrological world. Current potable reuse projects and studies have demonstrated the capability to consistently produce recycled water of a high quantifiable quality. In addition, there have been no clear adverse health effects in areas where recycled water has been used for potable purposes. Public health concern focuses on water quality, treatment reliability, and the difficulty of identifying and estimating human exposures to pathogenic microorganisms and potentially toxic chemicals that may be present in the inherently suspected water source. While most health related data generated to date prove such water is safe, definitive data is absent.

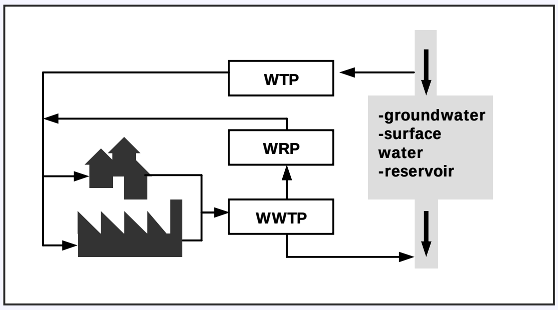

Figure 3: direct potable reuse

Direct Potable Reuse (DPR) is the direct reintroduction of highly treated effluent into the potable water distribution system (Figure 3). Currently, this is only practiced in Windhoek, Namibia and is at this time not a feasible option in the United States in the near future. The Denver Potable Water Reuse Project (1970-1979) has conducted extensive research on DPR. Health studies in both Windhoek and Denver have shown no adverse effects.

Presently, the supply of fresh water cannot keep up with the demands and increased usage by people for recreation, industry and agriculture, as well as a decrease in supply, a steady increasing risk for drought, more stringent environmental legislation, and rapidly expanding developments. Population increase is the main cause to the shortage of fresh water and is predicted to be limited in the near future by the lack of potable water supply. Reclaiming water is only answer to this problem. A focus towards water reclamation (and IPR) therefore characterizes today's wastewater treatment (Table 1).

Table 1: Overview of change in focus of the treatment of wastewater (after Ødegaard, 2000)

	Focus	Period
1850-1950	Hygiene	Sanitary engineering
1950-2000	Environment	Environmental engineering
2000-present	Reuse	Water environment management

Types of IPR

IPR can be accomplished through several methods. It can be achieved by augmenting three types of drinking water sources with highly treated wastewater: surface waters, reservoirs, or groundwater. Surface water augmentation is the most common form of unplanned IPR, while augmenting reservoirs and groundwater are the most common form of planned IPR. A combination is possible when the augmented surface water also recharges to groundwater. The discharged effluent in the drinking water source is to lose its identity through a degree of mixing and retention time in order to qualify for IPR. Mixing ratios and retention times found in literature vary significantly and range from 5 to 50% and 3 months to 2 years.

IPR through groundwater augmentation can be achieved in three ways: surface spreading, direct injection or vadose zone injection (Figure 3). Direct injection is practiced when water is conveyed and placed directly into a confined aquifer. Surface spreading, as opposed to direct injection, requires the existence of an unsaturated aquifer. Surface spreading is a indirect method of recharge whereby the water moves from the land surface to the groundwater by infiltration and percolation through the soil matrix. The third possible form of groundwater recharge is the vadose zone injection. For the purpose of IPR, vadose zone injection is not favorable because the wells cannot be backwashed and a severely clogged well can be permanently destroyed. A lifecycle of 5 years for a vadose injection well can still make this an economical choice. More detailed information about the characteristics of ground water recharge is found in Table 2.

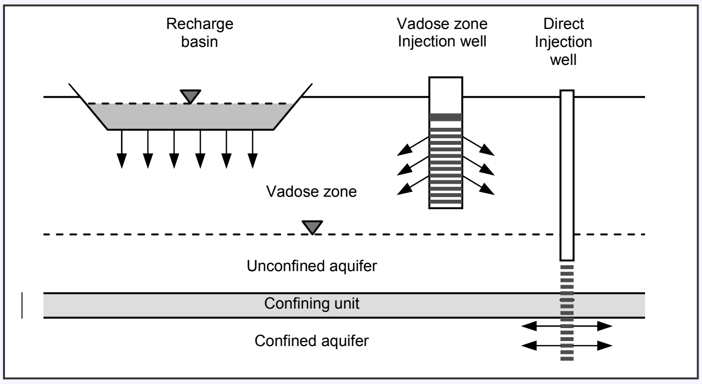

Figure 3: Types of groundwater recharge.

Table 2: Characteristics of the types of groundwater recharge for IPR

	recharge basins	vadose zone injection wells	direct injection wells
aquifer type	Unconfined	unconfined	unconfined or confined
pretreatment requirements	tertiary treatment	tertiary treatment	advanced treatment
estimated capital cost ($)	land and distribution system	25,000-75,000 per well	500,000-1,500,000 per well
capacity (m3/hectare-day)	100-20,000	1000-3000	2000-6000
maintenance requirements	drying and scraping	drying and disinfection	disinfection-flow reversal
estimated life cycle (years)	>100	5-20	35-50
soil aquifer treatment	vadose and saturated zone	vadose and saturated zone	saturated zone

IPR in California

Maintaining a reliable water supply is one of the most important issues facing a record fast growing California. In average water years, California receives about 240 km^3 of water from precipitation and imports from Colorado, Oregon and Mexico[2] of which 40 to 50% is dedicated supply[3]. Southern California relies on diverting water from the California Aqueduct (State Water Project), the Los Angeles aqueduct, and the

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[2] Coachella and All American Canals, 2004
[3] including reuse

Colorado River Aqueduct in addition to its local natural supply. Diverting water lacks reliability due to droughts and is becoming less acceptable because of growing awareness of the environmental impacts of these practices.

Population growth in Southern California is expected to rise from 18.2 million in 2000 to 26.9 million in 2030[4]. Reductions in its supply from the Colorado River Aqueduct (because Arizona and Nevada have recently demanded their portion[5]), the Los Angeles Aqueduct (to account for the Mono Lake's revival) and the California Aqueduct (for reallocation of the State Water Project to the Northern California Delta) have significantly decreased Southern California's overall water supply. The California Department of Water Recourse (DWR) has predicted chronic water shortages by the year 2020 and driven by an increasing population, the need for water is expected to grow. DWR "Predicts that by the year 2020, Californians will be short 8.6 km^3 of water per year during a period of drought and 3.6 km^3 in an average year." Southern California is, therefore, forced to be trendsetter in the reuse of water.

The Colorado River is currently in its 6th consecutive year of drought (1999-2005), which translates to 11 km^3 water. Historical stream flow records make this the worst drought in the last 80 years[6], which is amplified by the current population growth. According to tree-ring data, the worst drought on record dates back to the late 1500's and lasted 20 years, placing the current drought as the 7th worst ever in a 500 year proxy. The current drought in the Snow Water Content in the Upper Colorado River Basin is already at 75 to 115% of its yearly average, but may not result run-off for reservoirs to hold if followed by dry warm periods.

Recognizing the water's importance to the state's economy and quality of life, California is focusing on developing a mix of complementary water resources. The majority of municipal wastewater produced statewide is still being disposed into the Pacific Ocean. This untapped resource represents one of the largest potential complementary water resources for new water in California. California's recycled water use in 2004 was 0.6 km^3, half of the State's goal of 1.2 km^3 per year by 2010. Today, many communities are planning new or expanded water reclamation programs.

Exhausted alternatives to IPR

The highest quality water should be reserved for drinking water purposes. It is therefore unlikely that IPR will gain popularity unless water of lesser-suspected sources have been fully investigated and ruled out as viable options. Other options such as displacing potable water through dual distribution systems, conservation through aggressive volume based rates and education should be considered as well. Displacing water from agricultural uses, which accounts for 85% of the water use in California, takes planning and a long time to achieve because agricultural land needs to be purchased and taken out of service, which many corporations and farmers loath to do. It is, therefore, not considered to be an alternative in this thesis.

Implementing dual distribution systems in existing infrastructure has proven to be economically unfeasible. Non-potable urban demands are as widely dispersed physically as potable demands are and, therefore,

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[4] California Demographic Futures, 2005 summary report

[5] Also see: 0.1.1

[6] Cisco, Green and PHDI

require a near duplicate of the current existing distribution system. Treating water to the required standards for non-potable uses further elevates the cost for the dual distribution option. Urban demand for non-potable use also fluctuates daily and seasonally. In order to permit usage of these costly and large storage systems, water needs to be drinking water quality. It is, therefore, more cost effective to treat reclaimed water to drinking water standards and use the existing distribution system to supply the demand of urban non-potable use and thus, to practice IPR.

Non potable use through a separate distribution system is generally economically feasible for large users, such as golf courses, industry, and parks that are located in a certain vicinity of the water reclamation facility, which justifies the relatively inexpensive, separate distribution system. Most of the facilities inventoried in this project have a clientele consisting of such large users. Advanced planning of dual distribution systems in future urban development is economically feasible and is implemented in the Chino Valley area in California (see 0.1.18).

Conservation should be an important part of our daily lives and it is difficult to argue against. Californians, and Americans in general, are large volume consumers. The urban areas of Southern California have the highest average usage, with 430 liter per capita per day (lpcpd), whereas the entire United States average is 280 lpcpd and an average usage for Western Europe is 120 lpcpd. Water and its availability impact economic development and both the US's decentralized governing system and highly competitive society makes quantitative water use difficult to regulate. Markets for water are not well developed in California and the remainder of the United States. Although, an increase in price reflecting true cost would motivate users to conserve if such water pricing policy were allowed to operate. Wastewater and drinking water treatment facilities are reaching out to the public through the Internet, tours, and brochures, yet the knowledge of conservation is still lacking among the public. An aggressive leak detection and repair program should be in its place since 14%[7] of all water is wasted through leaks. Similarly, over-watering of residential lawns, gardens using sprinklers and evaporation losses can be avoided by converting to drip irrigation systems.

Desalination: a viable alternative to IPR

Desalination has been extensively researched over the past few years and is more often considered a viable option for urban areas within the vicinity of the Ocean (53% of the US population lives within 150 km of the coast). Desalination has become more affordable with the prices of imported water rising and the operating costs of desalination declining with higher flux membranes. Operating and managing costs are competitive when compared to IPR where secondary wastewater effluent must be treated to drinking water standards and serve a certain retention time after augmentation before being retrieved and treated by a drinking water facility. This will be even more of a viable option when the desalination plant is coupled with an existing coastal power plant, which can provide cheap electricity and the infrastructure for intake and discharge of ocean water.

Problems that have been encountered at both pilot plant and full size operating plant scale are the high residual concentration of Boron after treatment. High chloride and total dissolved solids concentrations form an issue at intake. Other problems are algae and other aquatic microorganisms (0.1.26). All of these factors

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[7] American Water Works Association 1999

abuse the treatment units to a much greater extent than advanced wastewater treatment. Desalination will not be further discussed, as it is considered a different topic in the framework of this thesis.

Water rights

Introduction

Water rights have played a major role throughout the entire history of the United States, especially in the arid regions of the Southwestern part. They are considered a separate entity from water quality laws and regulations, which cover quality parameters of water. Water rights consider water solely as a commodity.

A first form of water rights originated in North America with the native inhabitants who lived in California along the lower Colorado River and in Owens Valley. Living in symbiosis with nature, they would take dams down after they had served their purpose, and essentially gave nature the ultimate right over water. This changed during the Spanish and Mexican eras. Their desire to unite nature and humans resulted in force-laboring natives in constructing a life sustaining hydraulic system for community purposes. This is when the Pueblo Water Rights[8] were introduced--a paramount law associated with these early missions and still present in several states today.

After the United States conquest, the attitude towards water became one of acquisition such from others and to subsequently prosper at their expense. The doctrine of seniority, "First in time, first in right," which originated during the gold rush and was applied to gold found on federal land, was also applied to water. The traditional Hispanic community rights changed to individual rights with limited federal governmental influence. These evolving complexities of the federal system have been present in every water project since, setting the State of California apart from the remainder of the United States.

Water rights basics

Water rights are property rights, but the holders of these rights do not own the water itself; they possess the right to use it. A riparian's rights (primarily found in the Eastern States) is superior to the rights of an appropriator (the "First in time, first in right" principle) except in cases where the water has been appropriated before the riparian acquired the exclusive rights to the property and after the passage of the Mining Act of 1866, which recognized appropriation. A sensible use by a riparian will often take precedence over an appropriative right as long as the riparian parcel has been acquired prior to the date of appropriation. Water availability and needs differ significantly throughout the State of California, which result

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[8] Spanish medieval form of water right for municipal purposes

in a unique compilation of both appropriative and riparian rights.[9]. As far as groundwater is concerned, California classifies three legal categories: underflow of a surface stream, underground streams, and percolating waters. Surface water rights are applied to the first two categories, whereas distinctive groundwater laws apply to percolating waters, which include water in underground basins and water escaped from streams. Water right cases have historically played an important role in California and examples are given in 0.1.1.

When examining wastewater rights, one comes to the conclusion that the producer does not necessarily have the right to the use of its own effluent, although some states provide the owner of the wastewater treatment plant with the ultimate right to anyone who supplied the influent. During IPR, the effluent is either directly or indirectly discharged to surface and/or groundwater from which point on it requires the consideration of water rights. Wastewater that was discharged to surface water prior to 1980 in California did not need approval to be diverted, although case law would generally permit a wastewater producer to reduce its flow before it would leave its premises. Today's legislation requires the SWRCB to give approval for the reuse of wastewater by a wastewater producer to protect the appropriative rights of downstream users. Several examples of reclaimed water cases are mentioned in 0.1.2.

0.1.1 Water rights cases

The California Bay-Delta Act of 2003 reduced supply from the California aqueduct to Southern California by 15% to protect the San Francisco Bay-Delta ecosystem.

The Los Angeles Department of Water and Power was required to stop diverting one-fifth of the water it historically exported from the Mono Basin water in order to restore Mono Lake. Mono Lake's water quality and natural resources were declining progressively from a lack of stream flow.

Figure 4: Mono Lake

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[9] State water resources control board: the water right process

The ever-increasing water needs of the City of Los Angeles have caused severe aquifer depletion in Owens Valley (a 63 mile trough west of the Sierra Nevada Mountains), which have contributed to an increasing arid environment. This resulted in alkaline dust storms, which threatened the health of its native inhabitants. In 1997, after a 27 year dragging battle, the California Third District Court of appeals ordered Los Angeles to restore the pumping-decimated lower Owens River to what it had been before Los Angeles began diverting water in 1913.

In the Colorado River Compact[10], water has been divided between the upper basin (Colorado, New Mexico, Utah, and Wyoming) and the lower basin (California, Nevada, and Arizona). The water from the Colorado River has been appropriated in the Arizona vs. California case. The United States Supreme court ruled a monumental decision in favor of Arizona in 1963 in the amount of 3.5 km^3-- 9.2 km^3 has been allocated to Indian tribes.

In an international treaty, the Mexican Water Treaty (1943), The United States has agreed to annually deliver 1.8 km^3 of the Colorado River to Mexico.

0.1.2 Reclaimed water rights cases

In 1968, the City of Roswell, New Mexico, acquired the Walker Air Force Base along with the right to use 0.11 m^3/s of groundwater designated to the property and the air force base's wastewater treatment plant, which effluent was used for nearby irrigation. The city later abandoned the treatment plant and diverted its influent to the city's wastewater treatment plant. Due to its loss in return flow, the city then proposed to increase the number of wells in order to maintain their 0.11 m^3/s. The state engineer granted the proposal under the condition that the present use of reclaimed water continue. It was ruled in the Supreme Court that the state engineer might only infringe such contingencies if the allocation of reclaimed water would impair the rights of others.

Several cities in the Arizona Public Service vs. Long were contracted to sell a total of 5.3 m^3/s of cooling water for the Palos Verdes Nuclear power Plant. Downstream appropriators brought a suit to the city arguing that the contract was in conflict with the Arizona Groundwater Code. The city countered by stating that the reclaimed water was not subject to regulation because it had lost its original character and because it was property of the treatment provider. In 1998, the supreme state court of Arizona validated the contract ruling that the reclaimed water was neither surface nor groundwater and amended its related laws to exclude them from regulating reclaimed water.

Deer Creek Decision in 1994, by the California Regional Board held, downstream user rights secondary to the discharger's reclaimed water effluent. Irrigation and domestic use relied on the continuous flow created by the Deer Creek Wastewater Treatment plant, which had contracted a development to buy 110 m^3/s. However, fish and wild life had gained legal status as users.

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[10] Compact: a contractual agreement between two or more states

0.1.3 Water rights and Indian tribes

Indian tribes are an exclusive entity within the United States and also within the world of water management. They have unique water rights, which are often misunderstood, but at the same time are able to significantly influence future water rights. Indian tribes are responsible for developing sound, scientifically defensible standards, as well as criteria, advisories, and guidelines under the federal laws (Clean Water Act [0.1.4.1] and the Safe Drinking Water Act [0.1.4.4]). The court decision of 1908 in Winters v. United States, states that there is an existence of water rights for Indians, but its meaning, which has been clouded by many debates over half a century, eventually resulted in a crisis of national importance. The Winters decision, the so called “Reserved” rights, constitutes rights significantly different from all other water rights. Unlike riparian rights, diverting a stream onto non-riparian land can revoke the reserved rights. Unlike the doctrine of proprietary rights, the existence of reserved rights depend on whether the Indians are using the water and remains unimpaired should the Indians cease their uses. Until recently, there had been no decisive, evident, or clarifying view concerning the quantum, legitimate uses and priority of the Indian water rights.

Legislative and executive hurdles

Introduction

Within this thesis, legislative and executive barriers are considered the second category of hurdles for IPR. These barriers are encountered during the production, distribution, use, and discharge of reclaimed water. The complete hierarchy of laws and regulations and their execution in relation to wastewater and its reuse components will be further explored in this chapter. Understanding the complex and often inefficient methodology in regulating is necessary to show the current status of IPR in the United States and its possible path in the future. Figure 5 shows the relationship between the legislative and executive branch on a state, national and international level. The highlighted items will be covered to these levels in more detail in the following sections of this chapter, respectively.

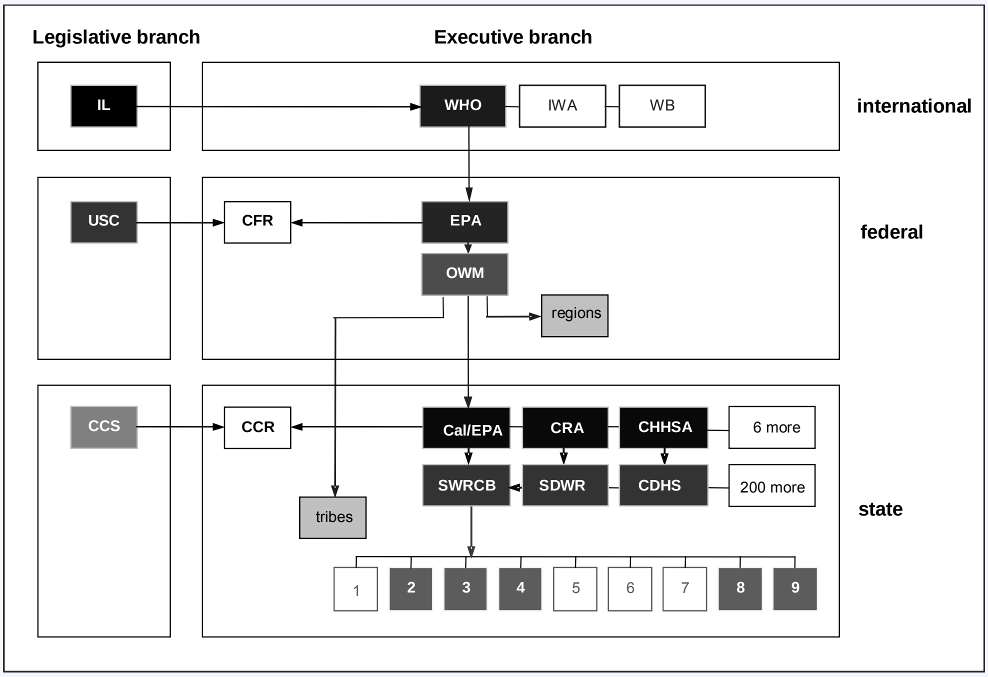

Figure 5: Inter-relations between branches on international, federal, and (California) state level.

Table 3: abbreviations for Figure 5

IL	International Law
WHO	World Health Organization
IWA	International Water Association
WB	World Bank
USC	United States Codes
CFR	Codes of Federal Regulations
EPA	Environmental Protection Agency
OWM	Office of Wastewater Management
CCS	California Codes and Statutes
CCR	California Codes of Regulations
Cal/EPA	California Environmental Protection Agency
CRA	California Recourses Agency
CHHSA	California Human Health Services Agency
SWRCB	State Water Regional Control Board
SDWR	State Department of Water Resources
CDHS	California Department of Health Services
1-9 (RWQCBs)	Regional Water Quality Control Board

International Institutions

Wastewater regulations on an international level are mainly implemented in development areas where the health burden is high, where interventions could make a major difference and where the present state of knowledge is poor. Every country has to comply with standards set by these international organizations. Standards in the United States are much stricter and in some cases even too strict, according to the World Health Organization (WHO), resulting in setting an unrealistic example for countries struggling to meet WHO standards. A brief summation of international organizations (Figure 6) involved in either setting regulations or supporting IPR project are described in the following paragraphs:

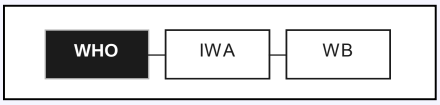

Figure 6: International organizations involved in wastewater

World Health Organization

The World Health Organization (WHO) is a specialized agency within the United Nations. The WHO works on various aspects of water, sanitation, and hygiene. IPR in the form of artificial recharge is recognized by the WHO as an attractive option. According to the WHO, recharge should neither degrade the quality of the groundwater, nor impose any additional treatment after pumping. The WHO's aquifer recharge regulations do not rely on the natural cleansing capability of the aquifer to remove contaminants to meet the water quality required within the aquifer. However, the capacity of the aquifer to remove contaminants is considered an additional barrier in protecting the abstracted water quality. As stated by the WHO, the recharge water reaching the saturated zone of the aquifer should have previously acquired the quality acceptable for drinking water.

According to the WHO, if the recharge is direct, then the injected water should be potable and should, as a minimum requirement, either meet the standards enforced in the country or contained in the WHO Guidelines for Drinking-water Quality[11]. In addition, the WHO advises that the injected water should be treated to prevent clogging around the injection wells, long-term health risks linked to mineral and trace organic compounds, and the degradation of the aquifer.

International Water Association

The International Water Association (IWA) is a founding member of the World Water Council and is involved in the Global Water Partnership, as well as the Collaborative Council on Water Supply and Sanitation. The IWA was founded in 1999 with the merger of the International Association of Water Quality (IAWQ) and the International Water Supply Association (ISWA). The IWA supports water professionals' discoveries of sustainable solutions to challenging global water needs. The IWA connects water professionals around the globe, integrating the leading edge of expert thoughts and ideas on research and practice and regulators and the regulated, across national boundaries and across the drinking water, wastewater, and storm water disciplines.

World Bank group

The World Bank (WB) group collaborates with The World Bank and The World Health Organization in dealing with water sanitation on projects of common interest. The WB's division of water supply and sanitation focuses mainly on development areas. The World Bank has invested in projects that contain a water reuse component and supports socially and environmentally acceptable and economically efficient water reuse related projects.

Federal executive and legislative hurdles

The government of the United States consists of a legislative, an executive, and a judicial branch. Promulgating and execution of laws and regulations result from an interaction among these three branches. Each of the fifty states has a level of local autonomy, but the regulation of wastewater is exclusively a state prerogative. The rationale behind the federal passive approach is that the states themselves are in a better position to assess their water reclamation needs and interests. The Federal cabinet departments may be involved in regulating reclaimed water, yet often only in the form of guidelines. The federal legislative branch is involved in drinking water and wastewater related legislative cases, which involve more than one

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[11] WHO, 1996

state. The possible effect of judicial branch on water and reclaimed water has been indirectly discussed in chapter 0. Relations between reclaimed water and the legislative and executive branch will be laid out in further details in the next two sections.

The cabinet's federal executive departments and administrative agencies regarding wastewater (Figure 7) write regulations to implement the authority of laws which are published in the Codes of Federal Regulations (CFR). The Environmental Protection Agency (EPA) is the latest addition to the Federal executive branch, which regulates water related issues, as well as for land and air.

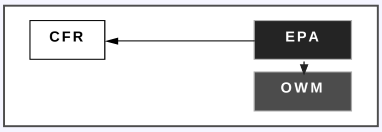

Figure 7: federal executive departments concerning wastewater

Environmental Protection Agency

The EPA was established in 1970 in response to a growing demand by the public for a cleaner environment. The EPA's mission is to protect human health and the natural environment. Prior to the establishment of the EPA, the federal government was not structured to make a coordinated attack on the contaminants that threatened human health and the environment.

The EPA works to develop and enforce regulations that implement environmental laws enacted by Congress. The EPA is responsible for researching and setting national standards for water management and delegates the responsibility for issuing permits for wastewater discharges (and thus, indirectly for IPR) and for monitoring and enforcing compliance to states and tribes. Where national standards are not met, the EPA can issue sanctions and take other measurements to assist states in attaining the preferred levels of water quality. The Office of Wastewater Management (OWM) is a branch of the EPA that handles recycled water. The OWM oversees a range of programs contributing to the quality of the waters and watersheds. OWM is in compliance for 30 years with requirements set by the Federal Clean Water Act (0.1.4.1).

0.1.4 Reclaimed water and the federal legislative branch

The federal legislative branch consists of the Congress (House of Representatives and Senate), which enacts all federal laws. The United States Code (USC) is the official compilation of Federal laws and the Code of Federal Regulations (CFR) is the official compilation of regulations, which expand on the laws written by the Congress. The final rules and regulations are published in the Federal Register after review by the U.S President's Office of Management and Budget. The Code of Federal Regulations (CFR) is divided into 50 titles, which represent broad areas subject to Federal regulation. The EPA covers Title 40. Figure 8 shows the relations between the legislative and executive branch and its laws and regulations that concern wastewater and drinking water.

Laws amended at a federal level that mainly control IPR are the Safe Drinking Water Act (SDWA) and the Federal Water Pollution Control Act, which is often referred to as the Clean Water Act (CWA). The CWA addresses the contamination of the nation's surface waters and regulates discharges through permits issued pursuant to the National Pollution Discharge Elimination System (NPDES) and by limiting the total mass of a specific discharged contaminant through the total maximum daily loads (TMDL) limits. The National Primary Drinking Water Regulations (NPDWR) of the SDWA often functions as a starting point to define potable water quality objectives, although it was not intended to define these when the source is municipal wastewater. Programs under both acts have historically followed independent paths while using different indicators for contamination and different approaches. Concerns about the potential increases in microbial contamination and the potential for the emergence of new pollutants, such as trace organics, has necessitated the consideration for a future strategy in which both acts are united. Another, yet subordinate federal regulation involved in the use of water and wastewater, is the National Toxics Rule (NTR). The NTR establishes numeric priority toxic water quality regulations in order to bring states in compliance with the CWA. A final federal regulation, which is important to mention is The National Environmental Policy Act (NEPA), which requires federal agencies to consider the environmental impacts of any newly proposed IPR project. The above-mentioned laws and others are further discussed in this chapter.

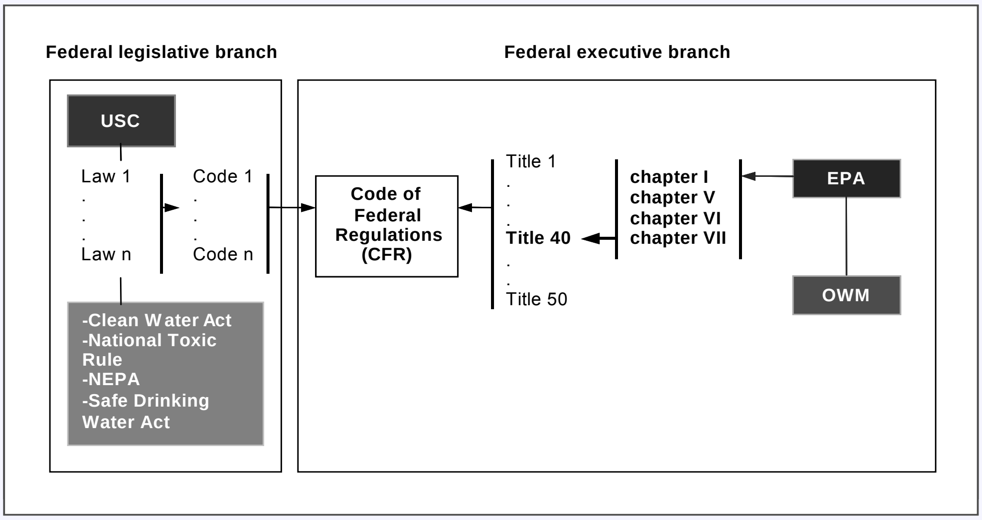

Figure 8: relationships between Federal law, regulations and departments.

0.1.4.1 Water quality and IPR: the Clean Water Act[12]

The Clean Water Act (CWA), also known as the Federal Water Pollution Control Act, is a Federal legislation enabling the protection of surface waters used as a drinking water resource. In addition, it indirectly controls the augmentation involved with IPR by controlling any discharge therein. The CWA ensures that the

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[12] 33 USC 1251 to 1387

quality of the receiving waters is protected. The law employs regulatory and non-regulatory standards. The act does not deal directly with ground water.

For many years following the passage of CWA in 1972, executive departments, such as the EPA focused mainly on the chemical aspects of the CWA. During the last few decades, more attention has been given to physical and biological integrity. In addition, focus has broadened over time from traditional point source facilities (municipal sewage plants, industrial facilities) to runoff from streets, construction sites, and other non-point wet weather sources. The CWA program has also included a shift towards an integrated approach versus a channeled one. The Clean Water Act approaches the water quality based aspect through three primary thrusts:

Pollutant tolerance: the Total Maximum Daily Loads[13]

CWA requires a Total Maximum Daily Load (TMDL) for surface water, which is impaired for water quality. A point source, such as a wastewater facility, which discharges into a river or water stream is given a Water Load Allocation. Different regulations apply to discharges to groundwater. A TMDL is a conservative and quantitative analysis of the total amount of pollutants a water stream can handle. The discharge of wastewater into a drinking water source for the purpose of IPR is thus regulated by the CWA through TMDLs. The number of TMDLs approved or established nationally has steadily increased from 500 in 1999 to nearly 3000 in 2002. In 2003, the EPA temporarily halted the rule’s implementation. States, industry, and local governments questioned the complexity, cost, and legal authority of many of the new July 2000 provisions. Environmentalists addressed the lack of attention to water quality impairment by non-point sources such as wet weather discharges. The rule was challenged in court on a dozen occasions.

