Report Code: 012_GBP_IIT_EQP_SOA_01_Ver 1_Dec 2011

Review of Wastewater Reuse Projects Worldwide

Collation of Selected International Case Studies and Experiences

---

GRB EMP : Ganga River Basin Environment Management Plan

by

Indian Institutes of Technology

IIT Bombay
IIT Delhi
IIT Guwahati
IIT Kanpur
IIT Kharagpur
IIT Madras
IIT Roorkee

Preface

In exercise of the powers conferred by sub-sections (1) and (3) of Section 3 of the Environment (Protection) Act, 1986 (29 of 1986), the Central Government has constituted National Ganga River Basin Authority (NGRBA) as a planning, financing, monitoring and coordinating authority for strengthening the collective efforts of the Central and State Government for effective abatement of pollution and conservation of the river Ganga. One of the important functions of the NGRBA is to prepare and implement a Ganga River Basin: Environment Management Plan (GRB EMP).

A Consortium of 7 Indian Institute of Technology (IIT) has been given the responsibility of preparing Ganga River Basin Environment Management Plan (GRBEMP) by the Ministry of Environment and Forests (MoEF), GOI, New Delhi. Memorandum of Agreement (MoA) has been signed between 7 IITs (Bombay, Delhi, Guwahati, Kanpur, Kharagpur, Madras and Roorkee) and MoEF for this purpose on July 6, 2010.

This report is one of the many reports prepared by IITs to describe the strategy, information, methodology, analysis and suggestions and recommendations in developing Ganga River Basin: Environment Management Plan (GRB EMP). The overall Frame Work for documentation of GRBMP and Indexing of Reports is presented on the inside cover page.

There are two aspects to the development of GRB EMP. Dedicated people spent hours discussing concerns, issues and potential solutions to problems. This dedication leads to the preparation of reports that hope to articulate the outcome of the dialog in a way that is useful. Many people contributed to the preparation of this report directly or indirectly. This report is therefore truly a collective effort that reflects the cooperation of many, particularly those who are members of the IIT Team. Lists of persons who have contributed directly and those who have taken lead in preparing this report is given on the reverse side.

Dr Vinod Tare
Professor and Coordinator
Development of GRBMP
IIT Kanpur

The Team

1.	A A Kazmi, IIT Roorkee	*kazmifce@iitr.ernet.in*
2.	A K Gupta, IIT Kharagpur	*akgupta18@rediffmail.com,akgupta@iitkgp.ac.in*
3.	A K Mittal, IIT Delhi	*akmittal@civil.iitd.ernet.in*
4.	A K Nema, IIT Delhi	*aknema@gmail.com*
5.	Ajay Kalmhad, IIT Guwahati	*kajay@iitg.ernet.in*
6.	Anirban Gupta, BESU Shibpur	*guptaanirban@hotmail.com*
7.	Arun Kumar, IIT Delhi	*arunku@civil.iitd.ac.in*
8.	G J Chakrapani, IIT Roorkkee	*gjcurfes@iitr.ernet.in*
9.	Gazala Habib, IIT Delhi	*gazalahabib@gmail.com*
10.	Himanshu Joshi, IIT Roorkee	*himanshujoshi58@gmail.com*
11.	Indu Mehrotra, IIT Roorkee	*indumfce@iitr.ernet.in*
12.	I M Mishra, IIT Roorkee	*imishfch@iitr.ernet.in*
13.	Ligy Philip, IIT Madras	*ligy@iitm.ac.in*
14.	M M Ghangrekar, IIT Kharagpur	*ghangrekar@civil.iitkgp.ernet.in*
15.	Mukesh Doble, IIT Bombay	*mukeshd@iitm.ac.in*
16.	P K Singh, IT BHU	*dr_pksingh1@rediffmail.com*
17.	Purnendu Bose, IIT Kanpur	*pbose@iitk.ac.in*
18.	R Ravi Krishna, IIT Madras	*rrk@iitm.ac.in*
19.	Rakesh Kumar, NEERI Nagpur	*r_kumar@neeri.res.in*
20.	S M Shivnagendra, IIT Madras	*snagendra@iitm.ac.in*
21.	Saumyen Guha, IIT Kanpur	*sguha@iitk.ac.in*
22.	Shyam R Asolekar, IIT Bombay	*asolekar@iitb.ac.in*
23.	Sudha Goel, IIT Kharagpur	*sudhagoel@civil.iitkgp.ernet.in*
24.	Suparna Mukherjee, IIT Bombay	*mitras@iitb.ac.in*
25.	T R Sreekrishanan, IIT Delhi	*sree@dbeb.iitd.ac.in*
26.	Vinod Tare, IIT Kanpur	*vinod@iitk.ac.in*
27.	Vivek Kumar, IIT Roorkee	*vivekfpt@iitr.ernet.in*

Lead Persons

1. Vinod Tare, IIT Kanpur
2. Purnendu Bose, IIT Kanpur
3. Subrata Hait, IIT Kanpur
4. Ligy Philip, IIT Madras
5. A A Kazmi, IIT Roorkee