Quality deprivation: the Anti-degradation Policy[14]

This policy prohibits new contamination into already impaired streams and protects clean water from becoming degraded. Most states do not succeed in applying the anti-degradation policy to either clean or dirty waters. Anti-degradation provides a three-way approach to water quality protection:

1. Protects existing uses: does not permit activity that would eliminate or interfere with an existing use establishing the absolute floor water quality.
2. Maintain “high quality waters”: Avoid, or at least hold to an absolute minimum, any lowering of quality of waters that meet currently or exceed standards.
3. Protect “outstanding” waters. Give the most ecologically significant and sensitive, the cleanest, and most recreationally popular waters the strict protection they need and deserve.

Each state must acquire an anti-degradation policy that is in accordance with or more stringent than the federal policy. States must also develop a system for implementing this policy consistent with all three tiers of its anti-degradation policy. Anti-degradation applies parameter by parameter. The Anti degradation rule can be applied locally on a section of a water body. Exceptions are made when the discharge proves to be of beneficial use for the local community when surface or ground water is augmented for IPR purposes.

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[13] 42 USC 300f-300j-26

[14] 40 CFR 131.12

Discharge permits: the National Pollution Discharge Elimination System

The CWA requires that all point source wastewater dischargers obtain National Pollution Discharge Elimination System (NPDES) permits, which are issued either by the EPA or by federal authorized states; NPDES permits are meant to sharply reduce contaminated discharges into waterways. The enforcement in California is carried out by the state through regional boards, which are mandated to adopt standards at least as stringent as the federal ones. Permit holders are allowed to discharge pollution into public waters in exchange for reporting the results of required monitoring and meeting the terms of the NPDES permits. The terms are required by law to prevent dischargers from causing or contributing to the infringement of water quality standards, though states and the EPA are often unsuccessful in meeting legal requirements. The terms of permits can also be enforced through citizens' lawsuits.

0.1.4.2 Water contamination criteria: the National Toxic Rule

The National Toxic Rule (NTR) was promulgated by the EPA in 1993 to bring 14 states, including California, Arizona, and Florida in compliance with the CWA requirements regarding the implementation of numeric criteria as part of a state's water quality standards[15]. The NTR sets water quality standards for toxic pollutants known to be protective of human and aquatic life that, in turn, could result in water quality protection related effluent limitations. This rule also comes into effect when water surface is augmented for the purpose of IPR.

The California Toxic Rule halted

Numeric priority toxic pollutant criteria were stymied in California due to a lawsuit brought upon the state by several dischargers that successfully challenged how the rule was implemented. From 1994 through 1998, California was without water quality standards for most priority toxic pollutants in the State's inland surface waters, enclosed bays, and estuaries as is required by the CWA[16]. The CTR was finally promulgated by the EPA on May 18, 2000 (40 CFR 131).

The Arizona Toxic Rule overruled

In 1976, the EPA found that Arizona's revisions to its water quality standards did not meet the requirements of the Clean Water Act (CWA) and promulgated federal numeric nutrient criteria for total nitrates and total phosphates for several river segments in Arizona. The Arizona Department of Environmental Quality adopted these numeric criteria and the EPA approved these adoptions and withdrew its federal standards.

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[15] section 303[c][2][B]
[16] Section 303[c][2][B]

0.1.4.3 Implementation of IPR projects: the National Environmental Policy Act

The National Environmental Policy Act (NEPA) requires federal agencies to integrate environmental values into decision-making processes by considering the environmental impacts of proposed actions and reasonable alternatives to those actions. To meet this requirement, federal agencies prepare a detailed statement known as an Environmental Impact Statement (EIS). When implementing new IPR projects, an EIS is drawn up. EPA reviews and comments on these EISs and assures that its own actions comply with NEPA.

0.1.4.4 Drinking water quality and IPR: the Safe Drinking Water Act[17]

The SDWA was originally passed in 1974, amended in 1986, and again in 1996[18], in order to establish health-based standards to protect drinking water quality by regulating 22 contaminants previously controlled by the Public Health Services. Twelve years following its inception, the SDWA had added only one new contaminant, which resulted in the 1986 amendment to expand the number of regulated contaminants to 83 and a mandatory addition of 25 contaminants per every 5 years. The 1996 amendment established a more realistic goal to add 3 contaminants every 5 years (see Figure 9). Currently, 87 contaminants are regulated, while an additional 60 contaminants are pending, which at the time of this publication are not subject to any proposed or promulgated national primary drinking water regulations, even though they are known to or anticipated to occur in public water systems and may require future regulations under SDWA.

The SDWA drinking water standards are used to regulate IPR because any regulations for IPR standards are currently absent. The SDWA regulates two categories of drinking water standards. The primary standards are legally enforceable standards that limit the levels of specific contaminants known or anticipated to occur in water, which have an adverse effect on public health. They take form in Maximum Contaminant Levels (MCL) and the treatment techniques described below. The secondary standards are non-enforceable and concern both cosmetic and aesthetic effects. States have the option to adopt them as enforceable standards.

In the primary standards, the SWDA requires two objectives for each contaminant: 1. the Maximum Contaminant Level Goal, levels of which no adverse health effects are known, while allowing an adequate safety margin and 2. its enforceable derivation thereof, the MCL. The MCL is set as close to the MCLG as feasibly possible, which the SDWA defines as the level that may be achieved with the best treatment techniques and technology available. When it is not economically and/or technically feasible to measure a contaminant level, a Treatment Technique (TT) is set rather than utilizing a MCL.

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[17] 42 USC 300f-300j-26
[18] 42 USC 300g-8

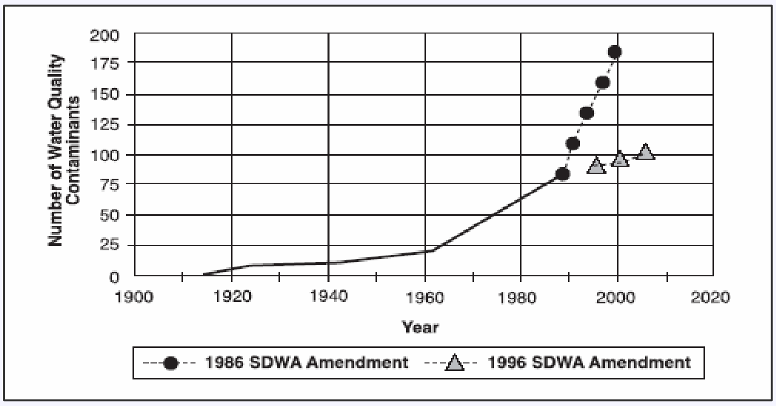

Figure 9 Contaminants Regulated by the SDWA[19]

A proposed change to the SDWA concerns the request of information collection of the monitoring and enforcement of the Underground Injection Control (UIC) portion of the SDWA, which will in a roundabout way regulate IPR rather than direct regulating. The EPA continues to work toward the strengthening of the control of microbial organisms, including Cryptosporidium, as well as for disinfectants and disinfectant by-products, a new standard for radon, revising the current radio nuclides regulation, and to set a new standard for uranium, protecting groundwater from microbial contamination and revising standards for arsenic.

Additional concerns have been raised regarding the fate and transport of trace organic compounds. These include endocrine disruptors, pharmaceuticals, hormones, antibiotics, anti-inflammatories, and personal care products (antibacterial soaps, sunscreen, bath gels, etc.) that are present in municipal wastewaters. None of these individual compounds are regulated or monitored by maximum contaminant levels (MCLs) in the SDWA. These newly emerging contaminants will be discussed in Chapter 0.

0.1.4.5 Federal laws and regulations under the SDWA

The following are specific drinking water laws including their most recent revisions. These laws apply to drinking water only, but are listed briefly to complete the circle of IPR. The latest revisions illustrate the tendency towards a more stringent regulation of microbial contamination and disinfection byproducts and the systematic collection of information for future regulating.

Enhanced Surface Water Treatment Rule

The original Surface Water Treatment Rule (SWTR), which became effective in December 31, 1991, was designed to protect against Giardia. During the process of developing the ESWTR, the UNITED STATES had

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[19] Adapted from EPA, Guidelines for Water Reuse, September 2004

its first major outbreak in Milwaukee, WI. Rather than delay the rulemaking for Giardia, the EPA promulgated the ESTWR, reserving the right for later regulation of Cryptosporidium.

The EPA's latest addition, the Long Term 1 ESWTR (LT1ESWTR), was implemented in May 2004 as extension to the ESWRT. Its purpose mainly serves to improve the control of microbial pathogens, specifically the protozoan Cryptosporidium in drinking water. The rule requires monitoring of systems that serve communities greater than 100,000. A LT2ESWTR has been proposed by the EPA to supplement existing regulations targeting Cryptosporidium treatment requirements in higher risk systems.

Disinfection/Disinfection Byproducts Rule

The Disinfection/Disinfection Byproducts Rule (D/DPR) regulates toxic compounds that are formed during the disinfection process in a two-stage process: Stage 1 establishes maximum residual disinfectant level goals (MRDLGs) and maximum residual disinfectant levels (MRDLs) for chlorine, chloramine and chlorine dioxide. It also establishes maximum contaminant level goals (MCLGs) and maximum contaminant levels (MCLs) for total trihalomethanes, halo-acetic acids, chlorite and bromate and Stage 2, DBPR, focuses on public health protection by limiting exposure to DBPs, specifically total trihalomethanes (TTHM) and five halo-acetic acids (HAA5), which can develop in water through disinfectants used to control microbial pathogens by a primary or residual disinfectant other than UV. To assess risks associated with the control of pathogens and to limit contact to DBPs, the Stage 2 DBPR and LT2ESWTR are being developed concurrently.

Information Collection Rule

In order to support future regulation of microbial contaminants, disinfectants, and disinfection byproducts, the EPA has brought the Information Collection Rule (ICR) into effect. The rule was intended to provide EPA with information on DBPs, pathogens, and engineering data to control these pollutants and contaminants.

State executive and legislative hurdles

The structure of the predominantly autonomous United States' state governments is similar to the federal government. California executive departments and administrative agencies write regulations to implement the authority of state laws. A number of these departments (Figure 10) are directly involved with water reclamation in order to protect and control water quality, water availability and public health. California is the trendsetter in the United States in developing water reuse regulations. Several of its laws implementing these regulations capitalize on the preceding federal laws. The purpose of this chapter is to provide overview of California's executive and legislative structure in relation to water reclamation and IPR.

0.1.5 IPR and the California state executive branch

The state of California has nine cabinet level agencies of which the California Environmental Protection Agency (Cal/EPA), California Recourses Agencies (CRA), and the California Health and Human Services

Agency (CHHSA) regulate water reclamation and IPR in regards to water quality, water availability, and public health. The California Department of Health Services (CDHS) and The California Department of Water Recourses (DWR) are subordinate departments of the CHHSA and the CRA that execute water related regulatory issues. The DHS is responsible for the adoption of regulations for the use of recycled water in IPR. The California Regional Water Quality Control Boards (RWQCB), which are subordinate departments of the CEPA, issue requirements for individual projects in conformance with the regulations adopted by DHS whereas the DWR has a more advisory role. These state executive departments and their relationships are schematically presented in Figure 10 and a short description follows next.

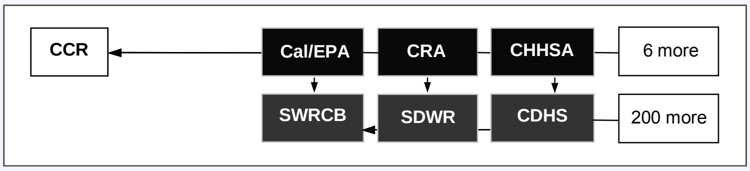

Figure 10: California state executive agencies (top) and departments (bottom) dealing with wastewater

In 1991, California's environmental authority, the California Environmental Protection Agency (Cal/EPA, also referred to in this thesis as the CEPA) merged into a single cabinet agency, bringing six boards and departments under the Cal/EPA umbrella organization. Among those were the Water Board, which consists of the State Water Resources Control Board (SWRCB), and the nine Regional Water Quality Control Boards (RWQCBs). These state executive departments and their relationships are schematically presented in Figure 10 and a short description follows in the next three sections.

0.1.5.1 Water quality: State Water Resources Control Board

The State Water Resources Control Board (SWRCB) and the nine Regional Water Quality Control Boards, also referred to as the Regional Boards (delineated consistently with the major watersheds and groundwater resources), make up the Water Board. The California Regional Boards issue requirements for water reclamation projects in conformance with the regulations adopted by the California Department of Health Services (CDHS). With passage of the Porter-Cologne Water Quality Control Act in 1969, together the Boards became the "principal state agencies with primary responsibility for the coordination and control of water quality."

Within the State Board, the Division of Water Quality is responsible for providing the statewide perspective on a wide range of water quality planning and regulatory functions, including the regulation of activities affecting wetlands under Federal and state Clean Water Act programs. The Division of Water Rights is also involved in regulating IPR discharges to wetlands.

0.1.5.2 Water availability: Department of Water Resources[20]

The Department of Water Resources (DWR) is one of the 8 subordinate departments of the California Resources Agency (CRA) and manages the water resources of California in cooperation with the State Water Resources Control Board and the Department of Health Services. The DWR controls the State Water Project, which supplies water through the California aqueduct to Southern California. The DWR also educates the public on the importance of water and its proper use and distributes water related information to the public. The DWR established the Recycled Water Task Force in 2002, the goal of which is to increase the use of recycled water from a current 0.86 km^3 per year to 1.2 km^3 by 2010 in several forms of which IPR is one.

0.1.5.3 Public health: California Department of Health Services

The California Department of Health Services (CDHS) is one of the 12 subordinate departments of the California Health and Human Services Agency (CHHSA). CDHS establishes water quality standards and treatment reliability criteria for water reclamation under Title 22, Chapter 4, of the California Code of Regulations, in cooperation with the Regional Boards and the Department of Water resources. Requirements for use of recycled water not addressed by the uniform statewide criteria are established by the DHS on a case-by-case basis. The CDHS also reviews newly emerging technologies. No regulations for IPR are currently in place.

0.1.6 Reclaimed water and the California legislative branch

Laws enacted by the California legislative branch concerning water reclamation are the most stringent in the United States and often more specific than federal laws. Water reclamation projects have operated successfully since 1920. The California legislature started regulating water reuse in 1969 and has alone enacted over 100 statutes relating to reclaimed water. However, there currently are no laws or regulations for IPR. Laws and regulations that predominantly control IPR indirectly are Title 22, the California safe drinking water act (CSDWA) and the California Water Code (CWC). The water quality provisions set forth in the California Water Code have been written to supplement provisions of several codes. Among them are the Porter-Cologne Act, the Water Reclamation Act 1991, and the California Environmental Quality Act (CEQA). These laws and regulations and their relations are shown schematically in Figure 11 and further discussed in this section.

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[20] CCR 23, division 3, CWC chapter 2, article 1

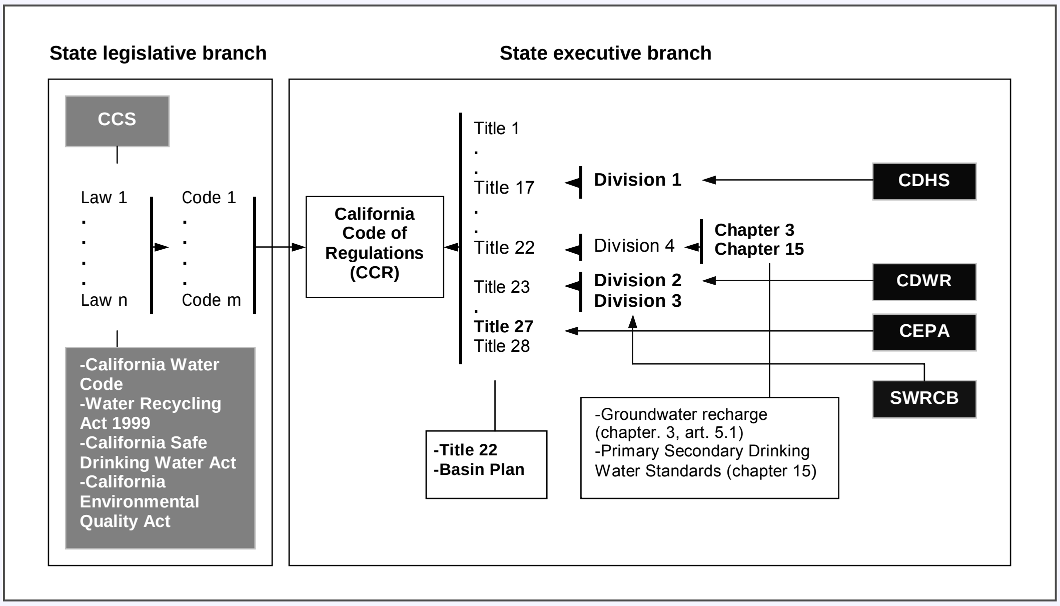

Figure 11: California's legislative and executive branch

0.1.6.1 All about water: the California Water Code

The California Water Code emphasizes a distinct strategy favoring the beneficial reuse of water to the maximum practical extent. It is the principal state regulation governing the use of water resources within the State of California. This law controls water rights, development and use of state water resources, water quality protection and management, management of water-oriented agencies, and more. The water code is mandated to be updated every 5 years and will be again in 2006. The following act is part of this code.

Porter Cologne Water Quality Control Act

The Porter-Cologne Water Quality Control Act (Porter-Cologne Act), which was the precursor to the federal clean water act of 1972, is an important part of the California Water Code. With the adoption of the Porter-Cologne Act in 1969, the State Legislature declared its intent to regulate water quality in California and to encourage the development of water reclamation. This act created the nine Regional Water Quality Control Boards and the State Water Resources Control Board. Under the Porter-Cologne Act, the discharge of waste is a privilege subject to specific permit conditions, not a right. The Porter-Cologne Act considers recycled water, which defines such as water which, as a result of treatment of waste, is suitable for a direct beneficial use or a controlled use that otherwise would not occur. It also declared recycled or recycled water to be a valuable resource. Aspects of the Porter-Cologne Act are similar, yet go further than federal water quality regulations.

The economic rule under Part B of the Porter Cologne Act states that compliance with any rule or law causing a facility to incur an unreasonably high cost could be overruled. The Los Angeles Bureau of Sanitation is currently involved in a lawsuit with the Regional Board claiming that the California Toxic Rule leaves the Tillman Plant (see: 0.1.20) with no other option than to install expensive membrane technology to deliver their Title 22 water. The lawsuit was initiated in 1998 and is currently headed towards the State Supreme Court.

0.1.6.2 Authorized water reuse: Water reclamation act 1991

Chapter 187 of the Water Reclamation Act of 1991 mandated reclaimed water to be used for irrigation and other non-potable applications whenever it is economically feasible. The legislation was signed in 2001. The Department of Water Recourses (DWR) has created a task force to investigate additional opportunities to use recycled water such as IPR.

The Water Reclamation Act of 2005, introduced during the current legislative session, would authorize the implementation of recommendations made by the Recycled Water Task Force that are intended to streamline regulations related to reclaimed water. These recommendations include adherence by local jurisdictions to uniform statewide water reclamation criteria as established by the Department of Health Services and to increase the use of recycled water by using dual plumbing of buildings and new developments. This proposed Act is intended to help the state meet its goal of reclamation 1.2 km^3 water per year by 2010.

0.1.6.3 Regulations for reclaimed water quality, discharge, distribution, and production: Title 22

Title 22 is the Social Security section in the California Code of Regulations. Division 4 of this title covers environmental health, which contains water related issues. They are divided into several chapters. For example, Chapter 3 covers all recycled water quality standards (see Figure 11: California's legislative and executive branch). Several aspects of water reclamation are divided under this chapter and the relevant ones are listed in detail below and Chapter 15 regulates the primary and secondary drinking water standards. Title 22 is commonly referred to as the law that allows for many uses of recycle water.

Groundwater Recharge

The California Department of Health Services' recommendations to the Regional Water Quality Control Boards for proposed expansion of and existing groundwater recharge projects with reclaimed water through surface spreading only, will be made on an individual case basis. These recommendations will depend on the provided treatment, effluent quality and quantity, recharge method, spreading area operations, soil characteristics, hydrogeology, residence time, and distance to withdrawal. Reclaimed water used for IPR, through either direct and indirect groundwater recharge or surface water augmentation, must meet primary drinking water standards specified in Title 22. This accounts for inorganic and organic contaminants, trihalomethanes and other disinfection by-products (DBP), radioactive man-made constituents, and bacteriological quality.

Design and reliability

Under Title 22, a water reclamation facility must allow for efficiency and convenience in operation and maintenance, as well as provide the highest possible degree of treatment under varying circumstances. All reclamation facilities are required to have adequate warning and backup systems to guarantee uninterrupted and reliable operations. The design of most of the facility's components require redundancy, such as duplicate treatment units, power back up supply, and long term storage and disposal systems.

Treatment requirements

Title 22 sets bacteriological water quality standards on the basis of the expected degree of public contact with recycled water. For water reuse applications with a high potential for the public to come in contact with the recycled water, Title 22 requires disinfected tertiary treatment. For applications with a lower potential for public contact, Title 22 requires three levels of secondary treatment, which differs in the amount of disinfection required.

0.1.6.4 More laws and regulations implicated with IPR

Implementation of IPR projects: the California Environmental Quality Act

The CEQA is the basis for environmental law and policy to protect environmental quality in the State of California. The CEQA is a statute that requires state and local agencies to identify the significant environmental impacts of their actions and to avoid or mitigate those impacts if feasible. These include the discharge of highly treated wastewater for the purpose of IPR. In addition, they are required to respond to comments from the public and other agencies concerning the project in question.

Water quality: California Safe Drinking Water Act

The California Safe Drinking Water Act (CA SDWA) was passed to build on and strengthen the federal Safe Drinking Water Act (SDWA). The CA SDWA authorizes the state's Department of Health Services (DHS) to protect the public from contaminants in drinking water by establishing maximum contaminants levels (MCLs) that are at least as stringent as those developed by the United States EPA and as required by the federal SDWA. Primary and secondary (except color) drinking water standards are used in Title 22 and for ground water injection for the purpose of IPR.

Regulating local quality and discharge: the Basin Plan

The Regional Board uses the Basin Plan as a regulatory tool. The Regional Board cites the Basin Plan's water quality standards and prohibitions to control a particular discharge. IPR will be controlled when a discharge augments potable water supplies. Its goal is to provide a program of actions designed to preserve and enhance water quality and to protect beneficial uses. The Basin Plan is also used by other agencies in their permitting and resource management activities.

0.1.7 Laws and regulations in California: a schematic overview

Figure 12 shows the inter-relations for the state of California between laws discussed in this and the previous chapter, and IPR. The left column shows the laws (CWA: 0.1.4.1, CWC: 0.1.6.1, CTR: 0.1.4.2, CEQA: 0.1.6.4) that control regulations and subordinate laws (Title 22: 0.1.6.3, TMDL-Antideg.-Basin Plan: 0.1.4.1), which determine the eventual discharge permits (NDPES: 0.1.4.1). In turn, the NDPES controls the discharge from a Wastewater Treatment Plant (WWTP), an Advanced WWTP, and the discharge from groundwater, as well as a reservoir or surface water stream into other waters. The next column on the left shows how water rights (0) control the effluent of a WWTP, of AWT, the influent for a WTP, and the intake of other water. In addition, this same column shows that Title 22 controls treatment unit processes for AWT. The right part of Figure 12 shows the laws and regulations that control the WTP and drinking water (WRA '99: 0.1.6.2, Title 22, CASDWA: 0.1.6.4 and its implemented federal regulations: D/DBPR, RPHL, ESWTR: 0.1.4.5). The dotted line represents DPR that hypothetically would bypass all but the CWC.

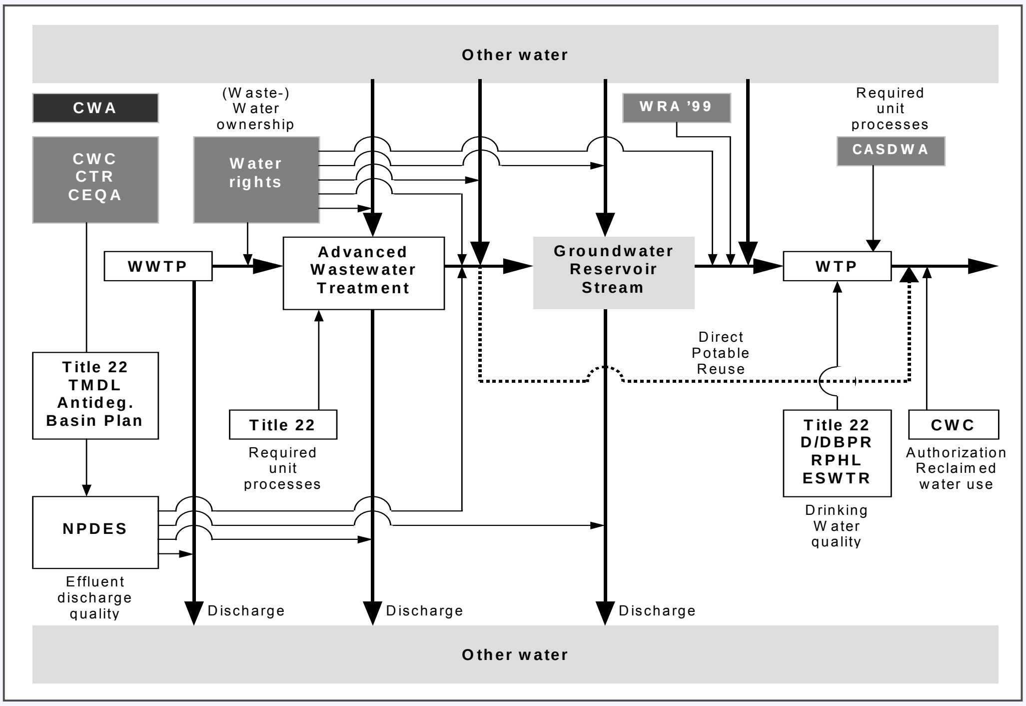

Figure 12: laws and regulations and its inter-relations with IPR in California

Table 4: abbreviations for figure 12

CWA	Clean Water Act
CWC	California Water Code
CTR	California Toxic Rule
CEQA	California Environmental Quality Act
WWTP	Wastewater Treatment Plant
TMDL	Total Maximum Daily Load
Antideg.	Anti-degradation Policy
NPDES	National Pollution Discharge Elimination System
CASDWA	California Safe Drinking Water Act
WTP	Water Treatment Plant
D/DBR	Disinfection/Disinfection By-Product Rule
ESWTR	Enhanced Surface Water Treatment Rule

State executive and legislative barriers for Florida and Arizona

Other impacted areas in the United States in which IPR is frequently practiced are the states of Arizona and Florida. In this chapter, they are addressed in short detail in regards to their executive, legislative, and institutional barriers and challenges. Several IPR facilities in these states are part of the conducted survey. Next to California, these two states have extensive reuse experience in the United States. Table 5 gives an overview of regulations that are currently in place for IPR for states that either have regulations or practice planned IPR.

Table 5: IPR in the United States[21]

	Arizona	California	Florida	Hawaii	Nevada	Texas	Washington
Treatment	Not regulated	Case by case	Advanced treatment, high-level disinfection	Not regulated	Not regulated	Not regulated	Oxidized, coagulated filtered, RO, disinfected
BOD (mg/L)			20				5
TSS (mg/L)			5				5
Turbidity (NTU)			Not specified				0.1 (average) 0.5 (max)
Coliform (n/100ml)			Total all samples less than detection				Total 1 (average) 5 (max)
Total nitrogen (mg/L)			10				10
TOC (mg/L)			3 (average) 5 (max)				1
Primary and secondary standards			Compliance with most primary and secondary				Compliance with most primary and secondary

0.1.8 The Florida and Arizona executive departments involving water reclamation

Compared to California, Florida and Arizona have a significantly less complex, as well as a less extensive executive and legislative branch. California serves in these areas as an example for both states and others, which are taking a back seat for the development of their new laws for water reclamation and IPR. Whereas Arizona has no regulations for IPR and California considers requirements on a case-by-case basis, Florida has clear requirements. Florida's requirements apply solely to the augmentation of surface water sources designated for the domestic drinking water supply and covers treatment and both primary and secondary drinking water standards. Arizona and Florida's main departments involved with water reclamation and governing the quality and availability of water as well as the protection of public health, are described in the following bullet points:

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[21] adapted from EPA, Guidelines for Water Reuse, September 2004

Water quality: Arizona Department of Environmental Quality

In 1986, the Arizona Legislature established the Arizona Department of Environmental Quality (ADEQ) in response to growing concerns about groundwater quality. ADEQ regulates the discharge and treatment of wastewater through the Arizona Pollutant Discharge Elimination System permits (AZPDES), Aquifer Protection Permits (APP), TMDLs, and Wastewater Reuse Permits (WRP). These permits establish specific discharge limits, monitoring and reporting requirements, and may also require these facilities to undertake special measures to protect the environment from pollutants. The primary focus of these permits is municipal/domestic and non-domestic (industrial) direct dischargers.

Water availability: Arizona Department of Water Resources

The Arizona Department of Water Resources (ADWR) works to secure long-term water supplies for Arizona's communities. The Department administers state water laws, explores methods of augmenting water supplies to meet future demands, and develops policies that promote conservation and equitable distribution of water. In addition, the Department oversees the use of surface and groundwater resources under state jurisdiction and negotiates with external political entities to protect Arizona's Colorado River water supply.

Public health: Arizona Department of Health Services

The Arizona Department of Health Services (ADHS) assists in protecting health by providing a full range of Public Health Laboratory services. The Laboratory monitors both groundwater and surface water for the presence of chemical and microbiological pollutants. The ADHS will draw up water quality regulations through its findings in cooperation with the Arizona Department of Water Resources and the Arizona Department of Environmental Quality.

Water quality: Florida Department of Environmental Protection

In 1993, the Florida Legislature merged the Department of Environmental Regulation with the Department of Natural Resources to form the Florida Department of Environmental Protection (FDEP), which is one of fifteen state government agencies in its executive branch. The FDEP is the lead agency in state government for environmental management. The department administers regulatory programs and issues permits for air, water and waste management.