Contents

1. Introduction

The increasing demand for water in combination with frequent drought periods, even in areas traditionally rich in water resources, puts at risk the sustainability of current living standards. In industrialized countries, widespread shortage of water is caused due to contamination of ground and surface water by industrial effluents, and agricultural chemicals. In many developing countries, industrial pollution is less common, though they are severe near large urban centers. However, untreated or partially-treated sewage poses an acute water pollution problem that causes low water availability. Global trends such as urbanization and migration have increased the demand for water, food and energy. Development of human societies is heavily dependent upon availability of water with suitable quality and in adequate quantities, for a variety of uses ranging from domestic to industrial supplies. Moreover, the forecasts for water availability are quite dire and water scarcity is endemic in most parts of the world. This emphasizes the need for water scarcity solutions and water quality protection from pollution. It is in this context, the Agenda 21 adopted by the United Nations Conference on Environment and Development, popularly known as the "Earth Summit" of Rio de Janeiro, 1992, identified protection and management of freshwater resources from contamination as one of the priority issue, that has to be urgently dealt with to achieve global environmentally sustainable development.

The need for increased water requirement for the growing population in the new century is generally assumed, without considering whether available water resources could meet these needs in a sustainable manner. The question about from where the extra water is to come, has led to a scrutiny of present water use strategies. A second look at strategies has thrown a picture of making rational use of already available water, which if used sensibly, could provide enough water for all. The new look invariably points out at recycle and reuse of wastewater that is being increasingly generated due to rapid growth of population and related developmental activities, including agriculture and industrial productions. Hence, wastewater reuse is perceived as a measure towards fulfilling following three fundamental objectives within a perspective of integrated water resources management.

- Environmental sustainability – reduction of pollutants load and their discharge into receiving water bodies, and the improvement of the quantitative and qualitative status of those water bodies (surface water, groundwater and coastal waters) and the soils.
- Economic efficiency – alleviating scarcity by promoting water efficiency, improving conservation, reducing wastage and balancing long term water demand and water supply.
- For some countries, contribution to food security – growing more food and reducing the need for chemical fertilizers through treated wastewater reuse.

The term wastewater reuse is often used synonymously used with the terms wastewater recycling and wastewater reclamation. But they are three different terms in practical sense as defined here:

Wastewater reclamation:	Involves the treatment or processing of wastewater to make it reusable (Asano, 1998).
Wastewater reuse:	Water reuse is the beneficial use of treated wastewater (Asano, 1998).
Wastewater recycling:	Water recycling is the use of wastewater that is captured and redirect back into the same water use scheme (Metcalf and Eddy, 2003).

Reuse of wastewater for domestic and agricultural purposes has been occurring since historical times. However, planned reuse has gained importance only two or three decades ago, as the demands for water dramatically increased due to technological advancement, population growth, and urbanization, which put great stress on the natural water cycle. Reuse of wastewater for water-demanding activities, which, so far consumed limited freshwater resources is, in effect, imitating the natural water cycle through engineered processes. Even though most of the river basins worldwide depend on treated wastewater mixed with surface water drainage to maintain water resources for safe abstraction, it appears that in several countries including India, the reuse of treated wastewater is still shrouded in a mist of apprehensions, possibly as a result of misconceptions, lack of knowledge and incorrect stakeholder and public perception. Policies are unclear, when present, and institutional capabilities to manage wastewater reuse are often lacking. Therefore, the prime objectives of this report are to:

(i) Present and compare the existing water quality guidelines and standards worldwide for wastewater reuse,

(ii) Present and review some selected case studies of operating wastewater reuse installations worldwide in order to introduce new ideas and exchange experience,

(iii) To review and discuss the environmental and public health aspects along with the economics of wastewater reuse,

(iv) To review and discuss the community and public perception and participation towards wastewater reuse, and

(v) To come up with general recommendations based on international case studies towards the promotion of wastewater reuse in the Ganga River Basin in respect to the Preparation of Ganga River Basin Management Plan (GRBMP).

2. Existing Water Quality Guidelines and Standards for Wastewater Reuse

In respect to wastewater reuse, there exists no common regulation in the world due to difference in geographical location, climatic, geological and geographical conditions, water resources, type of crops and soils, economic and social aspects, and country/state policies towards reusing wastewater for irrigation purposes. Some noted organizations and countries have already established reuse standards such as USEPA, State of California Water Recycling Criteria (Title 22), WHO, Israel, France, Italy, etc. The regulation requirements are based primarily on defining the extent of treatment required for wastewater reuse together with numerical limits on bacteriological quality, turbidity and suspended solids. A comparison of international guidelines and standards might help to develop guidelines for any specific area or country for wastewater reuse. Table 1 summarizes some of the existing guidelines and standards worldwide for wastewater reuse in agriculture.