Water availability: Florida Water Management Districts

The FDEP delegates its distribution of water use permits to its 5 water management districts (WMD). The Florida WMDs are regional agencies charged with managing and protecting water resources. They are delegated by the FDEP to distribute water reuse permits.

Public health: Florida Department of Health

The Federal Safe Drinking Water Act (SDWA) is administered by the EPA, which has delegated this responsibility to the FDEP, who in turn, has an agreement with the Florida Department of Health (FDOH) to implement this act. Under this agreement, the public drinking water systems program is responsible for the implementation of the SDWA program.

0.1.9 Florida and Arizona legislative branch: key water reclamation laws and regulations

Water recharge: Arizona Groundwater Code

Recharge programs included in the Arizona Groundwater Code allow the injection of surface water or treated wastewater into an aquifer for storage. Through these recharge programs, surplus renewable water supplies can be stored for use in the future. Under the Groundwater Code, Arizona has created 5 active management areas (AMA) to manage ground water covering only 20% of the arid state's surface. The groundwater code requires management plans to be in place until 2025.

Water reuse law: Florida Apricot Act of 1994

Two provisions of this act are significant to Florida's reuse program. The first allows for permitting of backup discharges for reuse systems when the utility provides advanced wastewater treatment and the second allows high-quality reclaimed water to be injected into potable ground waters.

IPR Regulation: Florida's Domestic Wastewater to Wetlands Rule

The most common form of IPR in Florida is when wetlands, serving as or contributing to drinking water resources, are supplemented with advanced treated wastewater (see 0.1.25). The Wastewater to Wetlands Rule controls the quality and quantity of wastewater subject to being discharged to the wetlands, and the quality of water discharged from the wetlands to contiguous surface waters. The regulation promotes the use of constructed and hydrologically altered wetlands by requiring less monitoring and allowing higher hydraulic and nutrient loading rates for those systems. These regulatory incentives attempt to create and restore wetlands. Many wetland systems are classified as reuse of reclaimed water per Regulation 62-610.810(g), F.A.C.. IPR through wetlands requires more stringent treatment (see: Table 5: IPR in the United States) than other types of reuse.

Public's relation to IPR

Introduction

The third category of institutional "barriers" considered in this thesis is the public's acceptance. Technology is far advanced but rather obsolete if water reclamation is not completely accepted by general public. Several recent IPR projects have found their destiny in public opposition whether scientifically justified or not.

Although IPR has been in the planning stages since 1950, it was only twenty years ago that researchers started looking into the public's perceptions and acceptance of this practice. Most of the recent studies conducted in the United States were primarily aimed at using applied incentives to increase the public's acceptance. This early approach viewed the public acceptance an obstacle while implementing IPR projects. The following approach attempted to persuade the public to accept these projects. It is now generally accepted that social marketing or persuasion is ineffective. Public acceptance and perception are now considered the main ingredients of success for any IPR project.

Understanding why the public is reluctant to IPR requires the explanation of certain human cognitive fundamentals through the law of contagion and is covered next, followed by what today's literature considers to be the influencing factors in the public's acceptation and perception of IPR. Implementing reuse projects in today's society is also covered in this section while the final topic covers the current general concerns in California regarding IPR.

Why humans react the way they react: law of contagion

Why the public objects to IPR projects requires a greater understanding of human cognition associated with the Law of Contagion. The Law of Contact or Contagion is the second sub-law of the Law of Association (first is the Law of Similarity[22]). This law states that objects, which have once been in contact with another object, continue to have influence on each other at a distance even though complete physical separation has been established. Water that has been in contact with contaminants will remain contaminated even after treatment has fully decontaminated the water. Thus, people will respond with disgust to both the contaminant and the associated water.

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[22] The first sub-law of association, the Law of Similarity, suggests that appearance equals reality. Something is perceived to be what it looks like. A container known to filled with potable water yet marked wastewater will not be consumed. If IPR will be considered wastewater, it will not be consumed

Psychological contamination is easy to achieve, whereas psychological decontamination is difficult to achieve. This explains why in depth conversations on the safety of IPR projects are not completely successful in diverting people's perceptions away from IPR water as being contaminated. The perceived presence of contagion is often permanent. There are some people who believe nothing will work to purify contaminated water. There are two primary ways to persuade them otherwise: first, extreme methods of purification (redundancy in treatment, 24 log removal, proven successful technology) are often effective for those using a physical-contact model of contagion. Second, for those using a non-physical model, opposite-contact (manufacturer of baby foods endorsing an IPR project) could redeem the contaminated.

Another way to further understand the law of contagion is to consider an object's essence. People associate purity with an object's history, not just its current physical condition. As a result, perceptions of recycled water include where it has been and what it once was. The public's perception of the essence of IPR water can change if the public's understanding of the validity of IPR changes.

There also appears to be a predisposition toward purity in the form of naturalness. People prefer natural (or pure) to artificial or processed products, even when the two products are physically identical (natural foods vs. genetically altered foods). The general population prefers natural processes to human processes and consider process more important than content. This predisposition partially explains why unplanned IPR is generally more accepted than planned IPR. Unplanned IPR is a more natural course of events than when it is planned.

People deal with these cognitive patterns by a process called framing. Framing ignores part of reality. People choose to ignore where objects have been in order to benefit from its advantages, i.e., cheap products made by underpaid underage workers in third world countries. A greater perceived benefit for IPR projects will increase the acceptability thereof. It is of great importance that the public is educated on the urge to conserve and reuse water to avoid future shortages.

Acceptance and perception issues in IPR

Resistance to IPR often starts on a small level and intensifies when local politicians get involved. Resistance has been shown to launch itself at any time during the course of the project. It has also shown that the lack of communication between proponents and opponents results in the delay and possible termination of the entire project. Insight from a social psychological point of view may result in reviving the project. The following is a summary of the main factors in literature[23] that influence the public's acceptability of a reuse project.

The Disgust or "Yuck" Factor

Objects such as excrement, urine, saliva, dirt and mud generally provoke a reaction of disgust, which will make the use of recycled water to be associated with the Law of Contagion. In CISRO 2003, the psychological rejection of potable reuse is said to be the main contributor for the part of the public that

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[23] Wagner 1994, Bruvold 1998, CSIRO 2003

rejects potable reuse completely. It is for this reason that reuse projects avoid using the term “recycled” and choose for names such as NEWater (Singapore) and Re-purified Water (San Diego) in order to steer away from terms that relate to treated wastewater. Recycled water treated to the highest standards may still be perceived to be “disgusting” for its contact with the items mentioned below:

Risk perception

Risk perception is often related to the safety of using recycled water considering that its source contained potential lethal pathogens and the not fully known effects of disinfection by-products and trace organics. Risk perception is said to be different between the lay public and experts[24]. The public tends to incorporate factors such as uncertainty, potential, and chance into their own formulated risk equation. Experts may consider a one in a million risk[25] of getting sick from drinking recycled water acceptable, whereas the public may perceive this as totally unacceptable because that one person could be them or, in what is considered an even worse case scenario, their own child. Especially in cases where the risks of a reuse project were poorly defined (The East Valley Water Reclamation Project: 0.1.20, The San Diego Re-purification Project 0.1.21), the level of outrage is likely to be significant. Risk communication is, therefore, considered crucial.

Affective decision-making begins with an assessment of the benefits: do I like what is being proposed? If yes, risk is perceived to be low. If no, risk is perceived to be high. The greater the perceived benefit is, the lower the perceived risk is. So, while experts consider risk and benefits to be positively related, the public often perceives them to be reciprocally related.

Source and specific use

The closer the recycled water is to the public, the more likely it will be rejected. Figure 13 shows the opposition as discussed in Bruvold (1998). Bruvold proposes two major influence perceptions to reuse:

1. Degree of human contract
2. The five factors (health, environment, treatment, distribution, and conservation)

The first factor was said to take greater effect when the public was asked about general reuse projects, while the second factor had a greater impact on the public’s perception when salient reuse options were used.

Sources

Directly associated with the “Yuck-factor” in using recycled water is the source of the water to be recycled, as well as the perceived quality of the recycled water and the perceived control over its quality.

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[24] CISCO 2003

[25] Which is the same risk of drinking ½ liter of wine or smoking 1.4 cigarettes per year

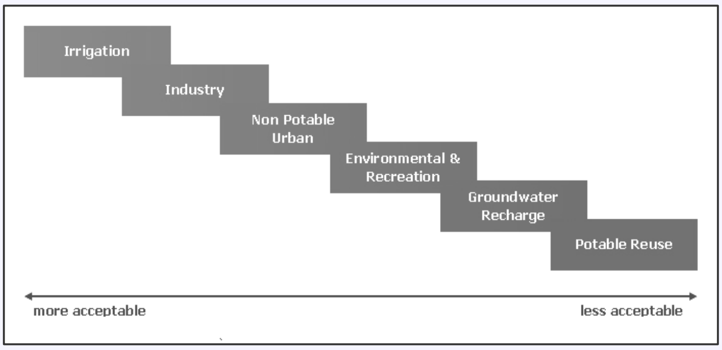

Figure 13: reclaimed water use and its acceptability

Choice, trust, and knowledge

In areas where water shortage is an issue, the public was more likely to choose recycled water as a viable source although the need for recycled water does not necessarily guarantee public’s acceptance. Many studies in the US have shown that the lack of trust in the United States Department of Energy plays a major role in the public’s acceptance. Mistrust in technology also impacts the acceptability negatively.

Justified use

There is also perceived notice among the general public that reuse projects should be geared towards large water users before domestic uses are targeted. The volume consumed for domestic use is said to be minimal. In addition, it is expected by the public that the price for recycled water should be less than regular drinking water as considered to be of lower quality.

Socio-demographic factors

Bruvold (1998) categorized his study findings on the relationship between socio-demographic variables and attitudes towards IPR and concluded that there is a positive correlation between educational, occupational level and income level. Knowledge about recycled water and the male gender were believed to have a positive link as well, while age and the length of residency were considered negative. Bruvold also studied the correlation between belief variables and recycled water and concluded that the section of the public with a positive perception believed that the existing water supply was already contaminated, a water shortage was present, technology would be successful, health risks would be insubstantial, economic benefits would be persuasive and that the general public favors recycled water. The section of the public with negative perception believed the exact opposites. It is suggested in literature that demographic factors were of significant influence in accepting recycled water; however, the findings are inconsistent. Currently, there is no significant global relationship between age, gender, and income other than the fact that older women tend to be less supportive (Hartley, 2003). Table 6 shows responses to several types of reuse.

Water supply availability and population growth concerns

Population growth is said to be induced by an increasing supply of water. The stakeholder that opposes the new development and its assumed associated population growth uses the scarcity of water availability as leverage, which eventually results in the opposition of any water project that is perceived to provide additional population growth. However, most reclaimed water projects are meant to preserve water reliability and to decrease the dependence on imported water for the existing population.

Environmental justice and equity issues

Environmental justice is defined by the EPA as the “fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies.” Environmental justice and equity issues are a result of either procedural or geographic inequity. Procedural inequities occur when meaningful involvement of community or stakeholder groups is absent. Geographic inequity occurs when the project places a greater portion of the risk on a particular community. These issues primarily surface for projects that are located in the economically less affluent areas. Environmental justice and equity issues emerge in recycled water project implementation when a disadvantaged community perceives that it is required to share the bulk of the burden.

Economic concerns

Stakeholders may perceive a water reclamation project as unnecessary and may assess the economics of potential alternatives differently by placing varied values and priorities to certain aspects of the project. When implementing an IPR water project, it is important to stress the avoided costs, such as the ones affiliated with newly imported potable supplies or expansions of existing treatment infrastructure in order to paint a complete picture of the economics of the project.

Table 6: The percentage of respondents opposed to specific uses of recycled water*

	ARCWS 2002 N=665	**Sydney Water** 1999 n=900	**Lohman & Miliken** 1985 n=403	**Miliken & Lohman** 1983 n=399	**Olsen et al.** 1979 n=244	**Kasperon et al.** 1974 n=400	**Stone & Kahle** 1974 n=1000	**Bruvold** 1972 n=972
Drinking	74	69	67	63	54	44	46	56
Cooking	--	62	55	55	52	42	34	55
Bathing	52	43	38	40	37	--	22	37
Washing	30	22	30	24	19	15	--	23
Toilet	4	4	4	3	7	--	5	23
Irrigation crops	--	--	9	7	15	16	--	14
Irrigation home	4	3	3	1	6	--	6	3
Irrigation golf course	2	--	--	--	3	2	5	2

(*) after Bruvold 1998)

Implementing IPR projects

Implementing an IPR project is a complex task as the phases of a typical IPR project as found in today's literature show below. The two main requirements for successful implementation of an IPR project throughout these phases have proven to be the involvement of the numerous stakeholders and the risk communication to these stakeholders. Details of these requirements are also listed below.

Phases of a typical IPR project

- Developing presentations and information-gathering sessions
- Distributing information
- Providing educational information explaining the need for the project, as well as information about the history and safety of recycled water use
- Implementing a 24-hour project information telephone hotline and an effective web site
- Informing and educating media representatives regarding details of the recycled water project
- Implementing, sponsoring, or supporting either new or existing educational programs about recycled water
- Better relationships with individuals mean greater success
- The stakeholder is the focus no matter what the organization's purpose is
- Individual attention in the form of customized response
- Multi-tiered communication recognizes that stakeholders will talk to each other about important issues maintaining effective one-on-one dialogs with individuals is feasible on a large scale

Engage stakeholders before conception and during all phases

It is a human trait to intrinsically favor restoring the bad, such as improving the quality of contaminated water, rather than improving the current supply[26]. Therefore, it is necessary to communicate to the stakeholders that the restoration of lost quality is more favorable than the improvement of the current quality rather than an attempt to satisfy the human need for restoration. The “Toilet-to-tap” scenario has become stigmatized and requires a form of de-conditioning. Ways to reduce adverse reactions is to build familiarity with the project and to desensitize it. This requires education through engaging the stakeholder during all phases of the project. The policy processes that are involved are characterized by relying large amounts of technical information. The basic message underlying this information is that water reuse technology applies redundancy in removing contaminants in wastewater through the use of multiple barriers. Its effluent is therefore useable for several uses of which IPR is one of them. This could be demonstrated through intensive water quality analyses.

Risk communication with stakeholders

Relaying risk assessments is the most challenging part of communication with the stakeholders. The core concern of stakeholders opposing the project will take position based on affective reasoning rather than a logical and analytical one. They will fixate on the unknown regarding constituents and subsequently advance their position. This precautionary principle is the basis of today’s risk assessment decision-making process used by regulators. Using the risk assessment principle responsibly encourages risks to be assessed and analyzed, the impacts and effects of the alternatives to be weighed, and the most effective project alternative to be selected.

Another mechanism that can be used to proactively address concerns regarding risks is the use of a “blue ribbon” panel or commission. A “blue ribbon” panel or commission is a panel comprised of technical experts and/or community members whose mission is to investigate either an issue or a project. For IPR, members can be drawn from academia, public and private sector wastewater or recycled water professionals, and interest groups. These “blue ribbon” panels or commissions have been successfully used by the OCWD to investigate new technology in the development of Water Factory 21.

Public’s concerns in California

Today’s implementation of IPR projects in California raises specific concerns among the public for the general acceptance and perception issues listed in 0. The rapid population growth is sometimes linked to the increase in water supply through reclaimed water projects. Environmental justice and equity issues, as well as economic issues are among the concerns raised. Several examples are listed under the following bullet points.

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[26] CH2Mhill, 2004

Water supply availability and population growth concerns in California

Due to Southern California's arid climate and its subsequent distant location form potable water recourses, water supply availability is an important issue for any new urban development project. Several laws have been amended requiring developers to supply detailed information about sufficient water supply to answer the demands of large development projects. The Dublin San Ramon Services District Clean Water Revival Project is an example of a project that was both subject to the concern of induced population growth and to the health effects of IPR. The MF/RO treated reclaimed water was meant to alleviate an effluent discharge problem by recharging a local groundwater basin. The project was eventually approved by having the advanced treated reclaimed effluent serve as urban irrigation water.

Environmental justice and equity issues in California

One of the strong opponents of the San Diego Re-purification Project (see 0.1.21), Herman Collins[27], stated that he was opposed to the perceived injustice because lesser affluent people were the main recipients of the recycled water. This untrue injustice eventually resulted in this project being put on indefinite hold. Equity issues are potential for political opportunism, which was not only the case in the San Diego Water Re-Purification Project, but also in the East Valley Wastewater Reclamation Project. The project was used as leverage in mayoral campaigns and the former city attorney James Hahn suspended the project exclaiming that the DWP had been unsuccessful in sufficiently informing the public about its conception and possible health risks.

Economic concerns in California

The City of Redwood City is an example of stakeholders developing alternative solutions to water resource issues different from those recommended by the agency project sponsor (i.e. the City of Redwood City). Stakeholders in Redwood were opposed to using recycled water for irrigation in 2000 because it was using more than its contractual allotment from the Hetch-Hetchy system. The stakeholders perceived the water reclamation project as unnecessary by placing different values to certain aspects of the project and assessed the project to be uneconomical.

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[27] Herman Collins later admitted that he has been misinformed by local politicians and regretted having supported the opposition against the San Diego Re-Purification Project

Constituents of concern

Introduction

This chapter focuses on heavy metals and the variety of trace organic compounds found in traditional secondary treated effluent. First, a brief coverage of detection methods is discussed (0) followed by (0), a discussion regarding newly emerging constituents. Finally, the conclusion of this chapter will be completed with an overview of heavy metals and trace organic compounds that are considered the two main categories of concern (0 and 0).

Current detection methods

Identification of constituents found in wastewater is a never ending quest with the ever-improving analytical detection methods. The limiting factor in finding these constituents is the detection method used, which will be covered for each contaminant in 0. Even though there has been a dramatic increase in the ability to detect contaminants in the recent years, there are still concerns that the current toxicological methods are not sensitive enough to characterize today’s level of water pollution.

Toxicity is the main parameter on which a target constituent is judged. All constituents are quantitatively detected. In order to manage the millions of constituents detected, only those that are potentially toxic will be identified and further explored to assess potential health effects. Spectral identification techniques, such as gas (low molecular weight) and liquid (high molecular weight) chromatography are coupled with low and high-resolution electron-impact mass spectrometry (GC-LC/EI-MS), are utilized to identify target constituents. Tandem mass spectrometry (LC-MS-MS) has experienced an impressive progress in recent years that has made the analysis possible of many environmental pollutants in a faster and more sensitive way.

Constituents of concern and the need to remove

Of growing concern are the newly emerging constituents in wastewater. Although not routinely detected for by advanced wastewater treatment facilities, newly emerging pollutants have raised concern for their unknown health effects, fate, and transport. They include: heavy metals, endocrine disrupters, pharmaceuticals, hormones, antibiotics, anti-inflammatories, and personal care products.

This newest water pollution starts with the intake and use of everyday products ranging from antibiotics to hormones, personal care products, and detergents. It is estimated that United States consumers spent 22 billion dollars on over the counter medication in 2003[28] alone of which its majority ends up in the municipal wastewater treatment plant. In addition to the constituents found in wastewater, there are pollutants that have been found in groundwater, such as perchlorate and Methyl Tert Butyl Ether (MTBE). The Human Calci Virus has also raised concerns when serious outbreaks have occurred on cruise ships in recent years.

Among the conventional contaminants, nitrates are of particular concern in advanced wastewater treatment. Standard secondary treatment does not remove nutrients in the United Stated, while this is customary in Europe. Nitrogen removal is, therefore, an important part of advanced treatment and has been the focus for regulation in recent years. Nitrates have human and environmental effects and have been found to be responsible for the Blue Baby Syndrome and to cause harmful algal blooms.

Antibiotics are expected to be the next future constituent of concern. Antibiotics induce or maintain genes conferring antibiotic resistance in microbial populations. Antibiotic resistance in human bacterial pathogens is a growing human health concern and the contribution of agriculture via antibiotic use for growth promotion (in contrast to therapeutic use) remains a topic of intense controversy.

Inorganic compounds of concern: heavy metals

Heavy metals are metals with densities higher than 5 g/cm3. Heavy metals in wastewater come from industries and municipal sewage and are one of the main causes of water and soil pollution. Accumulation of these metals in wastewater depends on many local factors, such as type of industries in the region, people's way of life, and awareness of its impact on the environment by careless disposal of wastes. Therefore, the presence of heavy metals in wastewater is not only of great environmental concern, but also strongly reduces microbial activity and as a result, adversely affects biological wastewater treatment processes.

Moreover, the toxicity of heavy metals in wastewater was shown to be dependant on factors like metal species and concentration, pH, wastewater pollution load, and solubility of the metal ions. Biosorption of heavy metals by microbial cells has been recognized as a potential alternative to existing technologies for the recovery of heavy metals from industrial waste streams. Most studies of biosorption for metal removal have involved the use of either laboratory-grown microorganisms or biomass, generated by the pharmacology and food processing industries or wastewater treatment units.

Heavy metals, such as lead, copper, iron, and zinc are naturally found in trace amounts in the earth's crust. However, heavy metals are used extensively in manufacturing and industry (see pesticides) and prolonged exposure can cause deadly health effects. Examples associated with dangerous heavy metals include the manufacturing of: DDT, dioxins, and polychlorinated biphenyls (PCBs).

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[28] NCPA: Study #270, shopping for drugs: 2004

Emerging trace organic compounds

Wastewater and its constituents have been established to be one of the major sources of surface water and groundwater pollution in the United States. The specific trace organics discussed in this section are usually discharged into sewers that transport these chemicals to wastewater treatment facilities. During conventional wastewater treatment, some of these organic compounds are aerobically degraded, which can result in compounds that are even more toxic than the parent compounds. The overall objective of this section is to investigate the occurrence, distribution, and fate of these compounds in municipal wastewater treatment facilities and effluent discharges, as well as the impact of these compounds on the water quality and ecological environment. The following most often emerging trace organic compounds are further explored:

N-Nitrosodimethylamine

In 1998, N-nitrosodimethylamine (NDMA) was found in a drinking water well in Northern California through direct contamination. NDMA was also found to be a byproduct of drinking water treatment from residual effects of chlorination. As a result of these early findings, DHS established a notification level in 1998 for NDMA because it is an extremely potent carcinogens part of the N-nitrosamines. Due to the relatively high concentrations of NDMA formed during wastewater chlorination, the planned and unplanned reuse of wastewater has become an important area of concern. Only a few laboratories are capable of detecting NDMA at very low concentrations on the order of just a few nanograms per liter (ng/L), or parts per trillion. Ultraviolet (UV) treatment can effectively remove NDMA, but there is considerable interest in the development world for less expensive alternative treatment technologies. These alternative technologies include approaches for removing organic nitrogen-containing NDMA precursors prior to chlorination and the use of sunlight photolysis and in site bioremediation in order to remove NDMA and its precursors. More about NDMA and its occurrences at the inventoried facilities can be found in Chapter 0

Endocrine Disrupting Compounds (EDC)

For over 70 years, scientists have reported that certain synthetic and natural compounds could mimic natural hormones in the endocrine systems of animals. These substances are now collectively known as Endocrine Disrupting Compounds (EDCs) and have been linked to a variety of adverse effects in both humans and wildlife. Reports of EDCs in water have raised substantial concern among the public and regulatory agencies; however, very little is known about the fate of these compounds during drinking and wastewater treatment. Numerous studies have shown that conventional drinking and wastewater treatment plants cannot completely remove many EDCs. Oxidation with chlorine and ozone can result in transformation of some compounds with reactive functional groups under the conditions employed in water and wastewater treatment plants. Advanced treatment technologies, such as activated carbon and reverse osmosis, appear viable for the removal of many trace organics including EDCs.

1,4-Dioxane

1,4-Dioxane is classified as a probable human carcinogen. It is used as a stabilizer for chlorinated solvents and it is formed as a by-product during the manufacturing of polyester and several polyethoxylated compounds. Inappropriate disposal and accidental solvent spills have resulted in the contamination of groundwater with 1,4-dioxane. Volatilization and sorption are not significant reduction mechanisms due to 1,4-dioxane's complete miscibility with water. At present, advanced oxidation processes (AOPs) are the only proven technology for 1,4-dioxane treatment. 1,4-Dioxane was believed to be very resistant to both a-biotic and biologically mediated degradation. However, recent studies have shown that 1,4-dioxane can be biodegraded and that cost-effective biological treatment processes can be developed.

Alkylphenol Polyethoxylates

Alkylphenol Polyethoxylates (APEO) are widely used as components for detergents, paints, herbicides and insecticides. They are usually discharged into sewers, which convey these chemicals to wastewater treatment facilities. APEO are nonionic surfactants whose degradation metabolites are of estrogenic properties. They are relatively stable and have been found in both sediment and surface water. The environmental significance of APEO metabolites and the threat they pose to wildlife is still a matter of debate. Even though advanced analytical procedures are available, researchers have been unable to obtain a complete mass balance during biodegradation studies. The ultimate fate of APEO and their metabolites is not fully understood. Biodegradation is believed to be the dominant degrading process, but photo degradation may also play an important part.

Fluorinated Alkyl Substances [check]

Fluorinated Alkyl Substances (FAS), which include perfluorooctanesulfonate (PFOS) and perfluorooctanoic acid (PFOA), consist of a diverse class of chemicals that are utilized in a wide range of products. As a result of their chemical stability and widespread use, FAS, such as PFOS and PFOA, have been detected in marine mammals and aquatic organisms throughout the world, including relatively pristine environments, such as the Artic. PFOS and related perfluorinated compounds have been associated with a variety of toxic effects including mortality, carcinogenity, and adverse development. Their widespread dispersal throughout the world and their potential toxicity has caused increasing concern among scientists and regulators. FAS were identified and quantified in groundwater, surface waters, and wastewaters, yet little is known about their transport or behavior in the environment. Numerous laboratory and field experiments are still needed to elucidate these processes. In addition, techniques for treating wastewaters containing FAS must be found to prevent their release into the environment.

Perchlorate

Perchlorate (ClO42) emergence in water has been primarily associated with the manufacturing and use of rocket propellant. Perchlorate can spread over large distances when disposed into groundwater since it is highly water soluble and absorbs poorly to soil. The successful perchlorate bioreactor tests indicate that biological treatment is a suitable method for soil remediation and water treatment of perchlorate-contaminated water. Perchlorate is on the EPA's Contaminant Candidate List (CCL), which means that it is a potential candidate for regulation. In addition, the ongoing Unregulated Contaminant Monitoring Rule (UCMR) requires perchlorate monitoring for large systems.

Studies have indicated that perchlorate inhibits the transport in the body of iodine, which in fetuses and children is necessary for brain development. It has been linked to thyroid damage, learning disabilities, decreased IQ and attention deficit disorder in children. It leaches into the ground and has been found in drinking water supplies in 35 states and has also been found in vegetables. A study by Texas Tech University researchers found that breast milk samples were on average five times higher than those detected in dairy milk purchased from grocery stores.

The chemical was found in virtually every sample taken in a new study of nursing mothers' milk in Lubbock, Texas, but researchers say it is too early to know whether these perchlorate levels are dangerous. It has also been found in the Colorado River, the major source of drinking water and irrigation in Southern California and Arizona. According to public health advocates, perchlorate has leaked into the drinking water supplies of more than 16 million Californians through unsafe disposal and storage methods practiced by the aerospace, defense, fireworks, and road flare industries.

Two techniques proven to remove perchlorate from drinking water are anaerobic biological reactors and ion exchange. Some bacteria can use perchlorate as an electron acceptor while oxidizing a large range of substrates. Perchlorate-respiring bacteria (PRB) are widely distributed in the environment and are enriched at perchlorate-contaminated sites. For those utilities with perchlorate contamination, perchlorate is a particularly difficult contaminant to treat, requiring the use of technologies such as ion exchange or reverse osmosis. For all of the above reasons, perchlorate is becoming an increasingly important issue to drinking water utilities.

Methyl Tert Butyl Ether (MTBE)

The production and use of fuel oxygenates has increased dramatically since the early 1990s due to federal and state regulations aimed to improve air quality. Currently, Methyl Tert-Butyl Ether (MTBE) is the most widely used oxygenate in gasoline followed by ethanol. Widespread use of oxygenates in gasoline has been accompanied by widespread release of these materials into the environment. Accidental gasoline releases from underground storage tanks and pipelines are the most significant point sources of oxygenates in groundwater. Because of their polar characteristics, oxygenates migrate through aquifers with minimal retardation, raising great concerns nationwide of their potential for reaching drinking water sources.

An evaluation of MTBE's occurrence in drinking water sources over time in three states showed that the frequency of MTBE detection since 1999 appears to be stabilizing in groundwater and slightly decreasing over time in surface water. Recent studies have demonstrated the effectiveness of conventional treatment technologies and the promise of emerging technologies for MTBE removal from contaminated media. However, the removal from water of Tert-Butyl Alcohol (TBA), an impurity in MTBE-blended fuels and an MTBE breakdown product, can be problematic using some conventional technologies such as air stripping and granular activated carbon. These limitations may generate additional problems for water purveyors, regulators, and site managers.

Human Calici Viruses[29]

There has been a notable surge of interest with regard to the viruses known as human Calici Viruses (HuCVs) and their impact on water-borne disease. Recent epidemiologic studies in Europe, combined with an active waterborne disease surveillance system in the United States, have identified the Norovirus, a member of the HuCVs, as a prominent agent of waterborne disease. Current estimates suggest that upwards of 95–96% of nonbacterial gastroenteritis outbreaks of unidentified etiology may be due to HuCV. Moreover, there have been a number of documented waterborne outbreaks of Norovirus both in developed and developing countries worldwide.

It is with the recent advanced molecular techniques that we have begun to develop a strategy for the detection of this organism in water. However, because of the lack of a culture method for the HuCV it is difficult to perform research on their removal or inactivation during both water and wastewater treatment processes. Alternative approaches, included: using recombinant Norwalk virus particles, indirect measures of inactivation based on molecular methods, or the culturable Feline Calicivirus as a surrogate. Results from these studies raise concerns about the mobility of HuCV in groundwater and their resistance to chlorine and monochloramine and suggest that ultraviolet radiation may be an effective inactivation method.

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[29] Environmental Engineering Science, Volume 20, Number 5, 2003

Advanced Treatment

Introduction

Environmental requirements in California often obligate that wastewaters be treated well beyond secondary drinking water standards for reclaimed water and to primary drinking water standards for IPR. Advanced wastewater is designed to remove suspended solids and nutrients commonly found in secondary effluent and prepare effluents for more reliable disinfection. In some cases, the advanced wastewater treatment may replace the conventional secondary treatment or may be combined with such in situ. Factors necessary to consider when choosing the appropriate configuration of an advanced wastewater facility are the nature of the constituents that need to be removed, the use of the final effluent (Non Potable Reuse, IPR), and the handling of the concentrate. This chapter begins with a general overview of the constituents targeted in advanced treatment (0). It will then give an overview of advanced wastewater treatment facility configurations as they have been encountered during the fieldwork (0), followed by a detailed section covering each type of treatment (0). A separate section will cover up to date membrane technologies (0). Finally, the chapter will end with a brief coverage of disposal of the concentrate (0).

Categories of constituents removal

Advanced wastewater treatment targets the removal of constituents in 4 categories. Each type of constituent and its relevant impacts are presented in tabular form (Table 7 through Table 10) for each of the following categories.

- Residual organic and inorganic colloidal and suspended solids
- Dissolved organic constituents
- Dissolved inorganic constituents
- Biological constituents

Table 7: Residual organic and inorganic colloidal and suspended solids

	Residual organic and inorganic colloidal and suspended solids
Suspended solids	• may cause sludge deposits or interfere with receiving waters • can impact disinfection by shielding organisms
Colloidal solids	• may effect effluent turbidity
Organic matter	• may shield bacteria during disinfection • may deplete oxygen resources

Table 8: Dissolved organic constituents

	Dissolved organic constituents
Total organic carbon	• may deplete oxygen resource
Refractory organics	• toxic to humans • carcinogens
Volatile organic compounds	• toxic to humans • carcinogens • form photochemical oxidants
Pharmaceuticals	• impact aqua species (e.g. endocrine disruption: sex reversal)
Surfactants	• cause foaming and may interfere with coagulation

Table 9: Dissolved inorganic constituents

	Dissolved inorganic constituents
Ammonia	• increases chlorine demand for disinfection • can be converted to nitrates and can deplete oxygen resource • with phosphorus, may lead to undesirable aquatic growth • unionized form is toxic to fish
Nitrate	• stimulates algal and aquatic growth
Phosphorus	• stimulates algal and aquatic growth • interferes with coagulation • interferes with lime clarification
Calcium and magnesium	• increases hardness and total dissolved solids
Total dissolved solids	• interfere with agricultural and industrial processes

Table 10: Biological constituents

	Biological constituents
Bacteria	• may cause diseases
Protozoan cysts and oocysts	• may cause diseases
Viruses	• may cause diseases

Encountered configurations

Figure 14 gives a general schematic overview of the advanced wastewater treatment configurations as they were encountered during fieldwork. All of the surveyed facilities produced effluent higher than secondary quality. There was a tendency towards the use of nitrification/de-nitrification to comply with the latest regulations for nitrates. Micro filtration and recently submerged micro filtration, in combination with reverse osmosis was implemented, replacing traditional treatment in the form of granular media filtration, carbon adsorption, lime clarification, and chlorination. Some of the surveyed facilities also included preliminary and primary treatment. More details about these facilities can be found in chapter 0 and 0.

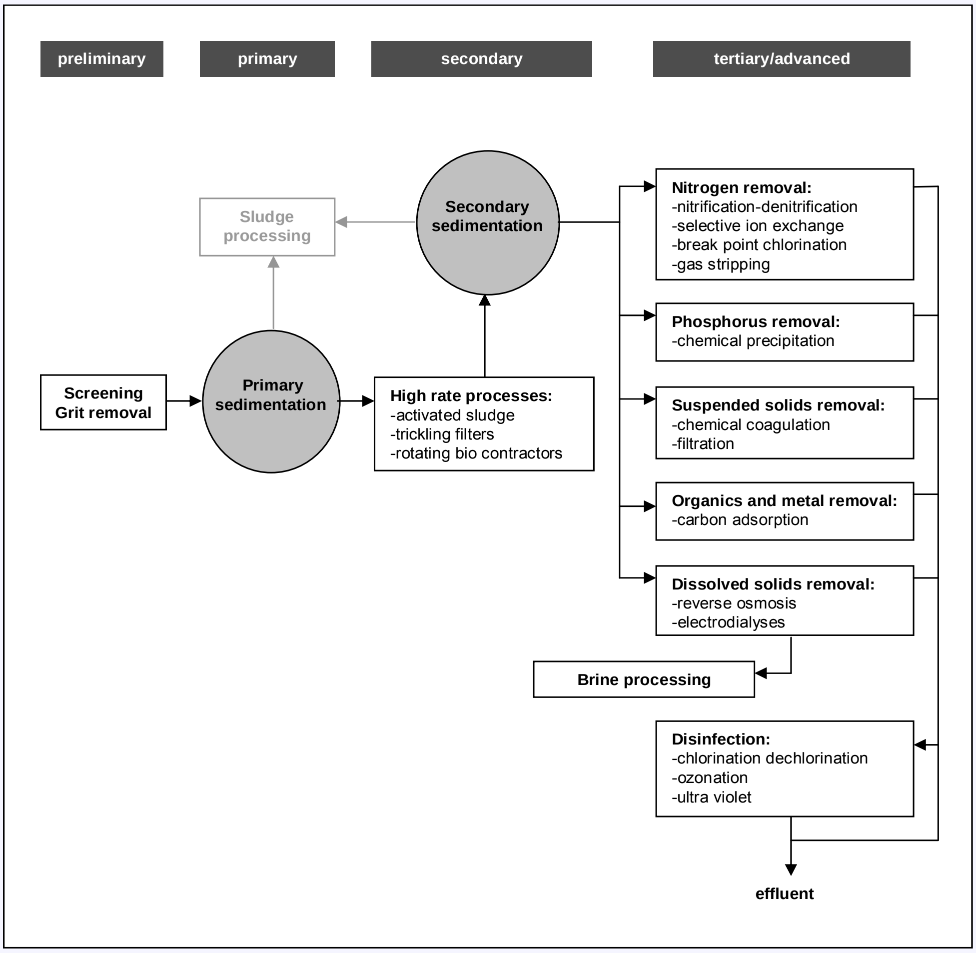

Figure 14: Possible advanced wastewater treatment configurations as encountered during survey

Advanced treatment types

Table 11 shows how each type of advanced treatment target each of the four categories of constituents discussed in 0. In some cases the type of advanced treatment can remove secondary categories of constituents. Each of these listed type of treatment are covered in detail in the following sections except from membrane filtration (MF and RO) which will be covered in 0.

Table 11: Advanced treatment types and the targeted category of constituents*

Advanced treatment type:	**Residual organic and inorganic colloidal and suspended solids**	**Dissolved organic constituents**	**Dissolved inorganic constituents**	**Biological constituents**
Filtration	X			
Membrane filtration (MF)**	X			
Coagulation/flocculation	X			
Activated carbon		X		
Chemical precipitation			X	
Nitrogen removal		X	X	
Reverse osmosis (RO)**		X	X	X
Chlorination				X
Ozonation				X
UV disinfection				X
Advanced oxidation				X

(*) represents only the category that a certain type of advanced treatment predominantly targets, it may target more

(**) discussed in 7.5

Filtration (depth, pressure and surface)

Filtration is the heart of the advanced wastewater treatment facility. It is the physical and chemical process of separating suspended and colloidal constituents from water by passage through a bed of granular material. Filtration goes beyond the process of mechanical straining principles commonly thought of in technical disciplines outside the water treatment world. Most common non-straining mechanisms are interception, sedimentation and diffusion. Filters can be classified by the direction of flow through the bed, the type of used filter media, flow rate, and whether driven by gravity or mechanical applied pressure. The filters encountered during the survey were depth filtration, which often consisted out of single or multi media; pressure filters; and surface filtration, which was encountered only once. Depth filtration is used for supplemental removal of suspended constituents to allow effective disinfection and, more recently, as a pretreatment for membrane filtration. Depth filtration can be replaced by surface filtration, which is the removal of suspended constituents through mechanically sieving of the water by a thin filter material much like a strainer. Membrane filtration will be covered in detail in chapter 0.

Coagulation and flocculation

Secondary effluent contains a variety of colloidal and suspended particles that cause color and turbidity. The physiological processes that are involved in tertiary treatment through coagulation and flocculation are the uniformly rapid mixing of coagulation chemicals (most often Alum) in the water followed by slow mixing, which will cause aggregation of particles that forms a settable of filterable mass. Constituents that are targeted range in size from 0.1 µm to 1.0 µm. Distinct mechanisms of the chemically induced coagulation include the double layer compression surrounding the suspended particles and subsequently refraining them from coagulating and settling, charge neutralization and, adsorption to induce the settling agglomeration of the particles. All inventoried facilities with tertiary treatment used coagulation and flocculation.

Activated carbon (powdered, granular)

Traditional treatment may remove nearly all Biochemical Oxygen Demand (BOD) related organics, but is effective as the refractory organics measured by the Chemical Oxygen Demand (COD). Pore structure and large surface area (1000 m^2/g) are the most important characteristics of activated carbon, which are responsible for the adsorption of constituents. Influencing factors during this process are the characteristics and concentration of the adsorbed constituent, pH and suspended solid contents of the wastewater, and the mode of operation. Granular or powdered activated carbon (GAC, PAC) was used in the surveyed facilities as efficient processes capable of removing organics and even some inorganics, which include some potentially toxic heavy metals from wastewater.

Chemical precipitation

Chemical precipitation in advanced wastewater treatment has been encountered in the form of lime clarification and has been traditionally used to target phosphorus removal and more recently as part of the pretreatment for RO systems. Lime is the term used for a variety of alkaline chemicals mainly containing calcium and oxygen. Two of the most frequently used forms are Quicklime (CaO) and Hydrated Lime (CA[OH]2). The clarification process is completed by final sedimentation, which is more often through gravity rather than chemically enhanced by polymers, silica or other aids. Lime clarification has recently been replaced by MF for cost and area reducing purposes and seems to be the becoming standard in advanced wastewater treatment. This would also eliminate the following step, recarbonation, inherent to lime treated wastewater which is. Recarbonation is the addition of carbon dioxide to water in order to lower alkalinity, which, incidentally, is high due to the secondary effect of the upstream lime treatment. The previously formed hydroxides are converted to carbonates and bicarbonates and thus, lowering the alkalinity or pH. This avoids the problems of deposition of calcium scale in pipelines and on filter and carbon beds because the lowering of pH establishes a calcium-carbonate equilibrium in the water. Lowering pH through recarbonation is also crucial for the downstream processes, such as filtration and activated carbon because it promotes adsorption of organics.

Nitrogen removal

The removal or control of nitrogenous matter in wastewater is associated with various environmental problems. Nitrogen compounds may cause undesired algal growth, whereas ammonia (NH3) can cause toxicity to aquatic life, corrosiveness, has detrimental effects on disinfection and nitrogen oxide (NO3), and is a health hazard. There are four processes of nitrogen removal explored during this research.

1 Nitrification/denitrification

Nitrification/denitrification is the process of converting nitrogen into a form, which can ultimately be removed. The influent ammonia nitrogen is first oxidized to nitrate nitrogen. This is carried out by two groups of autotrophic bacteria: Nitrosomonas and Nitrobacter, which are present in trickling filters and activated bio filters. At this point, the nitrogen has merely changed forms and has not yet been removed from the wastewater. In the second step, denitrification, nitrate nitrogen is converted into nitrogen gas in an anoxic environment by a broad range of bacteria, such as Pseudomonas, Micrococcus, Achromobacter, and Bacillus. The nitrogen gas naturally discharges into the atmosphere. Methanol is being used to speed up this otherwise slow process.

2 Ion exchange

Ion exchange selective for ammonium or nitrate, is the unit process during which clinoptilolite is used as a regenerant. This is a zeolite occurring naturally in Bentonite deposits in the Western United States and consists of complex aluminoscilates with sodium as the mobile ion. The most widespread use of this technology in advanced wastewater treatment is for water softening where calcium and magnesium ions are being removed. It can be operated in a batch or in continuous mode.

3 Breakpoint chlorination

Breakpoint chlorination is the addition of chlorine to water until the chlorine demand has been satisfied. At this point, further additions of chlorine will result in free residual chlorine that is directly proportional to the amount of chlorine added beyond the breakpoint. This breakpoint process is capable of a near complete removal of ammonia. More details as far as chlorine, its disinfection, and related effects are discussed in 4.6.

4 Ammonia stripping

Ammonia stripping is the easiest to operate and control, but it is limited in its inability to operate in freezing temperatures and it is subject to calcium carbonate scaling. Removing the nitrogen in the form of ammonia is an economical solution and recovered ammonia can be used for fertilizer. Elevating the pH to 12 is required, which can be established when put in series with lime clarification to shift the equilibrium between ammonium and ammonia to the gaseous part of the equation. Ammonia stripping also causes other gasses, such as carbon dioxide, oxygen, hydrogen sulfide, and a variety of volatile organic compounds to be removed from the treated water.

Chlorine disinfection and why not to do it

Chlorination has been the major disinfectant process for waste and drinking water for many years. Chlorine destroys the targeted organisms by oxidation of the cellular material. It may be applied as chlorine gas, hypo-chloride or other chlorine compounds in either solid or liquid form. Dosages range from 5 to 15 mg/L and contact times from 30 minutes to 2 hours.

Drawbacks of chlorine disinfection include the formation of disinfection by products, such as Trihalomethanes (THMs) and Haloaceticacids (HAAs) through the reaction of chlorine with residual natural organic matter. Investigation of the possible association between the exposure to these products and cancer (and more recently adverse re-productiveness) has raised concern about potential health effects. In addition, there is a large resistance to transporting hazardous chemicals, such as chlorine gas, while its sensitivity to terrorist acts in situ is another objection. This has altogether led to explore and use of alternative methods of disinfection.

Relatively few health-related studies have been carried out by studying the effects of disinfection by-products (DPB) on reproductive health outcomes. However, several studies point towards a connection between trihalomethanes (THMs) and low birth weight, although the evidence is not definitive. Doses used in these studies have been high and the assessment of exposure was often limited. So far, the main limitation of most studies has been the relatively crude methodology, in particular, for assessment of exposure.

There is no perfect disinfectant, but several characteristics can be considered in choosing the best suitable disinfectant. Factors that play a role in choosing the disinfectant for a treatment facility are the ability to oxidize pathogens, the level of hazardous in using the disinfectant, the level of disinfection byproducts, and the operation and maintenance costs.

Ozone disinfection

Ozone is another strong oxidizing agent. The unstable gas is generated by an electrical discharge through either dry air or pure oxygen. Because of its high oxidation potential, ozone oxidizes cell components of the bacterial cell wall and, subsequently, all of its essential components. Ozone has no residual due to its rapid decomposition, which in turn leaves no way of measuring it efficacy.

Ozone is more effective than chlorine, utilizes a shorter contact time, and can be generated in situ (a mere must since it is unstable). Ozone is also not affected by the ammonium ion and pH, which is the case with the use of chlorine. Also, additional aeration might not be necessary due to the near oxygen saturation as ozone decomposes to oxygen. On the other hand, ozonation is a more complex technology, requires corrosion resistant materials, and is expensive both as a capital investment and energy wise.

The main preference of using Ozone over Chlorine is the absence of chlorinated DBPs, such as THMs and HAAs. DBPs may be produced when high concentrations of bromide were present prior to treatment. Other DBPs (aldehyds and acids) can be formed in the absence of bromide. Ozone has been used in combination with chlorine and chloramine. Many disinfection byproducts formed by ozone and combinations of ozone with chlorine have been identified to be the same type of halogenated DBPs as formed by chlorine only, but they were fewer in number and lower in concentration.

Ultra Violet disinfection

An Ultraviolet (UV) disinfection system transfers electromagnetic energy from a mercury arc lamp to an organism's genetic material. When the UV radiation penetrates the cell wall of an organism, it destroys the cell's ability to reproduce. UV radiation is generated by an electrical discharge through mercury vapor and penetrates the genetic material of microorganisms and retards their ability to reproduce.

The source of UV radiation is either the low-pressure, medium or high-pressure lamp with low or high intensities ranging from 100 to 120 mWs/cm2. Medium and high-pressure lamps with high intensities are 15 to 20 times more effective and are generally used for large facilities. The medium and high-pressure lamp disinfects faster and has a greater penetration capability because of the higher intensity. These lamps operate at higher temperatures and consume significantly higher amounts of energy. Today, there is a tendency towards more use of high pressure lamps.

The main advantage of UV disinfection is the fact that it is a physical process rather than a chemical one. This eliminates the need to produce, handle, transport, or store hazardous or corrosive chemicals. UV disinfection requires significantly less floor space and there is no residual effect that can be harmful to humans or aquatic life. Organisms can sometimes repair and reverse the destructive effects of UV through either photo reactivation or dark repair, while residual suspended solids in the wastewater can leave UV disinfection ineffective. UV is less cost effective than chlorination, but significantly cheaper than ozonation. UV is added to most IPR projects in the United States as a final step, mainly to target NDMA.

Advanced Oxidation Processes

Advanced Oxidation Processes (AOPs) are used in advanced wastewater technology to oxidize complex organic compounds in that are residually present after the final step of the physical separation process, which is usually RO. These chemicals include low molecular weight constituents, such as agricultural pesticides and herbicides, fuels, solvents, and pharmaceuticals.

The purpose of all Advanced Oxidation Processes (AOPs), is to produce hydroxyl radicals (•OH), a highly reactive oxidizing agent that reacts with the dissolved constituents and initiates a series of oxidation processes until the targeted constituent is completely mineralized. Its main purpose is to target low molecular weight contaminants.

When AOPs are used, it may not be necessary to completely oxidize the targeted constituent[30]. Partial oxidation is often sufficient to reduce their toxicity. Because most of the oxidation by-products are unknown in their toxicity, it is common to completely oxidize the targeted constituents. The AOP can be characterized by the extent of degradation of the final oxidation process as follows[31]:

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[30] Metcalf and Eddy, fourth edition, pg 1196

[31] Rice, 1996

- Primary oxidation: a structural change in the parent constituent.
- Acceptable degradation (defusing): a structural change in the parent constituent to the extent that toxicity is reduced.
- Ultimate degradation (mineralization): conversion of the organic carbon to inorganic CO2.
- Unacceptable degradation (fusing): a structural change in the parent constituent resulting in increased toxicity.

There are currently a variety of advanced oxidation approaches available. Each has a scope of wastewater treatment applications that it is best suited for. Most common in advanced wastewater engineering are H2O2/UV and H2O2/O3. Advantages and disadvantages are displayed in Table 12

Table 12[32]: advantages and disadvantages of the most commonly used advanced oxidation processes

	Advantages	Disadvantages
H2O2/UV	H2O2 is quite stable and can be stored on-site for long periods of times	H2O2 has poor UV absorption characteristics and if the water matrix absorbs a lot of UV light energy, then most of the light input to the reactor will be waster. Special reactors designed for UV illumination are required. Residual H2O2 must be addressed
H2O2/O3	Waters with poor UV light transmissions may be treated Special reactors designed for UV illuminations are not required	Volatile organics will be stripped from the ozone contactor Production of O3 can be an expensive and inefficient process Gaseous ozone present in the off-gas of the ozone contactor must be removed Maintaining and determining the proper O3/H2O2 dosages may be difficult Low pH is detrimental to the process

Membrane filtration

The heart of today’s advanced treatment facility is membrane filtration. Membrane technology has existed since the 1960’s and has developed from an “Open” technology to a “Closed” technology. The Membrane market today is highly competitive making disclosure of the latest developments nearly impossible. What did become clear during the visits paid to 3 membrane factories in Southern California were trend towards the developments of low fouling mechanisms and lower feed pressures. What also became clear was that the market for Reverse Osmosis (0.1.14) membranes has stabilized, while the market for submerged micro filtration (0.1.11) is experiencing a steep incline in development.

There are basically four types of membrane filtration treatment techniques available. These are: micro, ultra, nano filtration, and reverse osmosis. Where granular (or depth) filtration consists out of two streams only (feed and filtrate), membrane filtration (sometimes referred to as cross flow filtration) distinguishes itself basically through the presence of a third stream, which is the concentrate. Granular filtration is the

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[32] After Water Treatment: Principles and Design, second edition 2005, pg 584

process during which particulate and colloidal matter is separated from water, whereas membrane filtration is extended to include dissolved constituents. The membrane is the separation barrier through which certain dissolved constituents (see Figure 15) are allowed to pass while others are retained physically. The driving force behind achieving such is a hydrostatic pressure or vacuum difference generated by pumps.

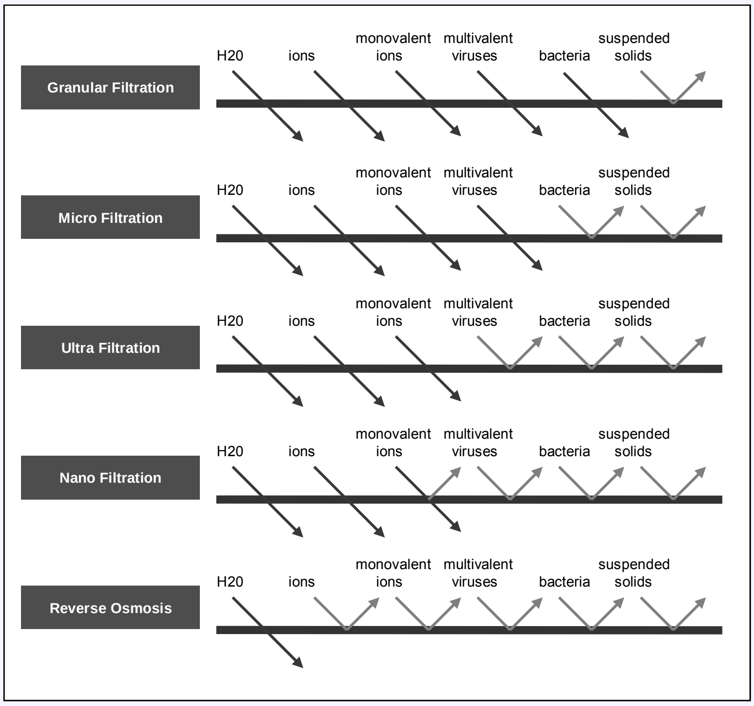

Figure 15: schematic overview of filtration characteristics

Membranes consist of a thin skin with a thickness between 0.20 and 0.25 µm supported by a structure of higher porosity and a thickness of 100 µm in order to provide stability. The principle materials used in fabricating membranes are cellulose acetate, polypropylene and thin-film composite, which recently is the most popular material for RO membranes. Thin film composites with improved characteristics are those of higher water permeability, lower feed pressures (and subsequently lower power costs), and higher salt rejection. The use of hollow fiber membranes (often micro filtration) as a pretreatment for reverse osmosis enables application of thin film composite membranes for wastewater reclamation. The benefits are the operation of RO at lower feed water pressures and it permeates with lower salinity levels than was possible when utilizing cellulose acetate membranes.

Membranes used in the water reuse industry are present on today's commercial market in the form of either tubular, hollow fiber or spiral wound. However, tubular wound is rarely used due to its low packing density. Spiral wound uses two types of flat sheet membranes, asymmetric and composite, and is the most common used configuration in water reclamation. Hollow fiber is used mainly for MF. Hollow fiber has the highest packed density, allows fewer membrane alternatives and requires high quality feed water. Spiral wound is most the popular configuration for UF, NF, and RO. In addition, hollow fiber is equally popular for UF applications.

Membrane Fouling is the process during membrane filtration in which feed water constituents deposit on the membrane surface and in the membrane matrix. The retention of these constituents are called foulants and cause an increase of resistance over the membrane and a decrease of flux. Five forms of fouling mechanisms can be distinguished and are schematically drawn in Figure 16[33]:

- Gel/cake formation: depositions on membrane surface (a)[34]
- Pore plugging: blocking of the membrane pores (b)
- Pore narrowing: adsorption inside the membrane pores (c)
- Concentration polarization: high concentration of foulants near the membrane (d)

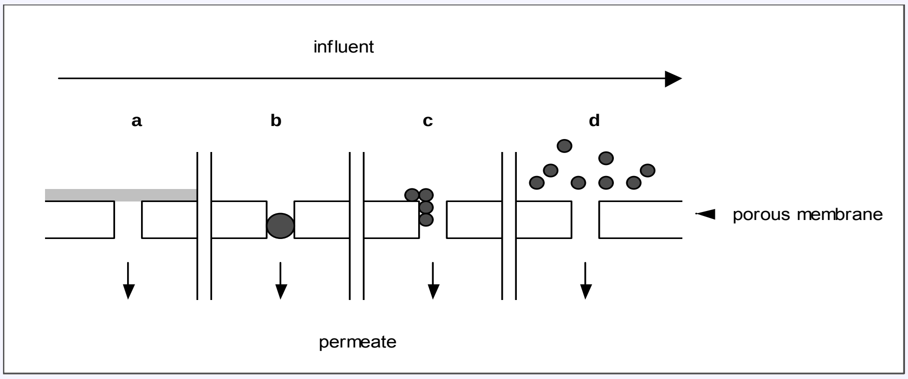

Figure 16: types of membrane fouling

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[33] adapted from Metcalf and Eddy, 4th edition, pg 1118, and Filtration characteristics in dead end ultra filtration, Roorda, pg 19

[34] this layer is also subjected to compression which could be considered as an additional fouling mechanism

Table 13: overview of filtration characteristics

	granular	MF	UF	NF	RO
popular material	anthracite sand	Polysulfone	polysulfone	polyamide	polyamide
pore size	>0.2	0.04-10	0.003-0.2	0.001-0.003	<0.0005
Molecular weight cut off	suspended particals 2-3 micron	500,000-100,000	3,000-100,000	200-10,000	<200
constituents barrier	suspended particles greater than 0.1 mm	suspended particles greater than 0.1 mm	most organics over 1000 MW	-95% divalent ions, -40% monovalent ion -organics greater than 150-300 MW	-99% of most ions
feed pressure range (kPa)	7-14	35-350	175-1,000	1,000-3,100	1,400-10,000 reclamation: 3,100 desalination: 10,000
popular configuration	dual media	hollow fiber (submerged)	hollow fiber spiral wound	spiral wound	spiral wound
reclamation applications	membrane pretreatment -removal suspended particals	-RO pretreatment -granular replacement -removal of small suspended solids	removal of pathogens, bacteria, viruses, and colloids.	-hardness removal -organic and microbiological removal	-mono-valent ions -inorganic removal

0.1.10 Micro filtration

Micro filtration (MF) is a low-pressure membrane process that removes virtually all particles greater than about 0.2 mm. Its performance is far superior to conventional granular media. Although the footprint is small, Micro Filtration (MF) is often used in reuse projects as pretreatment for RO to prevent premature fouling. It serves as pretreatment of surface water, municipal and industrial wastewater. MF functions in potable water production as a barrier for bacteria or as way of clarification.

0.1.11 Submerged Micro Filtration

Submerged Micro Filtration (SMF) has been commercially developed to eliminate the footprint completely. Bundles of hollow fibers are inserted directly into a coagulation basin of a drinking water treatment plant and/or directly into the aeration basin of an activated sludge wastewater treatment plant, in order to put a particle separation within other treatment functions. Permeate (product) water is generated by application of a partial vacuum (<70 kPa), i.e., a negative pressure.

While submerged MF is very promising, relatively little fundamental information is available to describe the process by which particles form a cake on the outside of the hollow fibers. Cake formation leads to fouling of the membrane surface. Therefore, a greater partial vacuum must be applied to produce the same permeate flux (water flow rate per unit area of membrane). This increases the cost of operation. Aeration is usually applied to generate water movement along the length of the fiber in order to limit development of the cake layer in order to retard the rate of increase in partial vacuum that is needed to maintain a constant permeate flux.

Engineering practice could benefit by quantification of effect of aeration on fouling reduction based on the type of particles to be removed (i.e., their fundamental filtration characteristics), the concentration of these particles, and the length and diameter of the fibers. Results of a well-controlled pilot test by Water Factory 21 to study submerged MF is discussed in 0.1.15.1.

0.1.12 Ultra filtration

UF is used when the influent is of better quality than in situations where MF is the pretreatment. The assumption that UF is an excellent pretreatment for Nano Filtration is supported by the successful data from the pretreatment for RO with UF. UF also targets viruses, such as Cryptosporidium and Giardia, but it essentially targets colloidal removal. UF is a low-pressure (175-1,000 kPa) process. UF is known to have a 4 log removal of bacteria and viruses and, therefore, used more in drinking water treatment applications. In wastewater applications, UF will polish biologically treated municipal secondary effluent for either discharge to surface water, reuse, or feed to reverse osmosis.

0.1.13 Nano Filtration

Nano Filtration (NF) is used in potable drinking water applications and is meant to remove both colloidal and many soluble organics. It will partially reduce hardness, TDS, and organics. It also reduces THM precursors while limiting the formation of THMs during chlorination. Nano filtration is a low to moderately high pressure (typically 1,000 – 3,100 kPa) process in which mono-valent ions will pass freely through the membrane, but highly charged, multivalent salts and low molecular weight organics will be rejected to a much greater degree. Typical NF applications in wastewater treatment involve water softening and drinking water treatment.

0.1.14 Reverse Osmosis

Reverse Osmosis (RO) is used in wastewater applications as the final physical treatment step mainly for irrigation and for IPR. Osmosis is the spontaneous process of water flow across a semi-permeable membrane barrier from the solution of low concentration to the solution of higher concentration. Reverse Osmosis is the reverse process driven by pressure. RO membrane elements are housed in pressure vessels in numbers ranging from 5 to 7. Today’s pressure vessels configuration in water reclamation are in three arrays decreasing in numbers by 50 percent . For example, the feed water will first pass through 20 vessels, then through 10 and eventually a third time through 5 vessels. Feed pressure ranges from 1,400 to 3,100 kPa for water reclamation and 10,000 kPa for desalination.

The application of RO membrane technology for treatment of municipal wastewater secondary or tertiary effluent has increased since the early 1990s. High fouling rates have been reduced with a new generation of low fouling composite RO membranes, which is to be attributed to the hydrophilic membrane surface. Proprietary details regarding the low fouling physical system were not obtainable. Information regarding improvements in pretreatment, chemical addition to the feed water, and the increase size of the RO elements and configuration was available and will be discussed next. These have been developed in recent years to enhance the performance of RO systems.

0.1.14.1 Reverse Osmosis pretreatment

The traditional multi-step RO pretreatment approach (flocculation, settling, clarification, media filtration, and disinfection) results in high membrane fouling rates regardless of membrane type (cellulose acetate or composite polyamide). Recently, the new pretreatment technology being utilized in RO processing of municipal effluent is either UF, MF, or submerged MF.

Another form of pretreatment is the installation of carbon filters. The advantages are their ability to remove organics from the feed water that could foul the RO and that they are more reliable in treating all the feed water than a chemical feed system. The disadvantage is that carbon filters are notorious for breeding bacteria, which can result in a biological fouling of the RO.