Table 1: Comparison of Selected Water Quality Guidelines/Standards of Wastewater Reuse for Irrigation

Parameter	**California Ca/T-22 (1978)**	**USEPA (1992)**	**WHO (1989)**	**Israel (1978)**	**Tunisia (1975)**	**Cyprus (1997)**	**Chile (1984)**	**France (1991)**	**Italy (1977)**	**Germany**
								EU Guidelines		
Type	Law	Guidelines	Guidelines	Law	Law	Provisional Standards	Guidelines	Guidelines	Law	Guidelines
Minimum Treatment Required	Advanced	Advanced	Stabilization Ponds	Secondary	Stabilization Ponds	Tertiary		Stabilization Ponds	Secondary	Only Heavy Metals are considered in the guidelines
Total BOD (mg/L)		10		15	30	10				
Suspended Solids (SS) (mg/L)		5		15	30	10				
Total Coliform (MPN/100 ml)	2.2	0		2.2					2	
Fecal Coliform (MPN/100 ml)		14 (which means not detectable)	1000			50	1000	1000		
Helminths (eggs/100 cm^3)			1		<1	0		1		
Sodium Absorption Ratio (SAR)									<10	
Main Treatment Process	Oxidation, clarification, filtration & disinfection	Filtration & disinfection	Stabilization ponds or equivalent	Long storage & disinfection	Stabilization ponds or equivalent	Filtration or disinfection		Stabilization ponds or equivalent		

3. Selected Case Studies

Several pioneering studies have provided the technological confidence for the safe reuse of reclaimed wastewater for beneficial uses. While initial emphasis was mainly on reuse for agricultural and non-potable reuses, the recent trends prove that there are direct reuse opportunities to applications closer to the point of generation. There are also many projects that have proved to be successful for indirect or direct potable reuse. Followings are the selected case studies of wastewater reuse as a viable alternative source of water:

3.1 Vitoria-Gasteiz, Spain

Title of Case Study: Vitoria-Gasteiz Integral Recycling Plan

Type of Case Study: Recycling Plan with measures already in place and which aims to incorporate regenerated wastewater in the water cycle.

Objective of Case Study: To demonstrate water recycling scheme which provides farm irrigation and improves river water quality.

Background of Case Study: Vitoria, a medium-sized city (227,568 inhabitants in 2006) situated in the north of Spain, is the administrative capital of the Basque Country. Vitoria is characterized as a service-based city with a well developed industrial sector. The city stands on the banks of the river Zadorra, a tributary of the river Ebro, and has been in constant growth since the 1950's. With regard to wastewater treatment, Vitoria has Crispijana wastewater treatment plant (WWTP) situated close to Vitoria-Gasteiz (Spain) urban area (0.5 million population equivalent) and is designed to treat a flow of industrial and municipal wastewater of 0.12 million m^3 per day. WWTP includes a secondary treatment by activated sludge process.

Salient Features: The Recycling Plan is a result of the extension of activities related with recycling for irrigation and to improve the quality of the river Zadorra for sustenance of fish life. In the initial phase (1994-1999) the recycling of 3 million m^3 per year of urban wastewater was implemented to cover the deficit of irrigation water for nearby irrigated farming. For this purpose a tertiary treatment plant was constructed in order to adapt water quality to the intended use. The regeneration process consists of physical-chemical treatment including flocculation, sand filtering and chlorination.

The quality indices obtained after the application of this treatment are as follows:

- Turbidity: < 0.5 NTU
- Electrical conductivity: < 600 µs/cm
- BOD$_5$: < 5 mg/l
- NH$_4^+$-N: < 2 mg/l
- NO$_3^-$-N: < 17 mg/l
- Phosphorus: < 1 mg/l
- Metals: < 0.1 mg/l
- Pathogens: Absent.

The Integral Recycling Plan helps the river Zadorra to become apt for fish life. The Recycling Plan helps to cover the deficit of irrigation water in the zone and to adapt the river quality for fish life. Expectations from recycling in the mid-term are estimated at 24 million m^3 per year, of which 8 million m^3 per year would be for farming use, 7 million m^3 per year for urban use and 9 million m^3 per year for the maintenance of the flow and the quality of the river Zadorra. As a final goal, the Integral Recycling Plan foresees the recycling of 100% of all generated wastewater.

Reference:

MED WWR WG, 2007. Mediterranean Wastewater Reuse Report, Mediterranean Wastewater Reuse Working Group (MED WWR WG), November 2007.

3.2 Sekem Farm, Egypt

Title of Case Study: Sekem Farm Zer0-M Project (sustainable concepts towards a zero outflow municipality)

Type of Case Study: Desert sandy area was reclaimed, irrigated with treated sewage water, community participation and community capacity building in combination creation of new communities, farmers and fertile soil, with zero out flow, efficient wastewater treatment facility.

Objective of Case Study: To implement an integrated model of wastewater management for peri-urban and deprived/remote regions for the purpose of saving and recycling the wastewater and to make the effluent suitable, safe and appropriate for its intended reuse while protecting the environment.