0.1.14.2 Chemical enhancement of Reverse Osmosis systems[35]

Acids

Acids, typically hydrochloric [HCl] or sulfuric [H2SO4], are fed to lower the feed pH. The feed water pH is often adjusted to prevent precipitation. Based on a lower operating cost, reduced fuming to the atmosphere, which can corrode surrounding metal components, and a better membrane rejection of the sulfate ion than the chloride ion, sulfuric acid is used more often than HCl acid.

Caustic

Caustics, for a few process applications, can be injected to increase the RO feed pH. Typically, the only caustic injected is sodium hydroxide [NaOH] because of its cost, availability, and its solubility in water. The quality of the NaOH can be technical grade (and free of any additives) most of the time. Brackish waters can contain potential foulants that become more of an issue at higher pH (e.g. hardness, alkalinity, iron, manganese, etc.). Pretreatment frequently uses a weak acid cation exchange system and a degasifier to remove these potential foulants.

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[35] From: Chemical pretreatment for NF and RO, March 2002, Hydranautics

Dechlorination chemicals

Free available chlorine in RO feed waters needs to be reduced for compliance of Composite Polyamide membrane warranties issued by the manufacturers. The two most common pretreatment methods for reducing chlorine levels are either by absorption onto activated granular carbon filter media or through the use of a chemical reducing agent, such as sodium bi-sulfite. Dechlorination after chloramination may be required prior to feeding the influent to the RO membranes. Chloramines are produced by mixing chlorine and ammonia. Residual free chlorine, which can deteriorate membranes significantly more quickly than chloramines, can be present if insufficient ammonia is used. Chloramine tolerance can vary by either the catalytic effects of high temperature, low pH, or the presence of transition metals.

Anti-scalants and dispersants

There is a variety of proprietary anti-scalants and dispersants available on today's market to improve the operation of RO systems. Anti-scalants are chemicals designed to inhibit the formation and precipitation of crystallized mineral salts that form scale. Most anti-scalants are proprietary organic man-made polymers. Dispersants are organic man-made polymers designed to inhibit the agglomeration and deposition of foulants onto the membrane surface. Dispersants are sometimes referred to as anti-foulants. Foulants tend to be a softer, non-crystalline deposit. Dispersant chemicals frequently have anti-scalant properties. The efficacy of differing dispersants can vary for different foulants, so one needs to know what foulant they are treating for. Foulants treated by dispersants are:

- Mineral scales
- Metal oxides and hydroxides [iron, manganese, aluminum]
- Polymerized silica
- Colloidal material
- Biological matter

0.1.14.3 Size and configuration: developments in membrane characteristics

RO membrane elements are being developed in larger sizes to increase permeate flow and to increase flux through lowering the feed pressure (without compromising the quality performance). This results in minimizing the floor space used by the membrane trains. Pressure vessels that contain the membrane elements are made more pressure resistant enabling them to encase more RO elements. Koch Membrane Systems currently tests their latest oversized membrane, the MegaMagnum® RO Element at the Scottsdale Water Campus (also see 0.1.22). The MegaMagnum delivers nearly 5 times the permeate flow when compared to the regular, already oversized Magnum and up to 8 times the permeate flow of other available membrane elements. More characteristics of these membranes are listed in Table 14.

Figure 17: MegaMagnum® RO Element (picture by Harm Jansen)

Table 14: Membrane characteristics

	Koch 8832 HR-575 Magnum	**Koch TFC 18061 HR MegaMagnum**	**Hydranautics ESPA2**	**Hydranautics LFC1**	**GE Osmonics**
permeate flow (m^3/d)	56.8	277	34.1	41.6	41.6
salt rejection (min)	99.5	99.5	99.5	99.5	99.5
membrane chemistry	proprietary TFC polyamide	proprietary TFC-HR polyamide	proprietary composite polyamide	proprietary composite polyamide	proprietary composite polyamide
membrane area ($m^{2)}$	53.4	260	37.0	37.0	37.0
max pressure (kPa)	4,140	2,070	4,140	4,140	4,140
max chlorine (ppm)	<0.1	<0.1	<0.1	<0.1	<0.1
max temperature (c)	45	45	45	45	45
feedwater pH range	4-11	4-11	3-10	3-10	3-10
max feedwater turbidity (ntu)	1	1	1	1	1
max pressure drop (kPa)	69/104	69/104	69	69	69
length (mm)	1,524	1,549	1,016	1,016	1,016
total diameter (mm)	203	457	202	202	202
weight (kg)	29	113	16.4	16.4	16.4

Concentrate Disposal

Concentrate disposal is an important issue because the ultimate goal of advanced treatment is to achieve a net gain. Disposal of the RO concentrate streams is often a challenge because the waste stream volume is about 15% of the feed stream volume. High salinity and anaerobic state makes the concentrate toxic to plants and animals, which limits the option for concentrate reuse. RO cleaning solutions are acidic or basic solutions that contain detergents or surfactants, which further contaminates the concentrate. The concentrate may be classified as hazardous material when RO is used to remove a specific contaminant, such as arsenic and radium. Concentrate disposal is classified as an industrial waste and regulated by federal, state, and local laws. The most common forms of concentrate disposals in the United States are:[36]

- Discharge to brackish surface water (oceans, brackish rivers, and estuaries)
- Discharge to a municipal sewer
- Deep well injection

Most plants (50%) discharge to the ocean. Inland facilities (30%) will discharge to the municipal sewer or a separately constructed pipeline to the ocean. Only 10% of facilities will use deep well injection, which is most common in Florida. Other technical feasible options are evaporation ponds and infiltration basis, but are used by only a small number of plants in the UNITED STATES They require large surface areas and involve high operating and maintenance costs and are, therefore, used when no other alternatives are available and where the value of product water is high.

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[36] After Water Treatment: Principles and Design, second edition 2005, pg 1495

Conducted survey for IPR projects

Introduction

Fieldwork was been conducted in California, Arizona, and Florida. A standard template was used to characterize these facilities by size, technology, type of IPR practiced, goals and the outcomes thereof. More specific details, such as used membrane types, relative costs and specific applicable laws and regulations were also inventoried. When available, studies conducted by the facility on emerging pollutants and membranes were also studied. Several people were interviewed per facility ranging from plant operator to designing engineers. Each facility is briefly described in the following chapters and summarized in tables at the end of each section. The influent and effluent quality parameters of each plant, as far as they were available, are put in tables found in chapter 0.

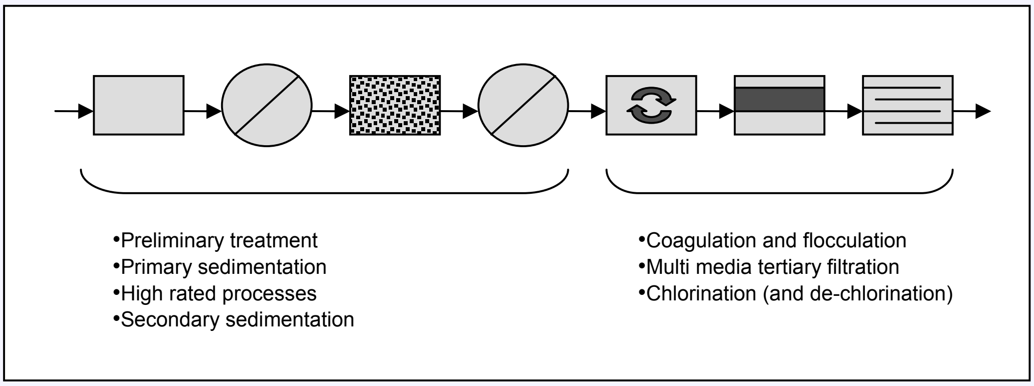

Figure 18: Traditional secondary (left) and tertiary (right) treatment

The inventoried facilities were encountered in several configurations. The majority of the facilities consisted of traditional treatment for their preliminary, primary, secondary and tertiary stage (Figure 18) and is referred to as “traditional secondary” and “traditional tertiary treatment” in the remainder of this chapter. Advanced wastewater treatment facilities using secondary or tertiary effluent as their influent had their tertiary and/or advanced treatment configured in which RO was placed central. Two standard RO configurations were often encountered, which is referred to in this thesis as “traditional RO pretreatment” (Figure 19) and “contemporary advanced treatment” (Figure 20). A few alternatives to and combinations of these treatments were encountered as well and will be illustrated separately for each relevant facility.

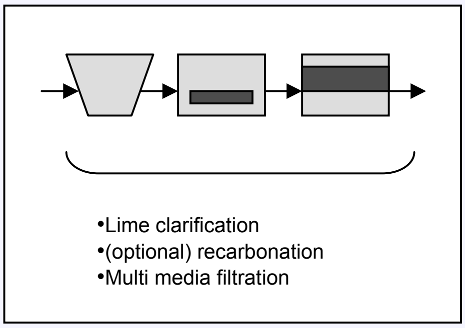

Figure 19: Traditional RO pretreatment

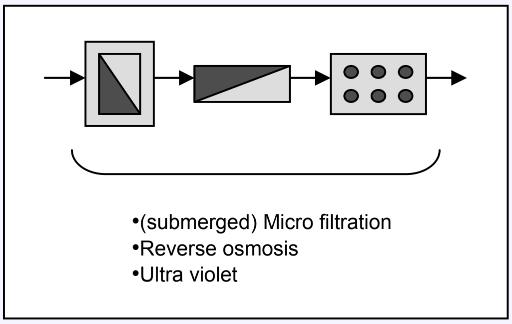

Figure 20: Contemporary advanced treatment

IPR projects in Southern California

0.1.15 Orange County, California: Water Factory 21

One of the most highly recognized and most regarded water purification facilities in the world of wastewater industry is Water Factory 21, a project built and operated by the Orange County Water District (OCWD). It was the first project in California to treat wastewater water to drinking water standards. (Previous to this project, the (secondary treated) wastewater was discharged to the ocean). The now advanced treated effluent is used as a hydraulic barrier against the intrusion of seawater into the local groundwater supply through injection into the local aquifer. This leads to IPR as the aquifer also serves as a drinking source. Since 1976, Water Factory 21 has been protecting the integrity of the large groundwater basin that serves north and central Orange County, while also helping to increase the reliability of the area's water supply. In

1977, a 0.2 m^3/s RO was installed for the removal of salts and organics. Ammonia stripping was discontinued in 1999 and WF 21 was permitted to inject 100% reclaimed water.

The facility takes conventional secondary treated effluent (high rated processes: 20% trickling filters, 80% activated sludge) from their neighboring Orange County Sanitation District and provides additional treatment using traditional RO pretreatment (lime clarification, re-carbonation, mixed media filtration) after which two-thirds of the flow would pass through granular activated carbon and one third of the flow would pass though RO and chlorination. The combined effluent meets or surpasses all drinking water standards even before it is blended with water from other supplies and injected into the groundwater basin. After blending it totals to 1.0 m^3/s which, is used for the 23 multi-point-injection into four separate aquifers, which supplies 75% of the water needs for nearly 2 million people.

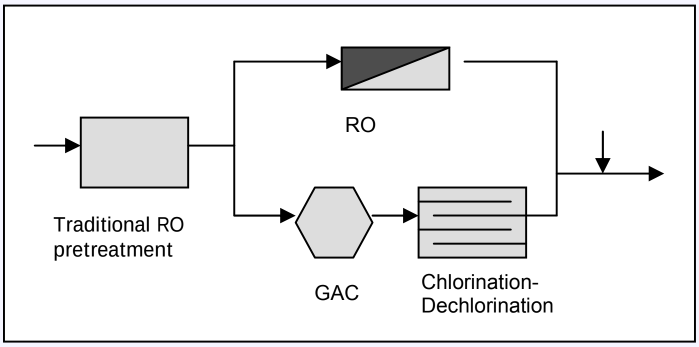

Figure 21: Process flow diagram of Water Factory 21

Table 15: MF and RO data WF 21

	MF	RO
type	Memcor CMF-S	Koch Fluid Systems 8832-HR polyamide
recovery	85%	85%
flux	41L/m^2hr	18/m^2hr
configuration	24x(6)	6 units (24-12-6) (6 elements per vessel)

0.1.15.1 Membrane pretreatment study at Water Factory 21

Water Factory 21 (WF 21) conducted an intensive research project in 2001 for their RO membrane pretreatment and pilot tested submerged MF, MF, and tubular UF. The objective was to determine the feasibility of each system for pretreatment, to establish design criteria and to demonstrate successful operation of the system at the established design criteria. Minimum design objectives demanded from the manufacturers were as follows:

- Test membranes must have been successfully tested at the Orange County Water District (OCWD)[37]
- A minimum of 250 m^3/d capacity
- Ability to produce acceptable quality for the RO feed
- Minimum of a 3 week run between cleaning
- Ability to run 150% of the design flux for 48 hours (clean flux start)

The three tested systems were:

1. Vivendi/US Filter/Memcor Continuous Microfiltration-Submerged (CMF-S) System: 32 modules
2. Pall Corperation Microza Microfiltration Systems (Pall): 50 modules
3. Zenon Environmental Systems Zeeweed Water Treatment System (Zenon) (UF): 6 module cassette

The water for demonstration was activated sludge secondary effluent provided by the Orange County Sanitation District (OCSD), which was known to be of better quality than what the full scale facility would receive, making it imperative that the pretreatment systems would achieve the appropriate cleaning intervals. Feed water temperature varied between 22º C and 28.5º C. Table 16 through Table 18 show the water quality of the feed and filtrate streams for each of the demonstration units during the testing.

Table 16: CMF-S filtrate

	Q1-feed			**CMF-S filtrate**		
Parameter	Turbidity	TSS	SDI	Turbidity	TSS	SDI
Unites	NTU	mg/L		NTU	mg/L	
Average	3.59	5.41	N/A	0.18	<1	1.52
Maximum	10.9	12.0	N/A	0.68	<1	3.56
Minimum	1.66	2.20	N/A	0.03	<1	0.13

Table 17: Pall filtrate

	Pall chlorinated 2^n effluent			**Pall filtrate**		
Parameter	Turbidity	TSS	SDI	Turbidity	TSS	SDI
Unites	NTU	mg/L		NTU	mg/L	
Average	3.52	5.41	N/A	0.15	<1	0.67
Maximum	12.2	12.0	N/A	0.93	<1	0.68
Minimum	1.31	2.20	N/A	0.06	<1	0.66

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[37] The predecessor of WF 21

Table 18: Zenon filtrate

	Zenon chlorinated 2° effluent			Zenon filtrate		
Parameter	Turbidity	TSS	SDI	Turbidity	TSS	SDI
Unites	NTU	mg/L		NTU	mg/L	
Average	4.04	5.31	N/A	0.18	<1	1.97
Maximum	7.94	13.0	N/A	0.53	<1	5.50
Minimum	2.55	2.40	N/A	0.05	<1	0.23

In order to achieve at least 21-days between cleaning and being able to maintain operation during peak flow events (1.5 times the normal instantaneous flow), the tested samples produced the following results in Table 19. All three tested systems passed the test and the CMF-S System was elected on economical grounds.

Table 19: Test results WF 21 MF pilot testing

	CMF-S		Pall		Zenon	
	Normal flow	Peak flow	Normal flow	Peak flow	mid recovery	Peak flow
Duration (days)	28, 28	3, 3.5	19, 21	2, 7	25	2, 2.1
Recovery (%)	88	88	90	90	90	84
Instant filtrate flux (gfd)	20.4	30.6	21.4	36.1	18	27
Instant filtrate flow (gfd/module)	4.5	6.75	9	13.5	8.2	12.5
Backwash cycle (min)	22	22	22.4	20	9.5	9.5
Backwash duration (sec)	30	30	110	220	30	30
Backwash flow (gpm/module)	10.5	10.5	7	7	12.3	18.5

0.1.15.2 Groundwater Replenishment System

After 29 years of operation, Water Factory 21 has proven that advanced treated wastewater can successfully be treated to drinking water quality and can be used for injection into groundwater basins. Currently, under construction, the GWR System remodels the Water Factory 21 and increases the water-reclamation production with significant numbers (see Table 27) by treating wastewater to drinking water standards. The GWR System, scheduled to produce water in 2007, belongs to an overall plan to aid in preventing the predicted water shortages in Orange County. The Orange County Water District (OCWD) and the Orange County Sanitation District (OCSD) are developing the GWR jointly. After five years of planning and analysis, the GWR was determined to be the most economical and most feasible new water supply for the region.

With OCSD, secondary treated effluent as its influent, the GWR System would supply the additional contemporary advanced treatment (SMF-RO-UV/H202). UV/H2O2 was chosen to comply with future NMDA regulations. The advanced treated water will then be conveyed to either:

- Existing spreading basins for percolation into and replenishing the groundwater supply

- Injection wells for a seawater intrusion control barrier

The Groundwater Replenishment System would be implemented in three phases, providing roughly 2.63 m^3/s of new water by the year 2003, 3.72 m^3/s by 2010, and up to 4.38 m^3/s by 2020.

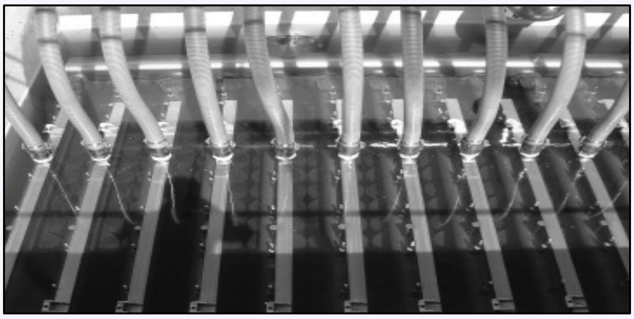

Figure 22: Inactive submerged MF modules at GWR System (picture by Harm Jansen)

For OCWD/OCSD, the PI&E effort has been and continues to be extensive. Outreach started with the public, with politicians, and with community leaders. Focus groups are used extensively to test program messages, which include: education approaches, phone conversations, survey questions, etc. Outreach channels include the GWR System's website, press releases, mail campaigns, tours and briefings, cable television ads, telephone surveys, focus groups, and legislative lobbying. Significant effort has been placed on identifying demographic sources of potential opposition.

Table 20: 2003 average NMDA concentrations at Water Factory 21

	Influent	**Before UV**	**After UV**	**After mixing**
NDMA (ppt)	33.2	252.3	7.8	4.8

Table 21: MF and RO data GWR System

	MF	**RO**
type	U.S Filter S10T sub-modules (15,000 hollow fibers) polypropylene	Hydranautics ESPA 2 composite polyamide
Recovery (%)	89	85
Flux (L/m^2hr)	34.4	--
configuration	Cell no. 1: 4 cloversx8x19 racks = 608 modules Cell no. 2: 4 cloversx9x19 racks = 684 modules	4 units (24-12-6) (6 elements per vessel)

0.1.16 Los Angeles County, California: West Basin Water Reclamation Project

The government owned West Basin Municipal Water District's wastewater reclamation facility in El Segundo, California has been privately operative since 1995. Reclaimed wastewater provides a variety of benefits for the West Basin service area, including irrigation, industrial use and injection for a seawater barrier. West Basin uses a combination of imported water and purified wastewater for the one-half mile long seawater barrier that encompasses over 100 injection wells to help protect the District's productive groundwater basin from seawater intrusion. The secondary effect of this practice is IPR as the by West Basin augmented groundwater basin also serves as a drinking water source.

Currently, 0.32 m^3/s of water that has been treated by micro filtration and RO processes provides high quality water, which is mixed with 0.45 m^3/s of imported water, which is supposed to improve the overall quality of the water mix in the groundwater basin that supplies the region's drinking water requirements. By 2006, the plant will expand to 0.55 m^3/s and eventually take full account for the 0.77 m^3/s needed for injection. The West Basin will implement UV disinfection in combination with H2O2 advanced oxidation in order to comply with the non-enforceable guidelines on NDMA. The West Basin claims that NDMA enters and leaves the plant in the same concentrations, but is elevated during treatment by the addition of chlorine and subsequently lowered by RO. UV treatment is 10 times more costly than disinfection alone.

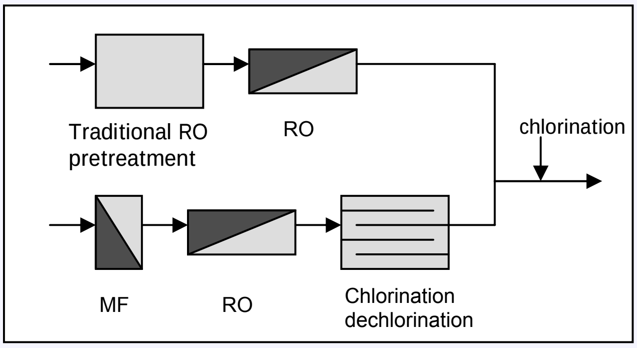

Figure 23: Process flow diagram of West Basin Water Reclamation Project

Table 22: Reverse Osmosis Membrane data West Basin

	RO
type	Unit 1 and 2: Hydranautics ESPA 2 Unit 3:Fluid Systems (Koch) 8822HR
recovery	85%
flux	16 L/m^{2}hr
configuration	Unit 1 and 2: (72:36:18) (6 elements per vessel) Unit 3: (60:36:120) (7 elements per vessel)

0.1.17 Los Angeles County, California: Montebello Forebay Groundwater Recharge Project

The Water Replenishment District (WRD) of Southern California operates the Montebello Forebay Groundwater Recharge Project, one of the oldest natural groundwater recharge sewer water projects in the nation. WRD has managed the project, which has been located in southeastern Los Angeles County since 1962. The San Jose Creek, Pomona, and the Whittier Narrows water reclamation plants provide traditional tertiary effluent, which underwent a change in 2003 (with addition of NDN) to comply with newly implemented nutrient regulations. Whittier Narrows was completed in 1962 as a result of a 1948 wastewater reuse study and is the first plant contributing to the Montebello Forebay basin.

The Montebello Project practices IPR by filtering an average of 1.97 m^3/s of advanced treated wastewater through 252 hectares of the Rio Hondo and the San Gabriel Spreading Grounds into the Los Angeles Central groundwater basin which serves as a drinking water source for 3.7 million people. This recycled water, which meets state and federal primary drinking water standards, makes up about 35 percent of the total recharge to the groundwater basin. Imported water purchased from the Metropolitan Water District of Southern California and storm water runoff make up the remainder of the water used to replenish the basin.

The Rand Corporation has conducted three epidemiological studies on the Montebello project. In two of the studies, health outcomes were examined for about 0.9 million people who receive water naturally filtered by the ground in their drinking water supply and compared to a group of about 0.7 million whose water supplies did not include the ground-filtered water. The conclusion reached by the Rand researchers was that there was no association between project water and any ill health effects, such as cancer, mortality, infectious disease, or adverse birth outcomes.

0.1.17.1 NDMA studies in Montebello Forebay

Typically, NDMA levels at the Montebello Forebay plants are well under 1000 ng/L but since July 2003, the levels have been greater than 1000 ng/L. The high NDMA levels coincide with the conversion to the nitrification/de-nitrification (NDN) treatment process, which was necessary in order to comply with the ammonia Basin Plan objectives. In addition, as a result of continuing work on enhancements for the NDN process, polymer usage has been temporarily increasing NDMA forming potential within the chlorine disinfection process. Measurements are taken to optimize the current polymer dosing system in an effort to lower NDMA effluent concentrations. Although the final effluent levels at the plants are higher than usual, attenuation of NDMA within the Montebello Forebay is expected to occur as a result of photolysis and soil aquifer treatment.

Table 23: NDMA levels for Montabello Forebay WWTPs

	San Jose East		San Jose West		Whittier Narrows		Pomona	
	mg/L	ng/L	mg/L	ng/L	mg/L	ng/L	mg/L	ng/L
10-2003		2550		1290		260		410
11-2003		2400		1700	<5	190		150
12-2003		>1000		83		180		250
01-2004		1300		700		70		610
02-2004	<5	2200	<5	590	<5	170	<5	550
03-2004		>1000		>1000		110		420
04-2004		3300		1600		850	<5	520
05-2004		3000		1200	<5	170		460
06-2004		>1000		3700		100		610
07-2007		>1000		2300		230		610
08-2004	<5	>1000	<5	200	<5	240	<5	760
09-20004		4300		1000		340	<5	580

NDMA has been detected in five of the six monitoring wells in WY 03-04, with six detections above the action level (AL) of 10 ng/L at two monitoring wells. The data suggest that the October 2003 spike was temporary and that water quality levels are continuing to decrease. An investigation is underway to determine the cause of the high NDMA levels at these two wells. Beginning January 15, 2004 and continuing until the conclusion of the investigation, reclaimed water will not be diverted from the San Jose Creek Outfall for spreading to the San Gabriel Spreading Grounds.

Table 24: NDMA levels for Montabello Forebay production and monitoring wells

	10-2003	12-2003	02-2004	04-2004	06-2004	08-2004
Production well nr.						
2947LM	**--**	ND	--	--	3.2	--
Monitoring well nr.						
1582W	ND	ND	ND	ND	2.5	ND
1590AL	ND	ND	ND	ND	ND	ND
1612T	**170**	**25**	**12.7**	ND	ND	ND
1613V	ND	ND	ND	ND	2.3	ND
1620RR	**460**	**41**	**60**	ND	ND	ND

Figure 24: Montebello Forebay spreading basins (Rio Hondo)

0.1.18 San Bernardino County, California: Chino Valley Basin

In an effort to augment local stream and groundwater supplies, the Inland Empire Utilities Agency (IEUA) was formed in 1950 for the purpose of importing supplemental water from the Colorado River and other outside water supplies. Since its formation, the IEUA has expanded its services to include regional sewage treatment and the production of recycled water. Recycled water is treated through sand filtration and is also exposed to chemical and ultraviolet light disinfection.

The Chino Basin covers an area of about 235 square miles of the upper Santa Ana River watershed and is one of the largest groundwater basins in Southern California. The basin contains about 6 km^3 of water, with an additional unused storage capacity estimated to be about 1.2 km^3. The average safe-yield of the basin has been set at 0.17 km^3 per year in the Chino Basin. This basin also functions as a drinking water sourse and recharging this basin with reclaimed water results in IPR. Other reclamation strategies by the IEUA offset an additional 1.3 and 1.8 m^3/s of potable water.

In an effort to meet growing demand, the IEUA has adopted water rates that provide an incentive for use of recycled water. IEUA produces recycled water that is used for groundwater recharge, industrial process water, and irrigation. Presently, about 15 percent of the 2.63 m^3/s of water currently generated by the agency's four wastewater treatment plants is reused locally each day.

0.1.18.1 NDMA studies in Chino Valley basin

The IEUA has a program of continuously evaluating changes to its wastewater treatment process in order to improve process operational efficiency and performance. Through this program, the IEUA has discovered that operating its activated sludge plants at very high mixed liquor suspended solids (MLSSs) concentrations and long solids retention times (SRTs) result in the removal of trace organics. The removals of trace organics have been investigated at the IEUA's RWRP-1, RWRP-2, and the Carbon Canyon facility and have included NDMA, diazinon, chlorpyrifos, and 17 beta-estradiol. The raw wastewater characterizations for NDMA in 2002 are presented in Table 25.

Table 25: NDMA levels for Chino Valley basin WWTPs, 2002

	RWRP-1			**RWRP-1**			**Carbon Canyon**		
10/01-02/02	min	max	avg	min	max	avg	min	max	avg
NDMA (ngL)	17	**180**	60	--	--	--	--	--	--

Table 26 presents the observed treated effluent concentrations for NDMA in 2003. The NDMA effluent concentration data collected by the IEUA is not considered sufficient to determine process removal rates.

Table 26: NDMA levels for Chino Valley basin WWTPs, 2003

	RWRP-1			**RWRP-1**			**Carbon Canyon**		
06/02/05-03	min	max	avg	min	max	avg	min	max	avg
NDMA (ngL)	2	79	12	4	5	4.5	2	10	6

0.1.19 Victorville, California: Victor Valley Water Reclamation Authority

The Victor Valley region is experiencing a surge in residential and business growth. Wastewater facilities had to expand to meet the demand of the growing population. Current projections show a shortfall of water and a need to expand wastewater facilities over the next 20 years. The Victor Valley Wastewater Reclamation Authority (VVWRA) augments local aquifers serving as drinking water resources and marginally supplies recycled water that is sold for irrigation, which off-sets imported potable water use.

The effluent is discharged in the Mojave River and to local recharge basins. The VVWRA practices IPR because both the Mojave River and the basins recharge to local aquifers that serve as drinking water sources downstream. The Mojave River is low sub-surface flow river and recharges completely to the local aquifers 5 to 6 miles downstream from the point of discharge.

The VVWRA has undergone one major change in 1998: the implementation of nitrogen removal through activated sludge in order to comply with current regulations. The plant has undergone several expansions since its initial construction in 1981 from 0.2 m^3/s to 0.50 m^3/s in 2002. An expansion to 0.64 m^3/s is under construction, while an expansion to 0.79 m^3/s is planned to start construction in January 2006.

Table 27: overview of current indirect potable projects in Southern California

Plant name location	**Year**	**Size**	**O&M**	**Technology**	**Type of IPR**	**Objective**	**Outcome**
Water Factory 21 Fountain Valley, CA (Orange County)	1976	1.14 m^3/s IPR	0.41 usd/1000l	Lime clarification Re-carbonation Mixed media filtration GAC + Chlorination or: pH sulfuric acid + RO	Augmenting ground (drinking) water supply by direct ground water injection (to prevent sea water intrusion)	-Prevent sea water intrusion by deep well injection of advanced treated wastewater (while augmenting drinking water supplies)	-Water Factory 21 has demonstrated that highly treated reclaimed water can be used successfully for direct injection projects.
GWR System Fountain Valley, CA (Orange County)	2003-2020	2.63 m^3/s IPR	0.25 usd/1000l (phase I)	Submerged MF RO UV/H2O2	Augmenting ground (drinking) water supply by direct ground water injection (to prevent sea water intrusion)	-Phase II and III are scheduled to produce 3.73 m^3/s in 2010 and 4.38 m^3/s in 2020	TBD
West Basin El Segundo, CA (Los Angeles County)	1995	0.13 m^3/s other 0.33 m^3/s IPR		Lime clarification Re-carbonation MF RO Chlorination	Augmenting ground (drinking) water supply by direct ground water injection (to prevent sea water intrusion)	-Reduce the region's dependence on imported water induced by droughts -Increase portion of reuse for injection to 100% (765 m^3/s)	-1.53 m^3/s for 5 different reuse purposes of which 330 m^3/s for GW injection. -TBD
Montebello Forebay Natural GW Recharge Project Pomona, CA (Los Angeles County) (3 plants)	1962	1.98 m^3/s IPR	0.14 (East) 0.11 (West) 0.18 (Pomona) 0.32 (Whittier) usd/1000l	Primary sedimentation Nitrification-denitrification Secondary sedimentation Chlorination Alum Coag/flocculation Dual media filtration Dechlorination	Augmenting ground (drinking) water supply through a surface water recharge basin	-Replenish the Central Basin by developing a local water supply through reclaimed water	-No degradation of groundwater quality over 42 years while 30% of the recharge has been reclaimed water
Chino Valley Basin. Chino Hills, CA (San Bernardino County, CA) (5 plants)	1950	0.66 m^3/s IPR 2.63 m^3/s total		Primary sedimentation Nitrification-denitrification Secondary sedimentation Single media filtration Chlorination-dechlorination	Augmenting ground (drinking) water supply through a surface water recharge basin	-Meet growing demand and reduce dependency on imported water -Offset and additional 1,300-1.8 m^3/s in 10 years	-25% of the effluent of the 5 plants is reused locally -TBD

	Victor Valley Water Reclamation Authority. Victorville, CA	1981	0.50 m^3/s IPR	0.28 usd/1000l	Primary sedimentation Nitrification-denitrification Secondary sedimentation Alum Coag/flocculation Tertiary moving bed filters Dechlorination	Augmenting ground (drinking) water supply through a surface water recharge basin	-Meet growing demand and reduce dependency on imported water -Sell recycled water for cooling towers	-Expansions are in place and under construction -projects are being developed.