Background of Case Study: Due to the special type of agriculture at SEKEM, organic vegetables and medicine plants grown under anthroposophy rules, wastewater is not allowed to be used on the main farm crops. The irrigated land nearby the project site was originally desert sandy soil, was deprived from any kind of nutrient elements, and lacked any organic matters. The Farm was using the very poorly treated wastewater for irrigating this forest trees. The purpose of the Zer0-M Project was to treat and reuse of wastewater, save the wastewater, protect the environment as well as the public health, to share the European experience with the Mediterranean countries. The work was designed to implement the European experience with the local practice to construct integrated models of wastewater treatment and reuse. The project aimed on concepts and technologies to achieve optimized close-loop usage of all water flows in small municipalities or settlements (e.g. tourism facilities) non-connected to a central wastewater treatment.

Salient Features: The Zer0-M Project aimed to demonstrate the efficient wastewater treatment and reuse relatively small-scale sewage treatment systems that can be an example of conventional decentralized technology. The SEKEM farm wastewater and reuse work was designed to implement a constructed application of a simple, low cost, low energy and sustainable technology for the treatment and reuse of municipal wastewater through the MEDA Water European Program Support Action. The daily flow was calculated once from the water demand and secondly according to the number of people connected: 500 students at 20 l/day, plus 100 persons at the offices at 20 l/day, laundry plus residential houses leading to a total 15 m^3/day. The technology used is a combination of physical and biological treatment employing three compartments degreaser/ sedimentation/septic tank followed by constructed wetland. The treated wastewater is used for irrigating forest trees. The sludge is to be dried over sludge drying beds of another constructed wetland. Presently the project is fully operated. Treated wastewater is used for irrigating the forest trees. Quality of the treated wastewater is within the permissible limits of the Egyptian standards. No problems with odor or insects exist. The SEKEM administration is going to extend the scheme to all the schools in the municipality which would lead to a flow of approximately 20 m^3/day.

Reference:

MED WWR WG, 2007. Mediterranean Wastewater Reuse Report, Mediterranean Wastewater Reuse Working Group (MED WWR WG), November 2007.

3.3 Durban, South Africa

Title of Case Study: Durban Water Recycling (DWR) Project

Type of Case Study: Municipal wastewater reuse for industrial purposes.

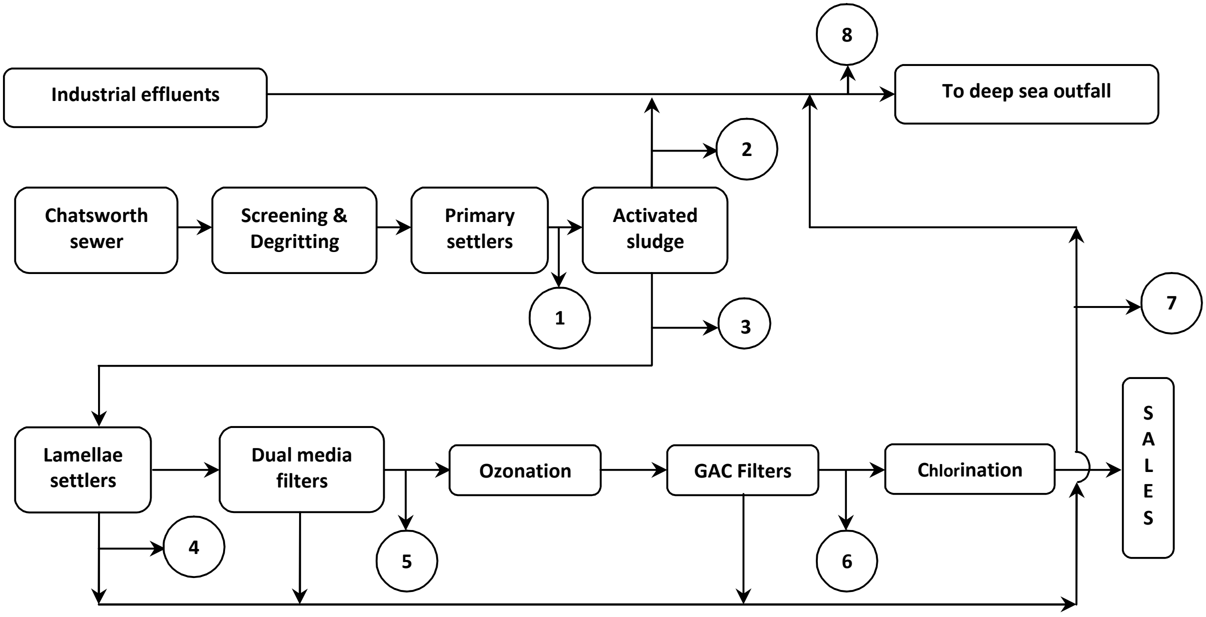
Objective of Case Study: To study a successful case of multi-sector partnership for water management and reuse projects.