Failed IPR projects in Southern California

The following two projects have exemplified how IPR projects, when compared to other water supply and wastewater management options, can offer the greatest benefits for the least cost. At the same time, these same projects have confirmed how public involvement and education are indispensable components and instrumental in successful project development. For example, the East Valley Water Reclamation Project never completed its construction because of public outrage instigated by political figures and the San Diego Re-purification project had proceeded up to 30% of its design, but has been put off indefinitely because of policy and public perception issues raised by politicians.

0.1.20 Los Angeles County, California: East Valley Water Reclamation Project

In June 1990, the Los Angeles City Council adopted a goal of reusing about 40% of the City's wastewater by 2010. In response to this goal, the City's Department of Water and Power (DWP) began the development of the East Valley Water Reclamation Project (EVWRP). The EVWRP was to have transported 1.4 m^3/s of de-chlorinated conventionally tertiary treated effluent from the Tillman Water Reclamation Plant and convey such through a 20-mile pipeline for groundwater recharge at the Hansen Spreading Grounds in the San Fernando Valley. Future planned industrial and irrigation uses were included. The volume was to be tripled when the project showed favorable monitoring results through its thorough well testing. This project was also part of a long-term effort to replace water supply which was lost as part of the Mono Lake case (also see 0.1.1).

EVWRP took an intensive approach in educating and informing the public. However, making the project details available to its potential users after conception was the initiator to the public's outrage. Significant public opposition arose when local media, which initially supported the project, began using the phrase "Toilet to tap". The project was then used as leverage in mayoral campaigns and the then city attorney, James Hahn, suspended the project claiming that the DWP had been unsuccessful in sufficiently informing the public about its impending project and the possible health risks associated with it. Once Hahn was elected Mayor in 2001, he shut down the EVWRP, and despite a 40 year history of successfully replenishing groundwater with recycled water in the Los Angeles County Montebello Forebay area, the 55 million dollar project was also shut down completely after having produced a mere 80 m^3.

The project was wrongfully associated with environmental justice claiming that the burden of reuse of water fell on the economically depressed San Fernando Valley. The city of Los Angeles currently considers adding groundwater recharge of recycled water as part of the recommended draft alternatives under the Integrated Resources Plan (IRP). The city is required by the Clean Water Act to perform wastewater facility planning once every 10 years, which emphasizes water reclamation. A draft for review will be available in the summer of 2005. Adding groundwater recharge to their options will create the possibility for the EVWRP to be reinstated.

0.1.21 San Diego, California: San Diego Water Re-purification Project

One place where water reclamation could help clear the pressures of growth is the arid San Diego, which imports 90 percent of its water. The City of San Diego had proposed, in conjunction with the San Diego County Water Authority (SDCWA) and the US Bureau of Reclamation, one of the largest potable uses of recycled water in the nation--the San Diego Water Re-purification Project.

This project would achieve IPR of recycled water from the San Diego's North City Water Reclamation Plant (NCWRP) (also see 0). The Advanced Water Treatment Plant (AWTP) would treat conventional treated tertiary effluent from the NCWRP using a treatment process train including MF, RO, Ion exchange, and ozonation. The advanced treated effluent from NCWRP would augment imported supplies in the city's San Vicente reservoir for a retention time of one year. The augmented water from San Vicente Reservoir would then be conveyed to the Alvarado Filtration Plant prior to being discharged to the San Diego's potable water distribution system. It was proposed to reach its customers by the end of 2005.

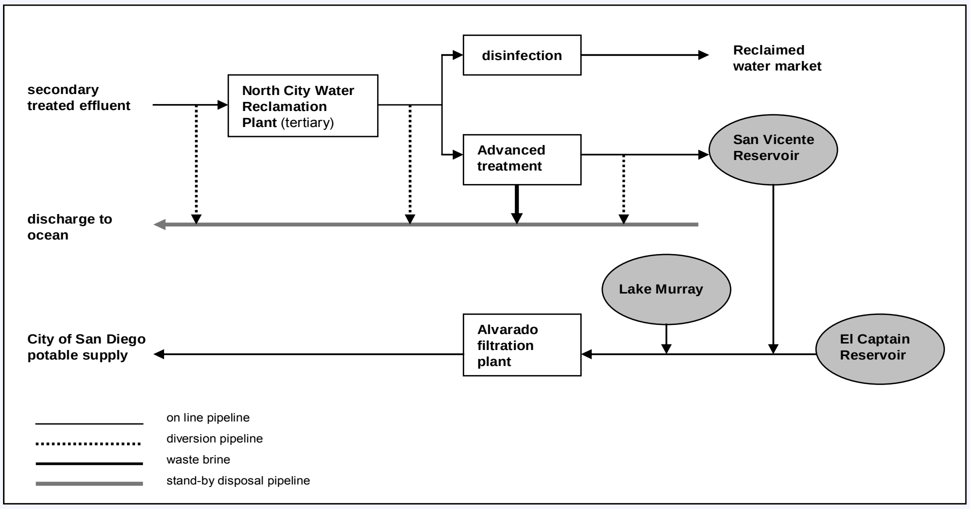

Figure 25: Schematic overview of the SDWRP

The project was introduced to the community as a means of protecting the city from potential future droughts. The San Diego City Council and the San Diego County Water Authority understood the significance of public acceptance and, therefore, created an inclusive research project to better understand the public's compliance with recycled water use and to recognize potential issues that needed to be addressed[38]. The City of San Diego presented their water re-purification project proposal to an independent advisory panel and a public review committee to further assure public acceptance. In both cases, it was concluded that recycled water was a viable option and would supply a much-needed alternative water source to the region. Additional public outreach included brochures, video presentations, feature stories in the news and other media outlets, and a telephone inquiry line.

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[38] Katz & Tennyson, 1997

The project received strong support from the public but became entangled in a political campaign. This campaign claimed that the city intended to treat wastewater from the more affluent communities to distribute as drinking water among those less fortunate. Health dangers from the project were specifically highlighted. The State Department of Health Services subsequently called a hearing for the project to which hundreds of worried residents turned up. The public had been exposed to negatively advertised posters stating the motto “Toilet to Tap” and the project was eventually put on indefinite hold by the city of San Diego.

0.1.21.1 San Diego, California: Advanced Water Treatment Pilot Plant[39]

The City of San Diego is currently pilot-testing two different UF membranes, four different RO membranes and a UV light on tertiary effluent from the NCWRP. This testing will help clarify water quality, membrane integrity and UV dosing issues. The basic treatment train being evaluated consists of tertiary effluent treated by either UF or MF and followed by RO and H2O2/UV. The peroxide and UV light are combined to perform advanced oxidation, which is very similar to what Orange County is practicing. The UV light being tested is a low-pressure, high output lamp.

The pilot work is being performed by MWH Americas, Inc. as three separate research projects for the City of San Diego. Two of the projects are partially funded by the California Department of Water Resources and the San Diego County Water Authority. These three projects are:

- Reverse Osmosis Membrane Integrity
- Long Term Testing of New Generation RO Membranes and Determination of Removal Efficiency for Recycled Water Contaminates[40]”
- Impact of UV on Emerging Contaminates

These projects, which include literature review, bench scale testing, columinated beam testing, analysis, and final reports are scheduled for completion in October 2005. Interim data from these projects were provided as information for the Water Reuse Study Independent Advisory Council in May 2005. Encouraging results are an incentive for the San Diego Water Re-Purification Project to be reinstated.

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[39] By Bill Pierce, City of San Diego Water Research Manager,04-05-2005

[40] NDMA, EDC and pharmaceuticals

Table 28: overview of proposed IPR projects in Southern California

Plant name location	Year	Size	O&M	Technology	Type of indirect potable	Objective	Outcome
East Valley Water Recycling Project Los Angeles, CA	1995	2.0 m^3/s IPR	0.08 usd/1000l	Primary sedimentation Nitrification-denitrification Secondary sedimentation Alum Coag/flocculation Rapid sand filters Dechlorination	Augmenting ground (drinking) water supply through a surface water recharge basin	1.4 m^3/s for ground water recharge by 1999 (including irrigation and industrial use)	Put on indefinite hold due to public opposition
San Diego Water Re-purification Project San Diego, CA	1985	0.94 m^3/s IPR 1.0 m^3/s total	0.47 usd/1000l	Lime clarification Re-carbonation MF RO Chlorination	Drinking water reservoir augmentation	Operate a full-scale plant supply by 2005 and provide a quality of water sufficient to raw water	Water quality surpassed quality of imported water, yet project was put on indefinite hold in 2003 due to political controversies.
Advanced Water Treatment Pilot Plant San Diego, CA	2005	--	--	UF or MF RO UV/H2O2	N/a	Clarify water quality, membrane integrity, and UV dosing issues	TBD

IPR projects in Arizona and Florida

Other areas in the US in which IPR projects are in production and commonly more accepted are either impacted by arid conditions, a rapid growing population, or depleting aquifers due to an increased potable water demand. This is mainly the case in Florida and Arizona.

Florida's flat topography gives little opportunity to hold water as a supply source. While some of the rainfall percolates into the groundwater and enhances the groundwater level, the majority of the rainfall after evaporation results in run off and eventually flows to the ocean. This water supply problem is further compounded by the additional influx of new residents, which has increased 24 percent in the past 10 years[41]. In addition, the new population settles in the coastal regions were groundwater supply is scarce due to salt-water intrusion. Arizona, at the other hand, is arid and has very little natural water resources and demand for water continues to rise. Between 1990 and 2000, it has experienced a 40 percent population growth rate, which is three times the national average. Both states have extensively increased water reclamation. Next are the most prominent projects, which have been surveyed.

0.1.22 Scottsdale, Arizona: City of Scottsdale Water Campus

Scottsdale, located in the desert of Arizona, has no natural surface water resources and relies on their ground water supply as a drinking water resource. Historically, the city has treated and disposed their wastewater. However, it was confronted with several water management problems due to a rapidly increasing population. It was being charged for its wastewater disposal and because its sewerage system needed upgrading. When the city also experienced a decrease in their ground water supply and fell subject to the passing of the Groundwater Management Act (GMA 1980), which mandated water lost by the city to be replaced, it was forced to explore alternative venues. As the GMA gave credits when groundwater was recharged, Scottsdale subsequently developed the Scottsdale Water Campus to treat wastewater to standards required for groundwater recharge.

Since 1998, the Water Campus has produced 0.53 m^3/s of highly treated wastewater through traditional tertiary treatment (see Figure 18) with recently installed disk filters for anthracite filters and chloramines disinfection, which effluent is primarily used for golf course irrigation. When irrigation is reduced in the winter, 0.45 m^3/s undergoes contemporary advanced treatment (see Figure 20) at the Scottsdale Water Campus where MF and RO treat the water to meet or surpass drinking water standards. Pretreatment to the MF consists of 400-micron screens and ammonia is added to tertiary effluent to ensure that the membranes are not exposed to free chlorine. This final effluent is subsurface recharged through 27 vadose zone wells to an aquifer, which serves as a drinking water source. This results in IPR. Imported water (CAP water[42]) is being used for recharge during the summer months and treated by MF only. The Water Campus is currently being expanded to 0.88 m^3/s in order to maintain a balanced water supply for which it is considering using the in situ tested Koch Membrane Systems MegaMagnum® RO Elements (see 0.1.14.3) to save floor space.

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[41] William H. Frey and Dowell Myers' analysis of Census 2000; and the Social Science Data Analysis Network (SSDAN)

[42] Arizona Department of Water Recourses: Central Arizona Project (CAP): The reclamation project and works authorized to bring about 1.5 million acre-feet of Colorado River water per year to Pima, Pinal and Maricopa counties

Table 29: MF and RO configuration Scottsdale Water Campus.

	MF	RO
type	U.S Filter 90M10C	Koch Fluid Systems 8832-HR polyamide
recovery	--	85%
flux	41L/m^{2}hr	18L/m^{2}hr
configuration	24x(6)	14x(24-10-5)

NDMA and perchlorate are contaminants that are a concern in Scottsdale and to prepare for this, the Water Campus is involved in several research projects covering the spectrum of emerging contaminants under scrutiny today. A future proposed solution is the addition of UV disinfection to the advanced treatment. Salinity will become another future regionally binding issue as the increasing population stresses traditional supplies to meet demands resulting in brackish groundwater and reclaimed effluent. Brine disposal issues are already present at the Water Campus and the Central Arizona Salinity Study (CASS) has entered a phase in which it attempts to develop solutions.

0.1.22.1 NMDA at Scottsdale Water Campus

NDMA sampling at the Scottsdale Water Campus started in 2001 and had no showing initially. NMDA showed concentrations of 6 and 30 ppt at wells near the recharge site. NMDA has not shown up since 2004 in the remaining 2 wells. No reason for the coming and going of NDMA has been found yet.

0.1.23 Tucson, Arizona: Roger Road Wastewater Plant & Tucson Water's Filtration Plant

The recycled water treatment process begins at Pima County's Roger Road Wastewater Treatment Plant (WWTP). Part of its effluent is conveyed to the Tucson Water's Filtration plant for advanced treatment. This water passes through pressure dual media (sand and coal) filters, sand filtration and is disinfected with chlorine. It is then stored in a reservoir for soil aquifer treatment (SAT) and is recovered through wells. It is mixed with the Roger Road WWTP's effluent to guarantee that the recycled water meets standards set by the Arizona Department of Environmental Quality before it is delivered for irrigation to its customers. The Roger Road WWTP uses traditional secondary treatment with bio trickling towers as their high rated process to comply with the newly enforced 2004 nutrient restrictions. Its final reclaimed effluent undergoes additional de-chlorination for discharge to the Santa Cruz River to preserve aquatic species. This river recharges an aquifer that is used as a drinking water resource, indirectly resulting in (unplanned) IPR.

In 1991, the city of Tucson established the right to own 90% of the Roger Road WWTP's effluent. At that time, this effluent was already known to be an important commodity. The city's department, Tucson Water, is considering IPR in the next 20 years by treating this effluent with a new full-scale contemporary advanced treatment facility (MF/RO/UV) and groundwater recharge. This is proposed in order to meet their predicted water needs in 2040 as is stated in their Water Plan 2000-2050. Tucson Water has expanded their intensive public outreach program and will involve the general public from scratch in the development of IPR options. Emphasis lays on educating the public to increase the awareness of future water shortages. No pilot testing as of today has been conducted. Future location of the new facility will most likely be near the Roger Road WTF premises.

Figure 26: Trickling Bio towers at Roger Road WWTP (picture by Harm Jansen)

0.1.24 Mesa, Arizona: Northwest Water Reclamation Plant (NWWRP)

The Northwest Water Reclamation Plant uses traditional secondary and tertiary treatment (no disinfection is required) to achieve their final effluent. This effluent is discharged to percolation ponds totaling 102 acres and recharging the local aquifer. When the discharge exceeds the holding capacity of these ponds, the effluent is discharged to the Salt River. In that case, UV disinfection will be used in order to comply with their NDPES permit.

Mesa’s NWWRP currently produces approximately 0.40 m^3/s of reclaimed water. Mesa's NWWRP direct uses for recycled water are supposedly limited to non-potable water purposes, such as irrigation and industrial uses because the Mesa’s public’s acceptance of IPR is known to be extremely low. Although not explicitly acknowledged by the NWWRP, IPR does take place through the means of recovering groundwater from its aquifer for drinking water purposes. Injecting NWWRP’s effluent had previously augmented this aquifer. NWWRP is rewarded with Long Term Storage Credits (GMA) for its aquifer recharge. These credits are recovered when water is extracted from the same aquifer after a retention time of longer than a year. Mesa has approximately 0.03 km^3 of Long Term Storage Credits for its injected recycled water.

Mesa recently signed an agreement with the Gila River Indian Community through which Mesa will ultimately deliver 0.035 km^3 per year of recycled water to the Gila River Indian Community and in exchange will receive 0.028 km^3 per year of CAP water. This agreement allows Mesa to exchange what was essentially a non-potable water supply for a potable supply.

0.1.25 West Palm Beach, FL: Wetlands Demonstration Project

The demonstration advanced wastewater treatment facility called the Wetlands Demonstration Project was constructed and managed at the East Central Regional Wastewater Treatment Plant (ECRWWTP) to demonstrate that wetlands in Southeast Florida can provide additional treatment of a high quality, advanced wastewater treatment effluent and to determine the optimal design for full-scale implementation of a wetlands based water reclamation program for planned IPR. The treatment processes of the AWT Demonstration Plant are designed to remove suspended solids and total phosphorus (TP) using coagulation in a solids contact clarifier, filtration and biological de-nitrification using attached growth in a de-nitrification filter (DNF) and disinfection by free chlorine contact. It was proposed that a combined membrane process train involving MF followed by RO could serve as alternative technology.

It was recommended that a future IPR treatment at the ECRWWTP should utilize a traditional AWT instead of the MF/RO. This was mainly due to the substantially higher capital and O&M costs (224%). These additional costs were not deemed necessary because both processes are expected to meet anticipated regulatory standards especially with the addition of the involved Soil Aquifer Treatment (SAT). MF/RO was achieved lower concentrations for most parameters. UV was favored over chlorination/de-chlorination as a disinfection process. Non-quantitative factors, such as liability and safety concerns involved with chlorine outweighed the slight economical disadvantage of UV.

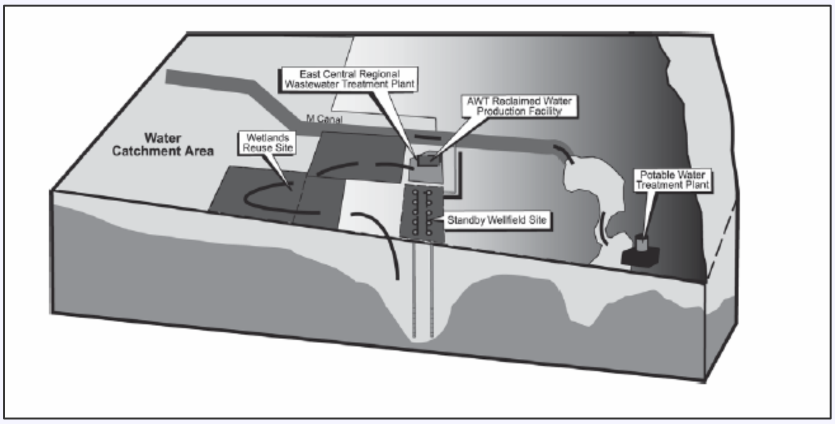

Figure 27: Wetlands Demonstration Project

Side by side operations of the two treatment trains allowed a performance and cost evaluation of the two treatment alternatives. Similarly, ultraviolet light (UV) was proposed as an alternative disinfection method for wastewater. Again, the parallel treatment process operation of UV disinfection with free chlorine disinfection allowed a cost and performance comparison. After travel through the wetlands, the water will be pumped to the City of West Palm Beach's well field where it will be recovered and pumped into the M-canal and eventually flow to the City Water Treatment Plant.

Table 30: overview of IPR projects in the remainder of the United States

Plant name Location	Year	Size	O&M	Technology	Type of indirect potable	Objective	Outcome
City of Scottsdale Water Campus Scottsdale, AZ	1998	0.44 m^3/s IPR 2.7 m^3/s total	0.15 usd/1000l	MF RO Cl	Augmenting ground (drinking) water supply through vadose zone wells	Recharging to supply increasing demand and to comply with GMA	Water Factory 21 has demonstrated that highly treated reclaimed water can be used successfully for direct injection projects
Pima County's Roger Road Wastewater Treatment Facility Tucson, AZ	1983	0.38 m^3/s IPR 1.8 m^3/s total		Clarification Trickling bio filters Pressure filters Chlorination	Augmenting ground (drinking) water supply through vadose zone wells		
Northwest Water Reclamation Plant Mesa, AZ	1990	0.79 m^3/s IPR	0.16 usd/1000l	Secondary treatment with activated sludge Nitrification/de-nitrification Sand filtration Chlorination or UV	Stream augmentation (aquifer recharge), Augmenting ground (drinking) water supply through vadose zone wells	Maintain a 100-year water supply requirement for development	On schedule
East Central Region WWTP, West Palm Beach, FL	2003	0.44 m^3/s 2.4 m^3/s total	0.15 usd/1000l (RO) 0.10 usd/1000l (AWT)	De-nitrification Flocculation Clarifier Bridge sand filter UV	Augmenting ground (drinking) water supply through wetlands supplementation	Restore 1,400 acres of wetlands and recharge the city's adjacent well field	Wetlands habitat stabilized

Failed IPR project in Florida

0.1.26 Tampa Water Resource Recovery Project

Originally introduced in 1982, the concept of discharging highly treated wastewater into the Tampa Bypass Canal, which would eventually enter the potable water source, moved to the research stage. A pilot plant was constructed in 1984 to explore four different supplemental treatment regimes. The City of Tampa, the Florida Department of Environmental Regulation and the West Coast Regional Water Supply Authority, now Tampa Bay Water, conducted the four-year research project as a joint effort, which ran from 1987 through 1989.

The pilot plant facility's three processes that were evaluated included traditional RO pretreatment (lime treatment, re-carbonation, and multi-media filtration). This was followed by either granular activated carbon (GAC), RO, or ultra filtration (Figure 28). All three processes were disinfected with ozone. The influent water for the pilot plant was withdrawn downstream from the Howard F. Cullen Advanced Wastewater Treatment Plant before chlorination. Applying the supplemental treatment to the denitrified, un-chlorinated effluent, rather than to the chlorinated effluent, provided a lower concentration of chlorinated organic compounds in the pilot plant’s influent and limits damage to the RO membranes by chlorine.

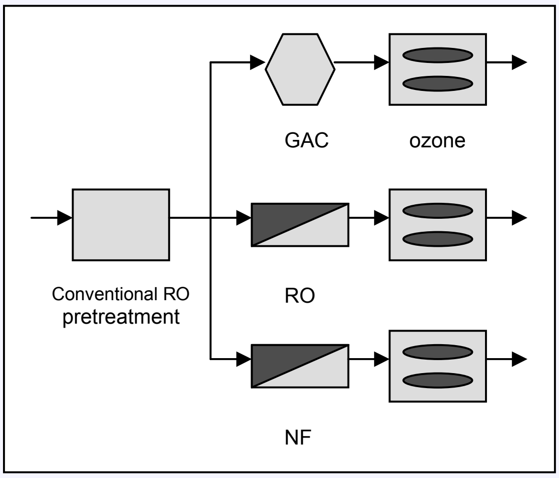

Figure 28: Process flow diagram Tampa Water Resource Recovery Project

Based on this research, the City of Tampa continued through the period of 1992-1998 with engineering feasibility studies of the Tampa Water Resource Recovery Project (TWRRP). This project was expected to contribute approximately 1.5 m^3/s to potable water supplies. Ecosystem Team Permitting then produced a draft permit for the project.

The plan received an official clean bill of health and the required permit, but it encountered public opposition (much of it from Pinellas County) that it could not survive. TWRRP was indefinitely postponed in a landmark decision when the Tampa Bay Water Board of Directors selected a 1.1 m^3/s desalination plant, the largest in the Western Hemisphere, and a reservoir in Hillsborough County as the future water sources to be pursued. The desalination plant has been off line for several months due to the clogging of the membranes by minuscule Asian green muscles. The membrane manufacturer blamed improper pretreatment as the cause.

Table Overview of the Proposed IPR project in the remainder of United States

Plant name location	**Year**	**Size**	**O&M**	**Technology**	**Type of indirect potable**	**Objective**	**Outcome**
Tampa Water Resource Recovery Project Tampa, FL	1987	1.5 m^3/s IPR	GAC/O3: 0.20 usd/1000l (20 mgd) 0.15 usd/1000l (50 mgd)	Pre-aeration Lime clarification Re-carbonation Filtration RO or UF or GAC Ozone	Surface water augmentation	Contribute approximately 1.5 m^3/s to potable water supplies	Project was feasible, but was turned down by public opposition. 1.1 m^3/s Desalination plant was constructed instead.

Established Non Potable Reuse projects in the United States

Several Non-Potable Reuse (NPR) projects have been surveyed to complete the overview of water reclamation in the United States and to put IPR in perspective. Some of these plants are world renowned for their water reclamation, whereas others are considering IPR in the future.

0.1.27 San Diego, California: San Diego’s North City Water Reclamation Plant

The North City Water Reclamation Plant (NCWRP) is the first large-scale water reclamation plant in San Diego's history and part of the single largest sewerage system expansion in the area in more than 35 years. This state-of-the-art facility can treat up to 1.3 m^3/s of wastewater, which is generated by Northern San Diego communities. Wastewater entering the plant undergoes primary and secondary sedimentation, tertiary filtering and chlorination, before it supplements the water supply of the region in the form of irrigation and industrial uses. The City of San Diego is planning to use the tertiary effluent for advanced treatment for IPR (see 0.1.21).

0.1.28 San Jose, California: San Jose / Santa Clara Water Pollution Control Plant

The San Jose/Santa Clara Water Pollution Control Plant is one of the largest advanced wastewater treatment facilities in California. It treats and cleans the wastewater of over 1,5 million people in and around San Jose. The Water Pollution Control Plant has the capacity to treat 7.3 m^3/s of wastewater. It is located at the southern most tip of the San Francisco Bay. Originally constructed in 1956, the Plant has the capacity to treat 1.6 m^3/s and only provided primary treatment. In 1964, the Plant added a secondary treatment process to its system. In 1979, the Plant upgraded its wastewater treatment process to an advanced tertiary system.

0.1.29 Malibu, California: Tapia Water Reclamation Facility

With no local water, Las Virgenes Municipal Water District provides 100% of potable supplies with water purchased from Metropolitan Water District. The Las Virgenes Reservoir is filled with MWD supplies during periods of low demand and holds up to a six-month supply for emergency backup. Las Virgenes has long been active in promoting the use of recycled water to irrigate community and commercial green spaces. Recycled water from the district's Tapia Water Reclamation Facility has reduced demand for imported potable supplies by 20%. Comprehensive and innovative conservation programs have further contributed to reducing water use. Known for its environmental stewardship, the district is realizing its goal of total beneficial reuse of waste products with its composting facility. This facility also transforms bio-solids into rich garden compost and uses methane gas from bio-solids digestion to generate electricity, using fuel cells.

The discharge of the Tapia Water Reclamation Facility in the otherwise dry Malibu Creek has established an ecosystem, which the facility is now mandated to maintain. Stricter regulations regarding nitrogen concentrations have resulted in the recent implementation of a nitrification/de-nitrification treatment component.

0.1.30 St Petersburg, Florida: Water Reclamation System

St. Petersburg's Water Reclamation System is not only the first to be built in the United States, but also remains one of the largest in the world. The city's innovative system provides more than 1.6 m^3/s to 10,483 customers for lawn irrigation. Reclaimed water is also an integral part of the city's overall water conservation effort. The initial reclaimed water distribution system, constructed in 1977, was limited to serving golf courses, parks, schools, and large commercial areas. Extensive biological research through the late 1970s and early 1980s resulted in approval by Florida Department of Environmental Protection (FDEP) and the Environmental Protection Agency (EPA) for the expansion of the reclaimed water system into residential areas. In 1986, a $10 million expansion system was completed to include service to a limited number of residential and commercial sites. Continued expansion of the reclaimed water system has significantly contributed to reducing potable water demands and made St Petersburg the largest community in the United States to achieve a “zero-discharge” of treated wastewater into surface waters.

Excess reclaimed water is deeply injected through 10 injection wells into a saline zone. It was hoped that the injected non-salient reclaimed water would form a bubble due to its buoyancy in the salient aquifer, such that it could be extracted in for (indirect potable) reuse if needed in the future. It was, however, observed that even after several years of injection there was still a mixture of reclaimed and saline water present and no water lens had formed.[43]

0.1.31 APRICOT Project, Florida: Regional Water Reclamation Facility

The Altamonte Springs Regional Water Reclamation Facility (RWRF) is a 0.55 m^3/s tertiary wastewater treatment facility accepting domestic sanitary sewage from the city, as well as neighboring municipal collection systems. Current flow averages 0.26 to 0.28 m^3/s. Primary treatment is accomplished with coarse screening, grit removal, fine screening, and primary clarification. Secondary treatment achieves biological nitrogen removal through the use of anoxic and aerated zones. Secondary clarification is followed by alum addition, flocculation, and denitrifying deep bed filters. The effluent is then re-aerated, disinfected, and passed on to a low-head transfer pump facility.

APRICOT (A Prototype Realistic Innovative Community Of Today) is the name given to the city of Altamonte Springs' public-access reuse system. Collectively, it refers to the city's tertiary wastewater treatment plant. On average, APRICOT delivers annually about 94 percent of its treated domestic wastewater for residential and commercial irrigation, cooling tower make-up, other commercial applications, and aesthetic uses. On a daily basis, between 0 percent and 175 percent of the domestic sanitary sewage flow is reused.

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[43] Water Conservation, Reuse, and Recycling: Proceedings of an Iranian-American Workshop (2005)

0.1.32 Orange County, Florida: Eastern Water Reclamation Facility

Orange County Utilities (OCU), FL operates three major water reclamation facilities: the Eastern Water Reclamation Facility (EWRF), Northwest Water Reclamation Facility (NWRF), and South Water Reclamation Facility (SWRF). These facilities serve the wastewater treatment needs of approximately 250,000 people within service areas totaling about 727 square miles. OCU's water reclamation facilities treat and reuse approximately 1.8 m^3/s wastewater. The total bio-solids production at OCU's water reclamation facilities is approximately 30 dry tons per day (200 wet tons per day).