Background of Case Study: The municipal authority, called “Durban Metro”, experienced a dramatic population increase following the abolition of Apartheid. The population increased from 1 million to nearly 3 million due to the incorporation of 30 local authorities and surrounding townships into the metropolitan area. As a result, Durban Metro was under considerable pressure to provide basic services to its growing domestic customers, among whom 26% live in the townships and rely on standpipes for clean drinking water. Moreover, several industries are located in this area. In particular, Mondi Paper Mill and SAPREF refinery need a continuous supply of high quality water for process and cooling purposes. Unfortunately, natural water resources are not sufficient in the region to meet the increasing demand for water of drinking and ultrapure quality: the average rainfall is 200 mm/year, and the region suffers from periodic droughts. In order to develop a workable solution to the water and sanitation problems of developing countries, the KwaZulu Natal pilot project was launched. It was part of the Worldwide “Business Partners for Development” (BPD) programme created by the World Bank in 1998. This project allowed Durban Metro to install and operate a new affordable distribution network for the townships through innovations in service delivery and tariff structures – first 200 l/day of water was free for domestic customers. This was the result of a successful tri-sector partnership (public-private-NGOs). Based on the success of this first initiative, the Durban Metro authority decided to go further by implementing a public-private partnership water reuse project: the Durban Water Recycling (DWR) Project.

Salient Features: The Durban Water Recycling (DWR), run by Vivendi Water in association with the Durban Metro, was commissioned adjacent to the Southern Wastewater Treatment Works in May 2001. The DWR Project receives effluent from the Southern Wastewater Treatment Works and treats it to an acceptable standard for industrial use. The project included treating primary sewage and re-purifying the 47,500 m^3/day reclaimed water. As a result, about 7% of Durban's total wastewater generated (i.e. equivalent to the demand for 220,000 households in the area) was reclaimed as high quality water conforming to the South African water standard (SABS 241:1999) and supplied to the Mondi Paper Mill and SAPREF Refinery at a cost 25% lower than potable water instead of being discharged to the sea. The purification of the wastewater was handled by the newly refurbished Southern Wastewater Treatment Works based on activated sludge process (ASP) and integrating the water recycling plant consisting of tertiary treatment including dual media filtration, ozonation, granular activated carbon (GAC) filters and chlorination. The flow diagram of the Southern Wastewater Treatment Works integrated with the Durban Water Recycling (DWR) Plant is shown in Figure 1.

The Durban Metro was able to overcome the challenge of supplying drinking water to a number of people drastically increased by the abolition of the Apartheid due to the commissioning of the DWR project. The success of this project led to the following beneficial outcomes:

- The reclaimed water produced a low cost, high quality water supply for its industrial customers;
- Reclaimed water is more than 25% cheaper than the potable supply;
- Seven percent of Durban's total wastewater generated is recycled, which means that 7% more potable water is available for the community, which is equivalent to the demand for 220,000 households; and
- The flow to the overloaded sea outfall was reduced, thus extending its life and providing environmental protection to the region.



1. Influent to the ASP; **2.** Waste activated sludge (WAS); **3.** Effluent from the ASP; **4.** Sludge underflow from the lamellae settlers; **5.** Effluent from the dual media filters; **6.** Effluent from the GAC filters; **7.** Tertiary sludges underflow; **8.** Sea outfall

Figure 1: Flow diagram of the Southern Wastewater Treatment Works integrated with the Durban Water Recycling (DWR) Plant

Reference

Friedrich, E., Pillay, S., Buckley, C., 2004. The environmental impacts of potable and recycled water: a case study on effluent toxicity. In: Proceedings of the 2004 Water Institute of Southern Africa (WISA) Biennial Conference, 2-6 May, 2004, Cape Town, South Africa, pp. 253–262.

MED WWR WG, 2007. Mediterranean Wastewater Reuse Report, Mediterranean Wastewater Reuse Working Group (MED WWR WG), November 2007.

3.4 Gerringong Gerroa, Nsw, Australia

Title of Case Study: Gerringong Gerroa Sewerage Scheme (GGSS), New South Wales, Australia

Type of Case Study: Reuse of municipal wastewater for irrigation purposes.

Objective of Case Study: To demonstrate an effluent reuse system with significant health and ecological benefits.

Background of Case Study: Gerringong and Gerroa are coastal towns with 3,500 permanent local residents. They are located 120 km from Sydney on the South East Cost of Australia. The region is a popular holiday destination and very well known for its diversified flora and fauna, as well as its beaches. This is why there was a public demand to minimize the effluents' negative impacts when released to the environment, especially considering that before the project started in June 2001, the area did not have a reticulated system and total wastewater generated passed to septic tanks. The existing sewerage facilities in the two towns consisted of on-site systems. Improper maintenance of these on-site systems resulted in rapid deterioration of effluent quality. This delicate situation held potential health risks, and contributed to the decline of the water quality in the local waterways and the bathing water quality. In this context, the Gerringong Gerroa sewerage scheme (GGSS) was implemented in 2001 and consisted of the construction of a state of the art wastewater treatment plant (WWTP) in the Gerringong Gerroa region which became operational in 2002.