The South Water Reclamation Facility (SWRF), with a design capacity of 1.35 m^3/s, is the largest of three water reclamation facilities owned and operated by Orange County Utilities (OCU). The SWRF provides wastewater treatment for a service area that encompasses most of Orange County south of the city of Orlando. Effluent from the SWRF is reused in several ways, including groundwater recharge (ground water basin is not used as a drinking water source: IPR is not practiced) by rapid infiltration basins, citrus irrigation, and urban reuse. Because of these effluent reuses, the facility is required to meet Florida standards for both unrestricted reuse and groundwater recharge—5 mg/L total suspended solids (TSS), 10 mg/L nitrate nitrogen, and high level disinfection. The plant is also required to remove viruses and to limit the effluent concentration of numerous constituents to satisfy quality requirements stipulated in contracts with citrus growers.

Table 31: Overview of established non potable reuse projects in the United States

Plant name location	Year	Size	O&M	Technology	Type of non potable	Objective	Outcome
San Diego's North City Water Reclamation Plant San Diego, California	1997	1.3 m^3/s	--	Primary sedimentation NDN aeration Secondary sedimentation Tertiary filters Chlorination	Commercial irrigation and industrial	Supplement water supply	--
San Jose, California: San Jose/Santa Clara Water Pollution Control Plant	1956 1979 (tertiary upgrade)	7.3 m^3/s	--	Primary sedimentation NDN aeration Secondary sedimentation Tertiary filters Chlorination	Supplement to San Francisco Bay	Water pollution control in the San Francisco Bay	Below required limits
Tapia Water Reclamation Facility Malibu, California	1972	0.42 m^3/s	0.64 usd/1000l	Primary sedimentation NDN activated sludge Secondary sedimentation Tertiary filters Chlorination	Irrigation and stream flow maintenance	-Treat local wastewater to high quality recycled water -Beneficial use, limited water resources, and reduce local dependence on imported water	--
Water Reclamation System St. Petersburg, Florida (4 plants)	1977	1.8 m^3/s	0.23 usd/1000l	Preliminary Primary sedimentation NDN activated sludge Secondary sedimentation Coagulation/flocculation Tertiary filters Chlorination	Deep injection Residential and agricultural irrigation Toilet flushing	Supplement water supply to account for increase usage.	Stabilized potable water use despite increase in total usage
Regional Water Reclamation Facility Apricot Project, Altamonte Springs, Florida	?	0.44 m^3/s	--	Preliminary Primary sedimentation NDN aeration Secondary sedimentation Coagulation/flocculation Tertiary filters Chlorination	Residential and commercial irrigation	Supplement water supply to account for increase usage	--

	Eastern Water Reclamation Facility Orange County, Florida (SE and SW)	1986	1.35 m^3/s (0.41 m^3/s + 0.94 m^3/s)		Primary sedimentation NDN aeration Secondary sedimentation Tertiary filters Chlorination	Groundwater recharge (non potable) Urban and commercial irrigation	Supplement water supply to account for increase usage	Stabilized potable water use despite increase in total usage.

Established non-surveyed IPR and DPR Projects

United States

The following projects have not been surveyed yet to practice IPR. These projects are either a milestone in IPR or are established in practicing IPR, however, they are not located in the California, Arizona, or Florida where IPR is predominantly practiced. A brief overview of each plant follows, while their characteristics are listed in the table at the end of this section.

0.1.33 Chanute, Kansas

In the summer of 1956 the Neosho River ceased to flow, which threatened Chanute's drinking water supply. The city considered several alternative sources and decided to re-circulate treated sewage, and on October 14, 1956 through March 1957, without public announcement, the city opened the valve permitting the mixing of treated sewage with water stored in the river channel behind the water works dam. Further precautions were required, including the chlorination of the sewage treatment plant effluent, re-chlorination of raw water, installation of a continuous chlorine residual recorder at the softening plant, and more frequent sampling. The treated water had a pale yellow color and an unpleasant musty taste and odor. Initial public acceptance was good but gradually changed when stories appeared in the local paper. There were no known cases of adverse health effects

0.1.34 El Paso, Texas: Hueco Bolson Recharge Project

In order to decrease the rate at which the drinking water resources of the Hueco Bolson aquifer were being depleted, the El Paso water utilities had considered to artificially recharge the aquifer with tertiary treated wastewater effluent from the Fred Harvey Water Reclamation Plant. The Hueco Bolson aquifer provides 65 percent of the municipal water supply of El Paso and, injected into the aquifer, has been in effect since 1985. The recycled water meets drinking water standards before it is injected. Its residence time in the aquifer is estimated between 5 and 15 years.

With a capacity of 0.53 m^3/s, the facility provides primary sedimentation, biological secondary, lime treatment, filtration, and ozonation. The effluent is finally passed through granular activated carbon filters to provide polishing before storage and injection. The cost of the injected water was estimated at 782 USD per km^3. in 1992.

Before the recharge project, water table levels were dropping at a rate of 0.5 to 2 meters per year because groundwater was being pumped at a rate 20 times faster than the aquifer's natural recharge rate. By 1990, the water level in the aquifer had risen 2.5 to 3 meters, which is higher than they would have been without the aquifer recharge project. Irrigation and industrial customers were subsequently added to the project.

0.1.35 Denver Potable Water Reuse Project

Denver began investigating the concept of IPR in 1968 and initiated a pilot plant (1970-1979), which was the precursor for The Denver Potable Water Demonstration Project This project evaluated the feasibility of Direct Potable Reuse (DPR) of secondary-treated municipal wastewater in 1985 with a multi barrier demonstration plant. It capitalized on a pilot plant from 1970-1979. Its influent was the Denver Metropolitan Wastewater Reclamation District's regional wastewater treatment facility's effluent, which was not nitrified.

The processes included high-pH lime treatment, sedimentation, re-carbonation, filtration, UV, carbon adsorption, reverse osmosis, air stripping, ozonation, chloramination, and ultra filtration. Various configurations of the multiple-barrier redundancy approach were used to produce a highly reliable effluent, which met or exceeded Denver's drinking water standards for almost every contaminant. A health effects study was conducted and concluded that no adverse health effects were detected from lifetime exposure to any of the samples.

0.1.36 Fairfax, Virginia: Upper Occoquan Sewage Authority (UOSA) Reclamation Plant

The UOSA plant discharges its effluent to its own reservoir. From there, the water flows to a tributary channel of the Occoquan Reservoir, a principal water supply source for approximately one million people in Northern Virginia, located about 20 river miles upstream of the water treatment plant intake.

The UOSA Plant was originally created in 1978 to eliminate pollution of the Occoquan Reservoir by 11 small sewage plants. However, because of the highly reliable technology and the high quality produced water, regulatory authorities endorsed UOSA's request for expansion, in order to increase the yield of the reservoir. During normal precipitation, the UOSA effluent consists out of five percent of the total inflow to the reservoir, with significantly higher percentages during times of drought.

The Water Reclamation Plant consists of traditional primary and secondary treatment, high pH chemical treatment, two-stage re-carbonation with intermediate settling, multimedia filtration, carbon absorption, ion exchange, and breakpoint chlorination. The initial capacity of 0.45 m^3/s has been increased to 1.4 m^3/s, making the 11 sewer plants obsolete. A $200 million expansion to 2.4 m^3/s is currently underway. In addition, the UOSA recycled water is now an essential part of the water supply strategies for the Washington metropolitan area.

0.1.37 More IPR projects operating successfully throughout the United States

The Clayton County Water Authority operates a land application system that has served the southern metropolitan Atlanta area for more than 20 years. Approximately 0.66 m^3/s is treated by this system and is discharged into nearby forestlands. The water percolates through the soils and flows into a creek that feeds a water supply reservoir for the area.

Since 1987 in suburban Dallas, the North Texas Municipal Water District operates an advanced wastewater treatment plant that has produced up to 1.1 m^3/s of water treated for return to the local watershed. The highly treated water flows into a lake which is a source of drinking water to the district's entire service area.

Table 32: Overview of other non surveyed IPR projects

Plant name location	Year	Size	Cost	Technology	Type of IPR/DPR	Objective	Outcome
Chanute, Texas	1956	--	--	Extra chlorination	DPR	Supply local water supply	No adverse health effects
Hueco Bolson Recharge Project El Paso, Texas	1985	0.53 m^3/s	--	Sedimentation primary Biological secondary Lime clarification Filtration Ozonation GAC Chlorination	Augmenting ground (drinking) water supply by direct ground water injection	Protect Hueco Bolson aquifer by producing water that meets the U.S. EPA's drinking water standards	The FHWRP is effective in removing the priority pollutants entering the plant
Denver Potable Water Reuse Project Denver, CO	1985	--	--	Lime treatment, sedimentation, re-carbonation, filtration, UV irradiation, carbon adsorption, reverse osmosis, air stripping, ozonation,	DPR	Evaluate the feasibility of direct potable reuse of secondary treated municipal wastewater	Study has demonstrated that the multiple-barrier process can remove contaminants to non-detectable levels
Upper Occoquan Sewage Authority (UOSA), Millard H. Robbins, Jr. Water Reclamation Plant Fairfax, Virginia	1978	1.5 m^3/s	--	Primary-secondary treatment, high pH chemical treatment, two-stage re-carbonation multimedia filtration, carbon absorption, ion exchange, and breakpoint chlorination.	Surface water augmentation	-Eliminate pollution of the Occoquan Reservoir -Expansion to 2.4 m^3/s	Eliminated 11 small WWTPs and increased the yield of the Occoquan reservoir

Established IPR and DPR project outside the US

The following projects are two well established IPR plants outside the United States. They have been briefly reviewed to diversify and complete the picture of IPR for this thesis.

0.1.38 Singapore: NEWater Project

The newest indirect potable water purification project in the world is in the city-state of Singapore. The "NEWater" project produced sewer water purified to drinking water standards on a test basis for two years. Before it was fully operational in early 2003, the Prime Minister led the way by drinking the NEWater to show his citizens the high quality and safety of the new purified water. The project uses water purification processes similar to Orange County's Groundwater Replenishment System design. The NEWater project provides a safe, reliable source of high quality water for Singapore's 4.3 million residents and greatly diminishes the country's dependence on water imported across the channel from Malaysia.

The three-step purification process (micro filtration, RO, and UV disinfection) used to produce NEWater results in water is better than the World Health Organization's drinking water standards. NEWater also meets or is better than the standards set by the United States Environmental Protection Agency, which are considered an international benchmark for water quality.

With the purity and safety of NEWater endorsed by an international panel of world-renowned water quality experts, the long-term plan is to add NEWater to Singapore's reservoirs before piping it to residential homes and commercial industrial customers.

0.1.39 Namibia: Windhoek

In an effort to supplement the potable water supply, a system for reclaiming potable water from domestic sewage was pioneered in Windhoek, Namibia in 1968. Surface water sources and ground water extraction had been fully appropriated and direct reuse of reclaimed water was instituted just in time to avert a water crisis caused by drought The system has been producing acceptable potable water to the city ever since as part of a larger program to conserve water and manage water demand[44]. The reclamation plant has been operating on an intermittent basis to supplement the main supplies during times of peak summer demand or during emergencies. The facility is known to not intake any domestic, infectious hospital, abattoir and/or industrial wastewater.

This system has gone through some successful improvements over the years, accompanied by comprehensive chemical, bacteriological, virological, and epidemiological monitoring. The current sequence of treatment processes involves primary and secondary treatment at the Gammans wastewater treatment plant (primary settling activated sludge, secondary settling, and maturation ponds). The secondary effluent is then directed to the Goreangab water reclamation plant, where treatment includes alum addition,

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[44] Harhoff and van der Merwe, 1996

dissolved air flotation, chlorination, and lime addition. This is followed by settling, sand filtration chlorination, carbon filtration, and final chlorination. The final effluent is then blended with treated water from other sources before distribution.

Initially, the secondary effluent intake from the Gammans WWTP by the Goreangab Water Reclamation Plant was gradually raised from 3 to 18% of the total potable water distributed to the city. Water quality from the Goreangab dam has been deteriorating over the years because of heavy pollution due to run off and unauthorized settlements around the dam. Upon the completion for the new multi barrier system, raw water intake from the Gammans WWTP was 50%. Currently, that portion is 100% because the quality and quantity of the Goreangab dam has deteriorated beyond a point where it cannot be used anymore. Windhoek exports an excellent rated Namibian beer that is made using this same reclaimed water.

Results and discussions

Introduction

The results and discussions of this thesis will be discussed in this chapter and begin in the first section with a general overview of the trends in water reclamation and IPR. The more detailed legislative, public and technological response to the developments in IPR is discussed in the following three separate sections. In the final section, the inventoried plants will be quantitatively compared in two IPR categories.

Trends in water reclamation and IPR

Water reclamation in the form of IPR has come a long way in the United States with its first attempt back in 1954 in Chanute, Kansas. IPR has since then often been implemented unplanned yet successfully such as health studies have shown for the Chino Valley Basin (1950) and Montebello Forebay (1962). These studies showed no adverse health effects of using filtered and disinfected secondary effluent for surface water recharge. Some of the planned versions of IPR in the late 80's and early 90's such as the East Valley Water Recycling Project (EVWRP, 1995), the San Diego Water Re-purification Project (SDWRP, 1985) and the Tampa Water Recourse Recovery Project (1987) encountered public resistance which eventually caused the project to fail. In some parts the public resistance was genuine and based upon health fears, and in other parts it appears that political candidates opposed the proposed projects during election campaigns, which elevated public concerns. An incorrect approach to educating the public, such as involvement only after project conception, was partly to blame as well. These projects failed to materialize although they were in most cases identical to existing, successful IPR projects, which demonstrate an inconsistency in decision making.

More recently implemented IPR projects such as the GWR System (2003), West Basin (1995), and The Scottsdale Water Campus (1998) seem to have found the appropriate formula for successful projects. Early and intensive outreach to the general public combined with highly advanced, proven technology insured the success of the project. These projects also relied upon favorable results from previous pilot projects in other locations, such as the Denver Potable Water Reuse Demonstration and the Lake Arrowhead Reclamation Pilot Study.

Legislative response

The decentralized governing system in the United States has its advantages and disadvantages. Disadvantages have displayed themselves in the early years of this century. Individual water rights and the doctrine of “first in time, first in right,” in combination with the limited Federal influence have created a climate of complex or uncertain regulations governing new projects. Nearly every newly proposed water project encounters resistance from the public or environmental groups with issues such as dubious ownership of the water rights and environmental impacts. In some cases it is not clear who owns the wastewater and has the right to reuse it. The Colorado River compact is the largest example of ambiguous ownership.

The current Federal system requires public involvement which is appreciated but can result in delays of unimplemented water reclamation projects. Public involvement may increase the awareness for the need of IPR projects and therefore may increase the chances for successful implementation. California has predominantly set the standards for the rest of the United States for water reclamation regulations and indirectly for IPR. Many other States practicing water reclamation and IPR duplicate regulations set by California. This very aggressive and enterprising approach has made California the front runner (Porter Cologne, Title 22, CASDWA).

Public education has played a key role in the successful IPR projects. The dynamics of a passive and uninformed public and its subsequent overreaction upon becoming aware of the facts have usually halted IPR projects. The Chanute, Kansas project was shut down immediately when the public discovered that their drinking water was recycled. The EVWRP and the SDWRP were IPR projects accepted by the public until political candidates wrongly labeled projects as toilet-to-tap or as social injustice. Such overreactions have strengthened regulations for future projects and in some cases they have be become too stringent as revised contaminant action levels (NDMA, 1999) confirm. The following are examples of regulations that are too stringent:

- The United Stated has some of the most stringent regulations in the world, so stringent that the WHO blames the United States for not setting a more realistic example for countries that are struggling to meet the WHO regulations.

- The 2003 TMDLs’ implementation was halted because it had been successfully challenged on a dozen occasions in court. The number of TMDLs had increased from 500 in 1999 to 3000 in 2002.

- The federal legislative branch is working towards a more integrated approach to the SDWA and CWA. The newly implemented Information Collection Rule (ICR) is a beginning in doing so.

- The 1986 amendments to the Safe Drinking Water Act (SDWA) mandated states to comply with regulations for 25 new contaminants every year for the next 5 years, brings the number from 75 contaminants to 200. A 1996 amendment had a more realistic approach by adding only 3 contaminants each year.

- The California Toxic Rule (CTR) was successfully challenged in court establishing its unstable foundation for its proposed new implementations. It would, for example, force the Tillman plant (see: 0.1.20) to install expensive membrane technology in order to comply with the newly proposed changes in the CTR.

Public response

Americans and Californians in particular are said to be very accepting of reclaimed water, yet several IPR have failed in the past. The public often understands the logic of using reclaimed water but refrains from using the water themselves. Even though water treatment technology in the US is highly advanced, public acceptance of water reuse has lagged. The influence of conflicting regulations and the limited ability of the governing agencies to cooperatively and successfully implement IPR is a major barrier to its development. In spite of these difficulties there is an overall growing awareness of the need of reclaimed water.

Studies conducted between 1972 and 2002 show that public's increasing awareness and knowledge of IPR is improving their ability to make more critical and informed decisions. The opposition to drinking recycled water has increased from 56% to 74% during this period. It must be noted that the respondents from earlier studies were less informed and educated on the subject of water reuse in general and IPR in particular.

The traditional approach of implementing water reclamation projects through the "decide-announce-defend" policy has clearly proven itself to be ineffective. Strategies in which public outreach and education happen after conception are also failing (EVWRP 1995, SDWRP, 1985) although alternative government systems might succeed (NEWater, Singapore 2003). Newly proposed strategies are to engage stakeholders before project conception and to effectively communicate risks to the stakeholders. This has proven to be the successful approach (GWR System 2003).

The public that perceives a higher social pressure to recycle and has a higher level of awareness for the environment, and subsequently for the conservation of natural resources, is more likely to accept recycled water. Implementation of water reclamation projects encountered more difficulty in societies that do not adopt collective approaches to decision making and problem solving.

Technological response

The technical response to IPR has undergone major developments in recent years. When IPR started in the US in 1954 with Chanute, Kansas project, only chlorination was used as an additional process and there were no known adverse health effects. IPR facilities performing groundwater recharge through recharge basins in the 1950s later added tertiary filtration with chlorination to their secondary treatment processes. De-chlorination was added in the 70's when the need to protect aquatic species was realized. Macro nutrients (N and P) were next targeted for removal and many facilities converted their aeration tanks to NDN tanks by adding fine air bubble diffusers and anoxic or anaerobic zones . More stringent requirements surfaced in the late 80's when IPR facilities started to directly inject advanced treated wastewater into groundwaters which served as drinking water resources. This caused these facilities to use advanced treatment technologies such as lime clarification, ammonia stripping, activated carbon and granular media filtration. The rapid development in membrane technology has resulted in high rejection, lower pressure RO membranes of which its effluent complied with the stringent regulations for IPR. The success of RO eventually allowed lime clarification, ammonia stripping, and carbon adsorption to be phased out. The latest membrane technology for RO pretreatment is submerged MF. Submerged MF drastically shrinks the footprint of the plant as this is physically integrated with the activated sludge process. MF processes are now displacing granular media filters.

The most common form of disinfection, chlorination has virtually disappeared in water reclamation. Problems with chlorination disinfection byproducts have been known for more than 30 years. Chlorine gas is hazardous to handle and agencies responsible for managing hazardous waste are discouraging its transport. UV light is the most popular form of disinfection in today's water reclamation plant. It also avoids production of a popular emerging pollutant NDMA. UV light has also gained ground because advanced membrane technology provides a better effluent which practically eliminates the shading of potential suspended solids. Ozonation, which was popular for about a decade, is no longer being selected for economical reasons.

Newly emerging pollutants in wastewater are of growing concern. Although not routinely detected for by advanced wastewater treatment facilities, newly emerging pollutants have raised concern for their unknown health effects, fate and transport. They include heavy metals, endocrine disrupters, pharmaceuticals, hormones, antibiotics, anti-inflammatories and personal care products. Advanced oxidation techniques, of which hydrogen peroxide is the most widely encountered form, target these new pollutants. Current detection methods are a limiting factor in identifying these pollutants. A more detailed look will be taken at the evolution in treatment configuration and RO in the next few paragraphs.

Evolution in configurations

A few standard configurations were consistently encountered in the inventoried facilities (see Chapter 0) Facilities performing groundwater recharge through the means of recharge basins often consisted of the following, which has been referred to in this theses as traditional tertiary treatment (see: Figure 18):

- Preliminary treatment
- Primary sedimentation
- High rated processes
- Secondary sedimentation
- Coagulation and flocculation
- Multi media tertiary filtration
- Chlorination (and de-chlorination)

Advanced facilities using secondary or tertiary effluent as their influent and performed groundwater recharge through direct injection had their tertiary and/or advanced treatment configured in which reverse osmosis was placed central. Two standard configurations were consistently encountered of which one has been referred to as traditional RO pretreatment earlier in this thesis (see: Figure 19) and consisted of the following:

- Lime clarification
- (optional) Re-carbonation
- Multi media filtration

The second standard configuration that has been encountered consistently in facilities that used tertiary or secondary influent as their influent has been referred to in this thesis as contemporary advanced treatment (also see: Figure 20) and was configured as follows:

- (submerged) Micro filtration
- Reverse osmosis
- Ultra violet

A few alternatives to and combinations of these treatment configurations have been encountered and have been illustrated separately for each relevant facility in Chapter 0.

Evolution in RO

Membrane technology has changed over the years to become proprietary science. It is for that reason that the more interesting details were not available. It has become clear thought that RO membranes have changed their material from cellulose acetate to composite polyamides over the past few years increasing flux and decreasing fouling. The number of units per pressure vessels tends to increase from 6 at older facilities to 7 units at newer facilities. Increasing the overall size of the membrane (the MegaMagnum: see 0.1.14.3) in order to limit floor space is currently under development. Neutrally charged membranes seem to be a new development, although some manufacturers claim that membranes always have been neutrally charged. Manufacturers also expressed that the development of RO membranes will reach a ceiling in the near future.

Up and coming: Submerged Micro Filtration

According to the visited membrane manufacturers, Submerged Micro Filtration (SMF) is the next hot item in membrane manufacturing. SMF (also see 0.1.11) will drastically limit floor space because it incorporates two treatment units (activated sludge and Micro Filtration) into one. Very little information was available on SMF because it is new and its information is proprietary. SMF for water reclamation has thus far, only been put to practice in the GWR System.

Plants and how well they performed

It has been clearly established that IPR through groundwater recharge can be achieved in two different ways. The first and most established form is through recharge basins. The contemporary form is injection into groundwaters, which requires less land and can be performed in developed areas. Both forms of groundwater recharge have undergone significant changes. Whereas the recharge basins have undergone a slow process of changes, direct injection has experienced a rapid development in new techniques. Plants that fall in either category have been reviewed and evaluated on the following parameters, in order of importance, to determine their probability in succeeding:

- Relative cost of the effluent (in relation to location and viable alternatives)

- Involvement of the public (before, during and after conception)
- Outcome of proposed goals
- Degree of updated technology
- Degree of establishment (in relation to years in production and recognition for its reliable production)
- Size of IPR component

Table 33 is an evaluation of the various IPR projects using fuzzy categories for relative successes and failures. Each of the above categories is listed in order of importance and is weighed in conformance with its rank from 6 to 1. Plants score 0 to 5 on these weighted factors for the worst and best representative. These scores are multiplied with the weight and added up to achieve a total score. The total possible score was 105. The GWR System (99) has most successfully developed these parameters and therefore sets the bar. Other facilities have often not developed these three parameters equally and score lower.

Table 33: Inventoried plants performing IPR through direct injection and surface water augmentation

Criteria	**Size of IPR component**	**Degree of establish-ment**	**Degree of updated technology**	**Outcome of proposed goals**	**Public involve-ment**	**Relative cost of the effluent**	**Total Score**
Weight factor	**1**	**2**	**3**	**4**	**5**	**6**	
Water Factory 21	3	5	4	5	4	4	**89**
GWR System	5	5	5	5	5	4	**99**
West Basin	1	4	4	5	4	4	**85**
Scottsdale Water Campus	1	4	5	5	3	4	**83**
San Diego Water Re-Purification Project (SDWRP)*	3	0	3	1	2	4	**50**
Tampa Water Recourse Recovery Project (TWRRP)*	4	0	3	1	2	4	**51**

(*) surface water augmentation

The GWR System, which is the follow-up on the Water Factory 21, leads in most aspects of the United States' plants performing direct injection. Its history, technology, size, and public involvement are cutting edge. Several expansions are planned in the next 20 years (see 0.1.15), including surface water recharge. It will be the first plant to perform surface water recharge while using RO as part of their treatment process. The SDWRP and the TWRRP have both failed in their attempts to augment surface water, which indirectly served as the supply for drinking water. Public involvement, or the lack thereof, and politics played a deciding role in the failure of these projects.

Table 34: Inventoried Plants Performing IPR Through Recharge Basins

	Size of IPR component	Degree of establish-ment	Degree of latest technology	Outcome of proposed goals	Public involve-ment	Relative cost of the effluent	Total Score
	1	**2**	**3**	**4**	**5**	**6**	
Montabello Forebay	4	4	2	3	4	5	**80**
Chino Valley Basin	3	5	2	3	4	5	**81**
Victor Valley Water Reclamation Authority	3	4	2	4	3	4	**72**
Tucson Roger Road Wastewater	3	3	2	3	3	4	**66**
Mesa Northwest Water Reclamation Plant	3	3	3	3	3	4	**69**
East Central Region WWTP	3	2	3	3	3	4	**67**
East Valley Water Reclamation Project (EVWRP)	4	1	2	1	2	5	**56**

Chino Valley Basin is leading the plants when surface water recharge is performed with a slight edge over the Montabello Forebay mainly because of its establishment since the 1950's. The West Palm Beach Wetlands Demonstration Project has been included in this model in order to indicate that the cost for RO treatment for surface water recharge is difficult to justify. The EVWRP fell subject to the Los Angeles mayoral race and thus, politics were the deciding factor in the failing of this project. The EVWRP also fell short in the area of public involvement because of outreach after the project's conception. This project is currently under review by the City of Los Angeles for reinstatement. It is a near copy of existing projects, such as the Montabello Forebay and Chino Valley Basin, which creates hope for the future operation.

Conclusion

The fight for new water supplies in the United States is over. All water supplies have been allocated. The competition for reclaimed water is next. The technology for water recycling is well developed and this study shows that it was rarely a deciding factor in the success of IPR projects. IPR is becoming a greater integral section of water reclamation and therefore several of the older, failed projects are currently reevaluated. The most successful projects involved the general public before conception and maintained communications before, during, and after construction. The Ground Water Recharge System is the best example thereof. A common occurrence is for agencies to assume that the public is apathetic when they demonstrate little interest. This was the case in several projects with the San Diego Water Re-purification Project and the East Valley Water Reclamation Project. The survey showed that such cases led to project failure due to the public losing its apathy and opposing the project because they felt uninformed. Further study is needed to acquire definitive epidemiological and toxicological data regarding health risks associated with IPR are critical in order to assure the public of the IPR projects' validity and thus to increase the probability for success of future projects.

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Appendix

This appendix shows the water quality data that were collected during the survey. For each plant, the same set of constituents was provided and the full suite is shown for the first listed plant--Water Factory 21 in Table 35 and Table 36. There was no one facility that was able to provide all the data and some of the facilities were only able to provide a few of the constituents. In order to save space, the constituents that were not provided for each the plant are omitted from the list. In other cases, a less than (<) sign appears, which defines the measured values as below the plant's method detection limit.