Salient Features: The sewerage scheme was designed to meet the local community needs up to the year 2022 for an estimated population of 11,000 inhabitants. Sewage is treated using a high level of tertiary treatment, including: inlet works comprising screening, de-gritting and flow measuring; secondary and tertiary treatment using biological treatment, clarification and sand filtration; advanced tertiary treatment involving ozonation, biological activated carbon (BAC), microfiltration and disinfection. The flow diagram of the Gerringong Gerroa Wastewater Treatment Plant for wastewater Reuse under the GGSS is presented in Figure 2. The effluent reuse system is designed to reuse up to 80% of the treated effluents produced. Final effluent is stored in a 50,000 m^3 storage reservoir before being pumped to a local dairy farm to be reused for pasture irrigation. When irrigation is not possible and the storage reservoir is full, high quality effluent is discharged to the local receiving waters via an on-site dunal system. The plant also produces Grade A biosolids that are recycled and used for land application.

The effluent reuse plant under the GGSS has provided improved wastewater services to more than 2,000 households. The reuse plant facilitates in reusing at least 80% effluent and 100% biosolids for agricultural purposes. Development and tourism in the area has increased and pollution to local streams (Crooked River and Blue Angle Creek), lagoons (Werri Lagoon) and beaches decreased substantially resulting in a positive impact to the area. Furthermore, the advanced wastewater treatment scheme enables water reuse on neighboring agriculture properties. This scheme is regarded as one of the most innovative ecologically sustainable sewerage schemes in Australia utilizing global best practice in water treatment processes.

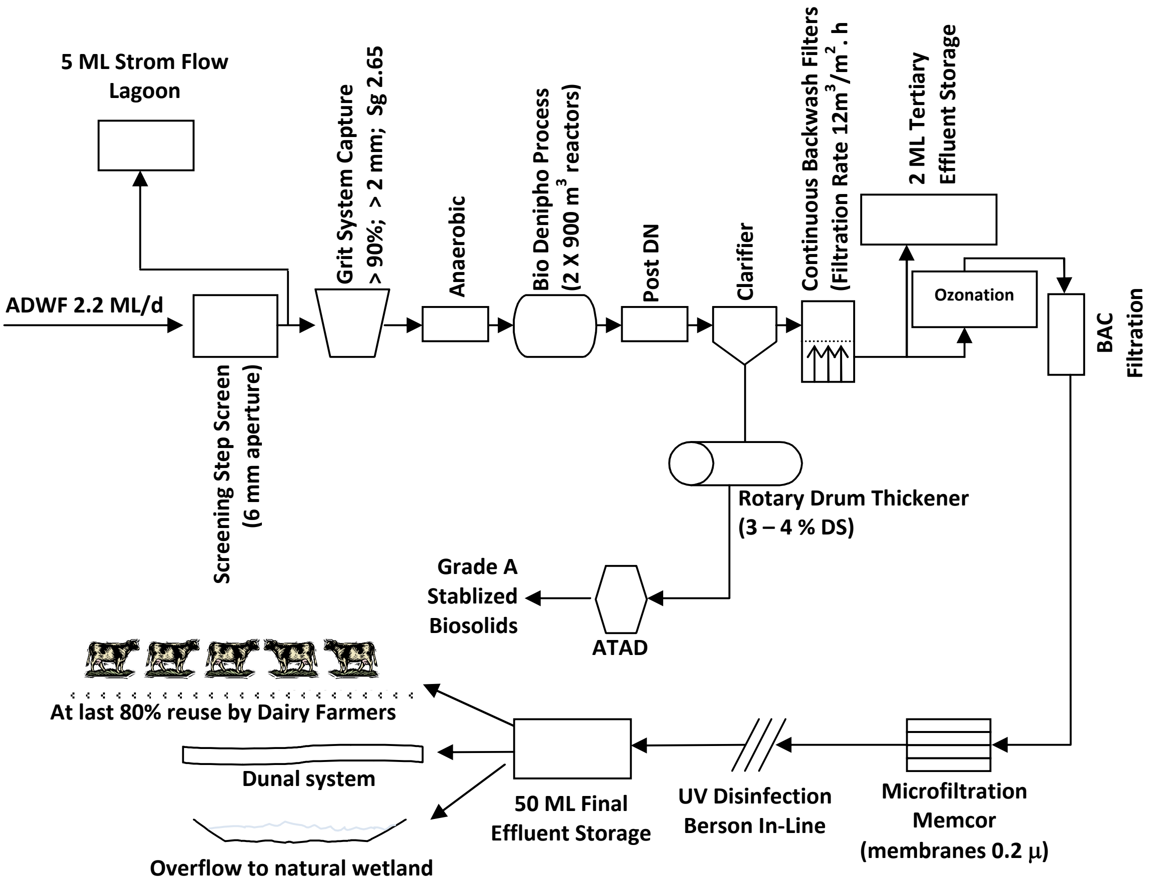


Figure 2: **Flow diagram of the Gerringong Gerroa Wastewater Treatment Plant for Wastewater Reuse**

Reference:

Boake, M.J., 2006. Recycled water – case study: Gerringong Gerroa. Desalination 188, 89–96.