IPR facilities in Southern California

Table 35: Water Factory (WF) 21, Fountain Valley, CA*

	Units	Influent	Effluent	Regulation: MCL
Conventional:				
Dissolved Oxygen	mg/L			
pH	mg/L	7.3	6.7	6.5-8.5
Chlorine	mg/L	237	18	250
Phenols	mg/L			
MBAS	mg/L			0.5
Cyanide	mg/L	14.7	8.1	0.15
TOC	mg/L	39	0.7	
BOD	mg/L			
COD	mg/L	10.2	3.0	
Temperature	C			
Turbidity 105	NTU	203	0.05	5
TSS	mg/L			
SS				
Oil and Grease	mg/L			
TOX	mg/L			
Nutrients:				
Nitrate (N03-N)	mg/L			
Nitrite (N02-N)	mg/L			
Kjeldahl Nitrogen	mg/L			
Ammonia (as N)	mg/L			
Organic-N (TKN)	mg/L			
Ortho-P	mg/L			
Total-P	mg/L			
Total N	mg/L	18.3	2.6	
Bacteriological:				
Total Coliform	mpn/100mL	1.5	<10E-6	<1
Fecal	mpn/100mL			
Streptococcus	mpn/100mL			
Enteroccocus	mpn/100mL			
Salts:				
Hardness mg/L (as CaCO3)	mg/L			180
Alkalinity mg/L (as CaCO3)	mg/L			
TDS	mg/L	936	60	500
Conductivity	umhos/cm	1,712	182	
Sulfate	mg/L	218	14	
Chloride	mg/L	237	18	
Fluoride	mg/L	1.0	0.2	2
Boron	mg/L			
Calcium	mg/L			
Magnesium	mg/L			
Sodium	mg/L			
Silica	mg/L			
Potassium	mg/L			
Metals:				

Aluminum	µg/L			200
Antimony	µg/L			6
Arsenic	µg/L			50
Barium	µg/L	51.2	1.2	1,000
Beryllium	µg/L			4
Cadmium	µg/L	3.0	ND-<1.0	5
Total Chromium	µg/L	1.6	ND-<1.0	50
Copper	µg/L	13.6	4.8	1,000
Iron	µg/L			
Lead	µg/L	1.2	0.2	15
Mercury	µg/L	<0.5	<0.5	2.0
Nickel	µg/L			100
Selenium	µg/L	4.8	<5.0	50
Silver	µg/L	0.6	1.0	100
Zinc	µg/L			5,000
Thallium	µg/L			2
Manganese	µg/L	43.9	2.0	50
Disinfection Byproducts				
NDMA	ppt	33.2	7.8	
Bromate	ppb			10
TTHM	ppb		12	80
HAA5	ppb			60
Trace Organic Compounds				
Endocrine Disruptors	ppb			
Pharmaceuticals	ppb			
Hormones	pbp			
Antibiotics	ppp			
Anti-inflammatories	ppb			
Personal Care Products	ppb			

(*)injection at Talbert Gap, March 2003

Table 36: Ground Water Replenishment (GWR) System, Fountain Valley, CA*

	Units	Influent	RO Influent	RO Effluent	% Removal	Regulation
Conventional:						
Chlorine	mg/L		1.9			250
MBAS	mg/L		0.23	0.03	87	0.5
Cyanide	mg/L		13	10	23	0.15
TOC	mg/L		9.42	1.23	87	
Nutrients:						
Ammonia (as N)	mg/L		25.2	2.3	91	
Organic-N	mg/L		1.3	0.2	85	none
Bacteriological:						
Total Coliform	mpn/100mL		<1			<1
Salts:						
Hardness mg/L (as CaCO3)	mg/L		203	9	96	180
Alkalinity mg/L (as CaCO3)	mg/L		36	18	50	
TDS	mg/L		890	61	92	500
Conductivity	umhos/cm		1570	155	--	
Sulfate	mg/L		378	15.5	96	
Chloride	mg/L		207	27	87	
Fluoride	mg/L		0.42	0.25	40	2
Boron	mg/L		0.34	0.32	22	
Calcium	mg/L		79.4	2.4	97	
Magnesium	mg/L		2.4	0.1	96	
Sodium	mg/L		187	21	89	
Silica	mg/L		15.5	3.5	77	
Potassium	mg/L		14.8	1.7	89	
Metals:						
Aluminum	μg/L		12.3	1.1	91	200
Antimony	μg/L					6
Arsenic	μg/L		<2.0	<2.0	0	50
Barium	μg/L		11	<1.0	>91	1,000
Beryllium	μg/L		--	--	--	4
Cadmium	μg/L		<1.0	<1.0	0	5
Total Chromium	μg/L		1.6	<1.0	>38	50
Copper	μg/L		8.5	1.5	82	1,000
Iron	μg/L		13	<1.0	>92	
Lead	μg/L		<1.0	<1.0	0	15
Manganese	μg/L		2.2	<1.0	>55	2.0
Mercury	μg/L		<0.5	<0.5	0	100
Nickel	μg/L		14.2	<1.0	>93	50
Selenium	μg/L		<5.0	<5.0	0	100
Silver	μg/L		<0.1	<0.1	0	5,000
Zinc	μg/L		<50	<50	0	2

(*) injection at Talbert Gap and Kreamer/Miller Basins

Table 37: West Basin Reclamation Project, El Segundo, CA

	Units	Influent	Effluent
Conventional:			
pH	mg/L	6.7 to 7.1	7 to 8
Chlorine	mg/L	<0.1	2 to 3
Phenols	mg/L		ND
MBAS	mg/L		ND
Cyanide	mg/L		ND
TOC	mg/L	10 to 15	0.2-0.4
BOD	mg/L	20 to 30	<3
Temperature	C	seasonal	seasonal
Turbidity 105	NTU	5 to 20	0.1 to 0.15
TSS	mg/L	15 to 25	<1
Nutrients:			
Nitrate (N03-N)	mg/L	<0.5 to 1	<0.1 - 0.1
Nitrite (N02-N)	mg/L	<0.5	<0.1
Kjeldahl Nitrogen	mg/L	30 to 40	1 to 2
Ammonia (as NL	mg/L	30 to 40	1 to 2
Organic-N (TKN	mg/L		<1
Ortho-P	mg/L	ND	<0.1
Bacteriological:			
Total Coliform	mpn/100mL	>1600	<2
Fecal	mpn/100mL	>1600	<2
Streptococcus	mpn/100mL		<1
Enteroccocus	mpn/100mL		<1
Salts:			
Hardness mg/L (as CaCO3)	mg/L		12 to 40
Alkalinity mg/L (as CaCO3)	mg/L	250 to 300	30 to 60
TDS	mg/L	?	20 to 50
Conductivity	umhos/cm	1300 to 1600	30 to 80
Sulfate	mg/L	90 to 120	<2 to 3
ChlorideL	mg/L	150 to 250	4 to 8
Fluoride	mg/L		<0.1 to 0.2
Calcium	mg/L		5 to 15
Magnesium	mg/L		<0.1
Sodium	mg/L		6 to 12
Potassium	mg/L		0.5 to 0.8
Metals:			
Antimony	µg/L		<5
Arsenic	µg/L		<2
Barium	µg/L		<100
Beryllium	µg/L		<1
Cadmium	µg/L		<1
Total Chromium	µg/L		<10
Copper	µg/L		<50
Lead	µg/L		<5
Mercury	µg/L		<1
Nickel	µg/L		<10
Selenium	µg/L		<5
Silver	µg/L		<1
Zinc	µg/L		<50

Thallium	µg/L		<1
Magnesium	µg/L		<100
Disinfection Byproducts			
NDMA	ppb	NA	NA
THM	ppb		1-3
HAA	ppb		<1
Bromate	ppb		<5
TTHM	ppb		1-3
Trace Organic Compounds			
Endocrine Disruptors	ppb		NA
Pharmaceuticals	ppb		1-3
Hormones	pbp		<1
Antibiotics	ppp		<5
Anti-inflammatories	ppb		1-3

Table 38: Pomona Valley, CA

	Units	Influent	Effluent	Regulations: MCL
Conventional:				
pH	mg/L		7.3	6.5-8.5
Chlorine	mg/L		<0.51	0
Phenols	mg/L		0.14	
MBAS	mg/L			0.5
Cyanide	mg/L			4.2
BOD5/20	mg/L		4	20
Temperature	C		24.4	
Turbidity 105	NTU		1.4	
TDS			545	750
SS			1	15
Nutrients:				
Nitrate (N03-N)	mg/L		1.15	
Nitrite (N02-N)	mg/L		1.89	1.0
Ammonia (as NH3-H)	mg/L		13.9	
Organic-N (TKN)	mg/L		2.0	
Ortho-P	mg/L		1.2	
Bacteriological:				
Fecal	mpn/100mL			<200 max
Fecal	mpn/100mL		<2	
Salts:				
Sulfate	mg/L		69	300
Chloride	mg/L		139	180
Boron	mg/L		0.47	1.0
Metals:				
Antimony	µg/L		<0.5-1.3	
Arsenic	µg/L		<1-2.4	
Beryllium	µg/L		<0.5	
Cadmium	µg/L		<0.4	5
Total Chromium	µg/L		<10	
Copper	µg/L		<8-14	
Lead	µg/L		<2-2	6.6
Mercury	µg/L		<0.04-<0.1	0.051
Nickel	µg/L		<20	
Selenium	µg/L		<1	
Silver	µg/L		<0.24-0.49	
Zinc	µg/L		60	
Thallium	µg/L		<1	
Disinfection Byproducts				
NDMA	µg/L		<1-<5	8.1

Table 39: San Jose East, CA

	Units	Influent	Effluent	Regulations
Conventional:				
pH	mg/L		6.9	6.0-9.0
MBAS	mg/L		<0.09	0.5
TOC	mg/L		6.0	
BOD5/20	mg/L		<3.0	20
COD	mg/L		21	
Temperature	C		79	100
Turbidity 105	NTU		0.9	2
TSS	mg/L		<2	15
TDS	mg/L		612	700
SS	mg/L		<0.1	0.1
Oil and Grease	mg/L		<4	10
Nutrients:				
Nitrate (N03-N)	mg/L		4.10	
Nitrite (N02-N)	mg/L		<0.081	1
Ammonia (as NH3-H)	mg/L		1.6	
Organic-N (TKN)	mg/L		1.4	
Bacteriological:				
Total Coliform	mpn/100mL		<1	2.2
Fecal	mpn/100mL		<2	
Salts:				
Hardness mg/L (as CaCO3)	mg/L		197	
Alkalinity mg/L (as CaCO3)	mg/L		152	
Sulfate	mg/L		122	250
Chloride	mg/L		148	250
Fluoride	mg/L		0.35	1.6
Calcium	mg/L		48.8	
Magnesium	mg/L		17.1	
Sodium	mg/L		138	
Potassium	mg/L		15.1	
Boron	mg/L		0.46	1
Metals:				
Arsenic	µg/L		1	50
Barium	µg/L		34	1000
Cadmium	µg/L		<0.4	5
Total Chromium	µg/L		<10	50
Copper	µg/L		<8	1300
Lead	µg/L		<3	15
Mercury	µg/L		<0.04	2
Nickel	µg/L		<20	100
Selenium	µg/L		<1	50
Silver	µg/L		<0.2	100
Zinc	µg/L		75	500
Iron	µg/L		95	300
Manganese	µg/L		27	50

Table 40: San Jose West, CA

		Units	Influent	Effluent	Limits
	Conventional:				
	pH	mg/L		7.1	6.0-9.0
A	MBAS	mg/L		<0.09	0.5
	TOC	mg/L		5.5	
	BOD5/20	mg/L		<3.0	20
	COD	mg/L		20	
	Temperature	C		79	100
	Turbidity 105	NTU		0.9	2
	TSS	mg/L		<2	15
	TDS	mg/L		532	700
	SS	mg/L		<0.1	0.1
	Oil and Grease	mg/L		<4	10
	Nutrients:				
	Nitrate (N03-N)	mg/L		5.48	
	Nitrite (N02-N)	mg/L		<0.096	1
	Ammonia (as NH3-H)	mg/L		2.8	
	Organic-N (TKN)	mg/L		1.5	
	Bacteriological:				
	Total Coliform	mpn/100mL		<1	2.2
	Fecal	mpn/100mL		<2	
	Salts:				
	Hardness mg/L (as CaCO3)	mg/L		190	
	Alkalinity mg/L (as CaCO3)	mg/L		166	
	Sulfate	mg/L		87.8	250
	Chloride	mg/L		108	250
	Fluoride	mg/L		0.60	1.6
	Calcium	mg/L		48.7	
	Magnesium	mg/L		14.0	
	Sodium	mg/L		110	
	Potassium	mg/L		<12.7	
	Boron	mg/L		0.50	1
	Metals:				
	Arsenic	µg/L		1	50
	Barium	µg/L		23	1000
	Cadmium	µg/L		<0.5	5
	Total Chromium	µg/L		<10	50
	Copper	µg/L		<8	1300
	Lead	µg/L		<2	15
	Mercury	µg/L		<0.04	2
	Nickel	µg/L		<20	100
	Selenium	µg/L		<1	50
	Silver	µg/L		<0.2	100
	Zinc	µg/L		91	500
	Iron	µg/L		60	300
	Manganese	µg/L		12	50

Table 41: Whittier Narrows WRP, CA

	Units	Influent	Effluent	Limits
Conventional:				
pH	mg/L		7.1	6.0-9.0
MBAS	mg/L		<0.09	0.5
TOC	mg/L		5.5	
BOD5/20	mg/L		<3.0	20
COD	mg/L		20	
Temperature	C		79	100
Turbidity 105	NTU		0.9	2
TSS	mg/L		<2	15
TDS	mg/L		532	700
SS	mg/L		<0.1	0.1
Oil and Grease	mg/L		<4	10
Nutrients:				
Nitrate (N03-N)	mg/L		5.48	
Nitrite (N02-N)	mg/L		<0.096	1
Ammonia (as NH3-H)	mg/L		2.8	
Organic-N (TKN)	mg/L		1.5	
Total Nitrate Nitrite			5.58	10
Bacteriological:				
Total Coliform	mpn/100mL		<1	2.2
Fecal	mpn/100mL		<2	
Salts:				
Hardness mg/L (as CaCO3)	mg/L		190	
Alkalinity mg/L (as CaCO3)	mg/L		166	
Sulfate	mg/L		87.8	250
Chloride	mg/L		108	250
Fluoride	mg/L		0.60	1.6
Calcium	mg/L		48.7	
Magnesium	mg/L		14.0	
Sodium	mg/L		110	
Potassium	mg/L		<12.7	
Boron	mg/L		0.50	1
Metals:				
Arsenic	µg/L		13	50
Barium	µg/L		31	1000
Cadmium	µg/L		<0.7	5
Total Chromium	µg/L		<10	50
Copper	µg/L		<8	1300
Lead	µg/L		<2	15
Mercury	µg/L		<0.04	2
Nickel	µg/L		<20	100
Selenium	µg/L		<1	50
Silver	µg/L		<0.2	100
Zinc	µg/L		91	500
Iron	µg/L		60	300
Manganese	µg/L		12	50

Table 42: Chino Valley Basin, Chino Hills CA*

	Units	Influent	Effluent	Limits?
Conventional:				
pH	mg/L	7.4/7.4		6.0-9.0
Phenols	mg/L		<1	
Cyanide	mg/L		<0.007	
TOC	mg/L		12	
BOD5/20	mg/L		<4	20
TSS	mg/L	277/290	1	15
TDS	mg/L	452/507		700
Nutrients:				
Ammonia (as NH4-H)	mg/L	23.7/29.3		
Organic-N (TKN)	mg/L	40.4/43.8		
Total Inorganic Nitrogen		24.4/42.3	12	
Salts:				
Hardness mg/L (as CaCO3)	mg/L		140	
Alkalinity mg/L (as CaCO3)	mg/L		144	
Sulfate	mg/L		62	250
Chloride	mg/L		102	250
Fluoride	mg/L		0.2	1.6
Calcium	mg/L		40	
Magnesium	mg/L		10.1	
Potassium	mg/L		93	
Boron	mg/L		0.34	1
Metals:				
Antimony	µg/L		<2 max	
Arsenic	µg/L		<5	50
Barium	µg/L		7	1000
Beryllium	µg/L		<2 max	
Cadmium	µg/L		<1	5
Total Chromium	µg/L		<1	50
Cobalt	µg/L		<4	
Copper	µg/L	57/67	<4	1300
Lead	µg/L	<13/<13	<2	15
Mercury	µg/L		<0.3	2
Nickel	µg/L		<3	100
Selenium	µg/L		<7	50
Silver	µg/L		<2	100
Zinc	µg/L		30	500
Thallium	µg/L		<2 max	
Iron	µg/L		85	300
Manganese	µg/L		5	50
Disinfection Byproducts				
NDMA	µg/L		<5 max	
TTHM	µg/L		<21	

(*) RP-1/RP-4, 2002: share the same point of discharge

Table 43: Victor Valley Water Reclamation Authority, Victorville CA *

	Units	Influent	Secondary Effluent	Tertiary Effluent	% Removal
Conventional:					
pH	mg/L		7.0	6.9	
MBAS	mg/L	9.7	0.11	0.15	
BOD	mg/L	385	6.8	1.8	99.7
COD	mg/L	873		23	
Temperature	C			23.9	
Turbidity 105	NTU			0.63	
TSS	mg/L	495	7.3		99.8
Nutrients:					
Nitrate (N03-N)	mg/L	<0.2	9.8	10.4	
Kjeldahl Nitrogen	mg/L	36.3	1.3	1.7	
Ammonia (as N)	mg/L	43.0	0.6	2.1	97.4
Salts:					
TDS	mg/L	400	368	1.6	
Sulfate	mg/L			58	
Chloride	mg/L			72	
Sodium	mg/L			97	
	mg/L				
Metals:					

(*)2004 avg:.:secondary effluent to ponds, tertiary to river

Failed IPR projects

Table 44 East Valley Water Recycling Project (EVWRP), Los Angeles, CA*

	Units	Influent (avg. 5)	Effluent (avg. 7)	Regulation
Conventional:				
pH	mg/L	6.9	7.2	6.0-9.0
Phenols	mg/L	ND		
MBAS max	mg/L		0.3	0.5
Cyanide	mg/L	ND	DNQ	2
BOD5	mg/L	382		
COD	mg/L	45		
Temperature	C	22	23	34
Turbidity 105	NTU			2 (5 max)
Nutrients:				
Nitrate (N03-N)	mg/L		0.76	
Nitrite (N02-N)	mg/L		0.29	2 (8 combined)
Ammonia (as NH3-N)	mg/L		17.4	
Organic-N (TKN)	mg/L		1.8	
Ortho-P	mg/L		1.43	
Total-P	mg/L	1.42	1.57	
Total N	mg/L	15.5 (total)	20.3	
PO4-P			1.7	
Bacteriological:				
Total Coliform	cfu/100mL		1870	
Fecal	cfu /100mL		467	
Salts:				
Hardness mg/L (as CaCO3)	mg/L		149	
TDS	mg/L		598	950
Conductivity	umhos/cm	1184	1056	
Sulfate	mg/L		105	300
Chloride	mg/L		139	190
Fluoride	mg/L		1	2
Metals:				
Antimony	µg/L	ND	ND	10
Arsenic	µg/L	18.0	5.7	1
Barium	µg/L	50	DNQ	1
Boron	µg/L	770	740	100
Cadmium	µg/L	ND	ND	1
Total Chromium	µg/L	24	ND	10
Copper	µg/L	94	DNQ	10
Nickel	µg/L	ND	DNQ	20
Silver	µg/L	6.00	DNQ	0.62
Zinc	µg/L	3.08	ND	10
Thallium	µg/L	ND	ND	5
Iron	µg/L	827	ND	100

Disinfection Byproducts			
TTHM	µg/L	3.16	10.5

(*)Tillman plant, 2002: Balboa Lake: 720 m^3/s, Wildlife Lake: 250, plant outfall: 650, Japanese garden: 200, plant reuse: 390

Table 45 San Diego Water Re-purification Project (SDWRP), CA

	Units	Influent	Effluent	Regulation
Conventional:				
TOC	mg/L	71/68	1.1/15	
COD	mg/L	427/371	15/9	
Turbidity 105	NTU	96/69	NA/NA	
TSS	mg/L	209/211	2.7/1.3	
TS	mg/L	1008/1180	81/254	
Nutrients:				
Nitrate (N03-N)	mg/L	0.1	0.6	
Ammonia (as NH3-N)	mg/L	24.8	1.1	
Phosphate-P	mg/L	14.1	1.6	
Salts:				
Sulfate	mg/L	177	3.1	
Chloride	mg/L	195	16	
Calcium	mg/L	67.7	3.6	
Magnesium	mg/L	29.8	3.6	
Sodium	mg/L	127	11.3	
Metals:				
Arsenic	µg/L	2.5	1.6	
Boron	µg/L	260	230	
Cadmium	µg/L	2.8	1	
Chromium	µg/L	17	2	
Copper	µg/L	103	17	
Lead	µg/L	29	3	15 federal
Mercury	µg/L	1.2	10	
Nickel	µg/L	21	4	100
Selenium	µg/L	5	3	
Silver	µg/L	8	5	
Zinc	µg/L	109	8	
Magnesium	µg/L	See above		
Iron	µg/L	800	40	
Manganese	µg/L	97	15	

(*) Aqua II: pilot plant 87-89/90/92

IPR projects in Arizona

Table 46: Pima Roger Road Wastewater Plant Tucson, AZ

	Units	Influent	Effluent
Conventional:			
pH	mg/L		7.2
Chlorine	mg/L		<0.05
Phenols	mg/L		ND
Cyanide	mg/L		trace
BOD	mg/L	220	11
COD	mg/L		360
TSS	mg/L	238	12
Nutrients:			
Nitrate (N03-N)	mg/L		ND
Nitrite (N02-N)	mg/L		ND
Kjeldahl Nitrogen	mg/L		43.0
Ammonia (as NL	mg/L		21.3
Organic-N (TKN	mg/L		43.0
Ortho-P	mg/L		3.35
Total-P	mg/L		6.73
Bacteriological:			
E-coliforml	mpn/100mL		9
Salts:			
Hardness mg/L (as CaCO3)	mg/L		199
Alkalinity mg/L (as CaCO3)	mg/L		271
Conductivity	umhos/cm		1070
Sulfate	mg/L		109
Fluoride	mg/L		0.717
Calcium	mg/L		62.0
Magnesium	mg/L		10.8
Metals:			
Antimony	µg/L		0.8
Arsenic	µg/L		6.0
Barium	µg/L		116.1
Beryllium	µg/L		ND
Cadmium	µg/L		Trace
Total Chromium	µg/L		5.7
Copper	µg/L		59.4
Lead	µg/L		4.3
Mercury	µg/L		Trace
Nickel	µg/L		15.0
Selenium	µg/L		1.2
Silver	µg/L		4.9
Zinc	µg/L		164.7
Thallium	µg/L		ND

Disinfection Byproducts		
NDMA	ppb	ND
Bromate	ppb	trace
Trace Organic Compounds		
Endocrine Disruptors	ppb	ND
Pharmaceuticals	ppb	ND
Hormones	pbp	ND
Antibiotics	ppp	ND
Anti-inflammatories	ppb	ND
Personal Care Products	ppb	ND

Table 47: Mesa Northwest Water Reclamation Plant, AZ

	Units	Influent	Effluent
Conventional:			
Dissolved Oxygen	mg/L		3.45
Chlorine	mg/L		19
Phenols	mg/L		<2.5
Cyanide	mg/L		<20
Temperature	C		25
Nutrients:			
Nitrate (N03-N)	mg/L		4.99
Nitrite (N02-N)	mg/L		4.99
Kjeldahl Nitrogen	mg/L		1.42
Ammonia (as NL	mg/L		<0.10
Total-P	mg/L		error
Salts:			
TDS	mg/L		1068
Metals:			
Arsenic	µg/L		1.40
Beryllium	µg/L		<1.0
Cadmium	µg/L		<1.0
Total Chromium	µg/L		<10
Copper	µg/L		21
Lead	µg/L		<1.0
Mercury	µg/L		<0.2
Nickel	µg/L		<10
Selenium	µg/L		1.10
Silver	µg/L		<10
Zinc	µg/L		<50
Thallium	µg/L		<1.0
Boron	µg/L		450.0
Disinfection Byproducts			
NDMA	µg/L		2.5
TTHM	µg/L		0.2

IPR projects in Florida

Table 48: East Central Region WWTP* West Palm Beach, FL

	Units	MF Influent	RO Influent	RO Effluent	Total% Removal
Conventional:					
pH	mg/L	7.2	6.7	6.8	NA
TOC	mg/L	53	22	1	97.5
BOD	mg/L	8.27	1.18	<0.5	91.2
TSS	mg/L	7.84	0.79	<0.5	90.6
Nutrients:					
Nitrite (N02-N)	mg/L	0.030	0.026	0.072	66.4
Kjeldahl Nitrogen	mg/L	4.26	2.72	1.55	77.0
Ammonia (as N)	mg/L	0.36	1.15	0.61	39.6
Ortho-P	mg/L	0.053	0.032	0.014	72.9
Total-P	mg/L	0.53	0,36	0.14	73.4
Bacteriological:					
Fecal	mpn/100mL	851	5	3	98.9
Salts:					
Hardness mg/L (as CaCO3)	mg/L	158	203	92	53.7
TDS	mg/L	292	330	61	77.0
Sulfate	mg/L	58	73	17	77
Chloride	mg/L	58	67	10	80
Fluoride	mg/L	0.50	0.6	<0.01	84.4
Boron	mg/L	<0.2	<0.2	<0.2	NA
Calcium	mg/L	80	72	21	71.4
Magnesium	mg/L	25	22	6	83.3
Sodium	mg/L	51	68	19	57.0
Silica	mg/L	0.79	<0.1	<0.1	85.0
Metals:					
Arsenic	µg/L	7	<7	<1	NA
Barium	µg/L	<10	<10	<10	NA
Beryllium	µg/L	<4	<4	<4	NA
Cadmium	µg/L	32	<5	<5	65.6
Total Chromium	µg/L	<10	<10	<10	NA
Copper	µg/L	51	<10	<10	74.8
Iron	µg/L	310	<10	<10	95.0
Lead	µg/L	9	<1	<1	86.3
Manganese	µg/L	<10	<10	<10	NA
Mercury	µg/L	2	<0.2	<0.2	87.0
Nickel	µg/L	29	<20	<20	34.8
Selenium	µg/L	<1	<1	<!	NA
Silver	µg/L	<10	<10	<10	NA
Zinc	µg/L	774	1043	356	54.7
Thallium	µg/L	<2	<2	<2	NA
Silver	µg/L	<10	<10	<10	NA

Table 49: Tampa Water Recourse Recovery Project (TWRRP), Tampa, FL

	Units	Influent	Effluent
Conventional:			
Dissolved Oxygen	mg/L	1.49	20.56 w/ozone
pH	mg/L	6.52	7.02
Chlorine	mg/L	0	0
MBAS	mg/L	0	0
Cyanide	mg/L	<0.007	0.0006
TOC	mg/L	11.59	1.88
Temperature	C	27.1	24.5
Turbidity 105	NTU	1.8	0.05
TSS	mg/L	3.25	0.68
TOX	mg/L	103	13
Silica	mg/L	11.34	4.04
Nutrients:			
Nitrate (N03-N)	mg/L	1.36	1.3
Nitrite (N02-N)	mg/L	0.47	0.04 w/ozone
Kjeldahl Nitrogen	mg/L	1.64	0.34 “
Ammonia (as NL	mg/L	0.32	0.03 “
Organic-N (TKN	mg/L	1.32	0.31
Total-P	mg/L	5.78	0.17
Bacteriological:			
Total Coliform	mpn/100mL	53600	0.31
Fecal	mpn/100mL	17300	0.14
Salts:			
Hardness mg/L (as CaCO3)	mg/L	218	133
Alkalinity mg/L (as CaCO3)	mg/L	221	98
TDS	mg/L	576	461
Conductivity	umhos/cm	887	761
Sulfate	mg/L	92.9	95.6
ChlorideL	mg/L	141	138
Fluoride	mg/L	.073	.061
Magnesium	mg/L	10.11	3.35
Sodium	mg/L	100	100
Potassium	mg/L	12.64	12.63
Metals:			
Antimony	µg/L	ND	ND
Barium	µg/L	<0.02	0.011
Beryllium	µg/L	ND	ND
Total Chromium	µg/L	70.98	47.78
Copper	µg/L	<0.003	<0.002
Lead	µg/L	0.001	0.0004
Mercury	µg/L	3E-5	2E-05
Nickel	µg/L	0.005	0.005
Selenium	µg/L	ND	ND
Zinc	µg/L	0.022	0.008
Thallium	µg/L	ND	ND
Cobalt	µg/L	<0.006	ND
Iron	µg/L	0.015	0.026
Molybdenum	µg/L	0.016	0.01
Strontium	µg/L	0.33	0.18

Vanadium	µg/L	ND	ND
Disinfection Byproducts			
TTHM	ppb	9.7	2.84 w/ozone
TTHM	ppb	9.7	20.7 w/Cl

Established NPR facility

Table 50: San Diego North City Water Reclamation Plant, CA *

	Units	Influent	Effluent	MCL
Conventional:		64/Penasquitos		
pH	mg/L	7.61/7.54	7.47	
MBAS max	mg/L		0.16	0.03
Cyanide	mg/L	0.006/<0.002	0.0061	0.002/0.2
TOC	mg/L		8.2	0.250
BOD5	mg/L	223/253	<2	2
Turbidity 105	NTU	122/155	1.2	
TSS	mg/L	241/327	<1.6	
Bacteriological:				
Total Coliform	cfu/100mL		<2	
Salts:				
Hardness mg/L (as CaCO3)	mg/L		282.2	0.08
TDS	mg/L	1120/904	941.3	42
Sulfate	mg/L		203	0.5/300
Chloride	mg/L		228	7/228
Fluoride	mg/L		0.4	1/0.05
Calcium	mg/L	89.2	64.8	0.08
Magnesium	mg/L	40.3/34.5	29.2	0.02
Sodium	mg/L	221/170	59	-
Potassium	mg/L	17.3/17.9	13.2	2
Metals:				
Antimony	µg/L	5/7.05	3	23/6
Arsenic	µg/L	1.14/1.41	0.56	0.4/50
Barium	µg/L	111/122	38	10/1000
Boron	µg/L	366/370	373	15/700
Cadmium	µg/L	0.4/0.331	0.1	1/5
Total Chromium	µg/L	3.5/10.1	1.8	5/50
Copper	µg/L	151/124	44	4/-
Lead	µg/L	4/6.26	-	18
Mercury	µg/L	0.21/0.20	0.01	05/2
Nickel	µg/L	5/11.5	4	14/100
Selenium	µg/L	1.36/1.38	0.66	0.28/50
Silver	µg/L	3/3.44		6.6
Zinc	µg/L	120/118		4
Thallium	µg/L		ND	40/2
Manganese	µg/L	220/	88	4/50
Iron	µg/L		146	30/300

(*) 2004 reclaimed water portion only

Table 51: Tapia Water Reclamation Facility, Malibu, CA

	Units	Influent	Effluent	MCL
Conventional:				
pH	mg/L		8.14	
Chlorine	mg/L		2.2	4
TOC	mg/L		3.3	TT
Turbidity 105	NTU		0.17	0.3 (5 max)
Nutrients:				
Nitrate (N03-N)	mg/L		10	ND
Bacteriological:				
Total Coliform	cfu/100mL		0.10	5.0
Salts:				
Hardness mg/L (as CaCO3)	mg/L		135	
Alkalinity mg/L (as CaCO3)	mg/L		28	
TDS	mg/L		395	1000
Conductivity	umhos/cm		1600	557
Sulfate	mg/L		60	500
Chloride	mg/L		79	500
Fluoride	mg/L		0.2	2 ppm
Calcium	mg/L		28	
Magnesium	mg/L		16	
Metals:				
Arsenic	µg/L		ND	50 ppb
Boron	µg/L		270	
Disinfection Byproducts				
TTHM	µg/L		60	80
HAA5	µg/L		14.8	60

Table 52: Apricot Project, Altamonte Springs, FL

	Units	Influent	Effluent	Limits
Conventional:				
Dissolved Oxygen	mg/L		6	6
pH	mg/L		7.0	6.0-7.4
Chlorine	mg/L		0.01	0.01
BOD5/20	mg/L		5	8
SS	mg/L		5	30
Nutrients:				
Nitrate (N03-N)	mg/L		0.42	10
Organic-N (TKN)	mg/L		3	5
Salts:				
Fluoride	mg/L		0.999	4
Metals:				
Barium	µg/L		0.0111	2
Cadmium	µg/L		0.14	5
Copper	µg/L		0.867	1.3
Lead	µg/L		2.8	15
Disinfection Byproducts				
TTHM	µg/L		24	100

Table 53: Eastern Water Reclamation Facility (SW and SE), Orange County, FL

	Units	Influent	Effluent	Limits
Conventional:				
BOD5/20	mg/L	149	3.6/1.3	
TSS	mg/L		7.2/1.4	
Nutrients:				
Nitrate (N03-N)	mg/L		2.6/5.5	
Organic-N (TKN)	mg/L	35	4.7/1.6	
Total-P	mg/L	8	2.1/3.9	