MED WWR WG, 2007. Mediterranean Wastewater Reuse Report, Mediterranean Wastewater Reuse Working Group (MED WWR WG), November 2007.

3.5 Ochiai Water Reclamation Center for Meguro River Restoration, Tokyo, Japan

Title of Case Study: Ochiai Water Reclamation Center for Meguro River Restoration, Tokyo, Japan by Tokyo Metropolitan Government

Type of Case Study: Beneficial treated wastewater reuse for river restoration.

Objective of Case Study: To demonstrate wastewater reuse system for river water quality and biodiversity restoration.

Background of Case Study: The Meguro River, which flows through a residential area in Tokyo, had been abandoned by residents due to the decreasing flow of water and increasing pollution with an unpleasant color and odor due to ever increasing urbanization since the Meiji Period. In order to restore river water quality and biodiversity, the Tokyo Metropolitan Government used highly treated effluent from the Ochiai Water Reclamation Center to discharge into the river.

Salient Features: Located very close to the sub-center of the Shinjuku area, the Ochiai Water Reclamation Center is environment-friendly and thoroughly controlled as a water reclamation center surrounded by residential districts. The treatment area includes most of Nakano-ward and a part of Shinjuku-ward, Setagaya-ward, Shibuya-ward, Suginami-ward, Toshima-ward and Nerima-ward, totaling 3,506 ha in area. The treatment units of the reclamation center include grit chamber and primary sedimentation tank as preliminary and primary treatment, activated sludge process (ASP) as secondary treatment and A_2O process for nutrient removal, sand and membrane filtration and UV radiation as tertiary treatment. The schematic of the sequence of various treatment units of the Ochiai Water Reclamation Center is presented in Figure 3. The highly treated water (Table 2) is discharged for restoration of streams in Meguro River and other two rivers which nearly dried up in the southern downtown area of Tokyo and some part of the treated water is used effectively for flushing water in toilet in buildings of Nishi-shinjuku and Nakano-sakaue districts. The generated sludge is pumped through pressure pipelines to Tobu sludge plant for treatment. With the drastic improvement in water volume and quality, various living species have returned to the Meguro River. The condition of the Meguro River before and after restoration is shown in Figure 4. Many insects and small animal populations have been re-established, and fish such as Japanese trout, striped mullets and gobies also returned to the river after the introduction of highly treated water. Biodiversity and environmental amenities have thus been restored effectively with wastewater reuse.

Table 2: Average Influent and Effluent Water Quality for the Ochiai Water Reclamation Facility

Parameters	Intake water		Discharge Water	Regional water quality standards
	Low stage	High stage	High stage	
BOD_5 (mg/L)	220	190	1	25 or bellow
COD (mg/L)	92	92	7	—
Total nitrogen (mg/L)	31.7	27.9	11.5	30 or bellow
Total phosphorus (mg/L)	3.7	3.0	1.5	3.0 or bellow

Reference:

MED WWR WG, 2007. Mediterranean Wastewater Reuse Report, Mediterranean Wastewater Reuse Working Group (MED WWR WG), November 2007.

UNEP, 2005. Water and Wastewater Reuse: An Environmentally Sound Approach for Sustainable Urban Water Management, United Nations Environment Programme, Osaka, Japan.

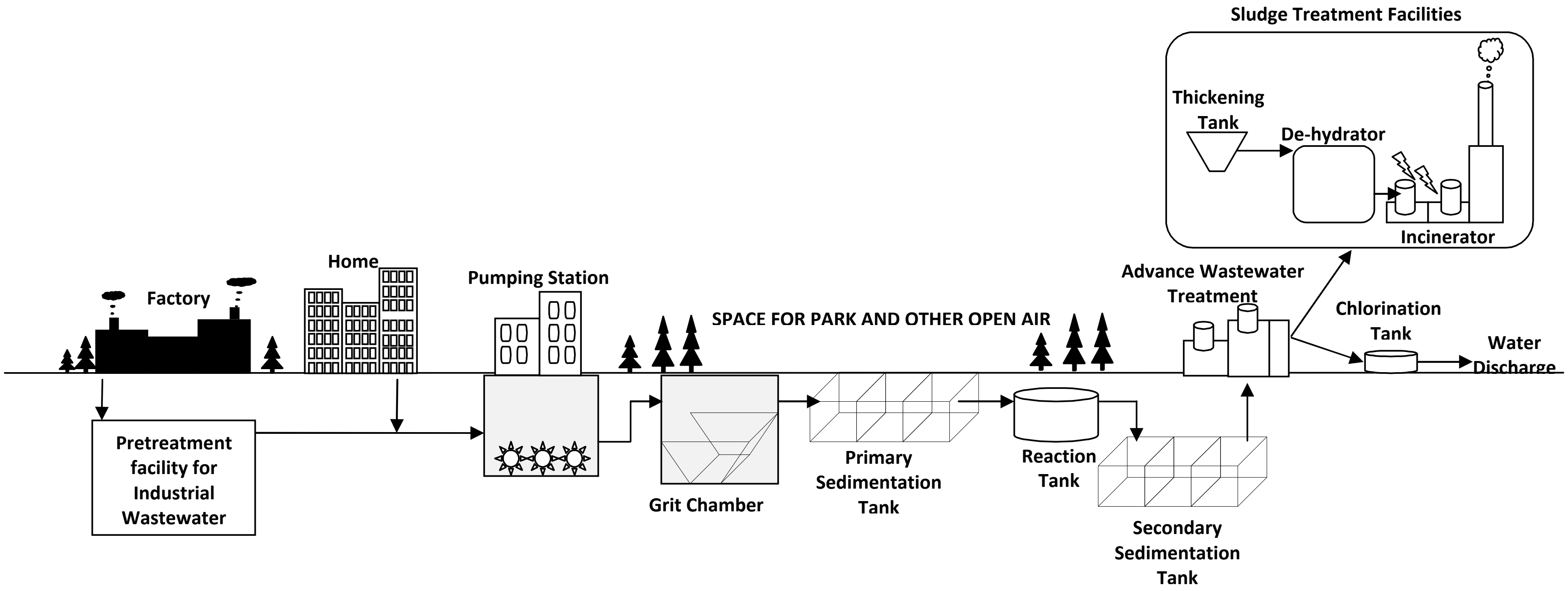


Figure 3: The Sequence of Treatment Units in Ochiai Water Reclamation Facility for Wastewater Reclamation

(a) (b)

Figure 4: The Condition of Meguro River (a) Before and (b) After the Restoration using Reclaimed Wastewater

3.6 Pomona Water Reclamation Plant With Integrated Aqua-Culture Wetland Ecosystem, Los Angeles County, California, USA

Title of Case Study: Pomona Water Reclamation Plant with Integrated Aquaculture-Wetland Ecosystem (AWE), Los Angeles County, California, USA
Type of Case Study: Reuse of municipal wastewater for irrigation purposes.

Objective of Case Study: To demonstrate an effluent reuse system with significant health and ecological benefits.

Background of Case Study: Los Angeles (LA) County, California is a severely water-stressed region, depending on imported water from the neighboring river basins (Colorado River for example). However, the imported supplies are dependent on climate variability, environmental, political and energy consumption issues. Over 90% of LA's wastewater was discharged into the San Gabriel River then to ocean, or directly into the ocean at San Pedro Bay. In this context, there has been an increasing effort to upgrade all of LA's treatment plants to tertiary wastewater facilities and to expand water markets for wastewater reuse inland as an alternative to ocean disposal in order to maintain integrated water resources management.

Salient Features: The Pomona Water Reclamation Plant (WRP) is located at 295 Humane Way in the City of Pomona. The plant occupies 14 acres northeast of the intersection of the Pomona and Orange Freeways. The original plant was known as the Tri-City Plant and was owned by the cities of Pomona, Claremont, and La Verne. It was placed into operation in July 1926 with effluent reuse beginning in 1927. The Sanitation Districts took over operations in 1966 and increased the plant capacity to 4 MGD/day (15.16 MLD). In 1970, the plant capacity was expanded to 10 MGD/day (37.9 MLD) with the construction of additional primary, aeration, and final sedimentation tanks. In 1977, the plant capacity increased to 15 MGD/day (56.85 MLD) with the implementation of tertiary level wastewater treatment, including activated-carbon gravity filters, chlorine contact tanks, and a dechlorination system. In the early 1990s, the plant underwent a third expansion with the construction and retrofit of the activated-carbon gravity filters to deep bed anthracite filters and the addition of a third chlorine contact tank for additional disinfection capacity.

Currently, the Pomona WRP provides primary, secondary and tertiary treatment of wastewater at 13 MGD/day (49.27 MLD) (see Figure 5). The plant serves a population of approximately 130,000 people. Approximately 8 MGD/day (30.32 MLD) of the purified water is reused at over 90 different reuse sites. Reuse includes landscape irrigation of parks, schools, golf courses, greenbelts, etc.; irrigation and dust control at the Spadra Landfill; and industrial use by local manufacturers. The remainder of the purified water is put back into the San Jose Creek channel where it makes its way to the unlined portion of the San Gabriel River. Therefore, nearly 100% of the water is reused since most of the river water recharges into the ground water.

Although it is a common perception that tertiary sewage treatment plants (TSTPs) are the preferred method of waste utilization and are ‘environmentally friendly’, many TSTPs do not remove inorganic nitrogen and phosphorus to levels below which these nutrients stimulate marine aquatic production. Therefore, the existing WRP is further upgraded using an aquaculture–wetland ecosystem (AWE) to simultaneously accomplish aquatic food production and inorganic nitrogen removal from the tertiary-treated wastewater received from the Pomona, TSTP. The AWE consists of a 28-m^3 wastewater supply tank, three 200–240 m^2 (1-m deep) aquaculture ponds, and a 0.05 ha artificial wetland (Figure 6).

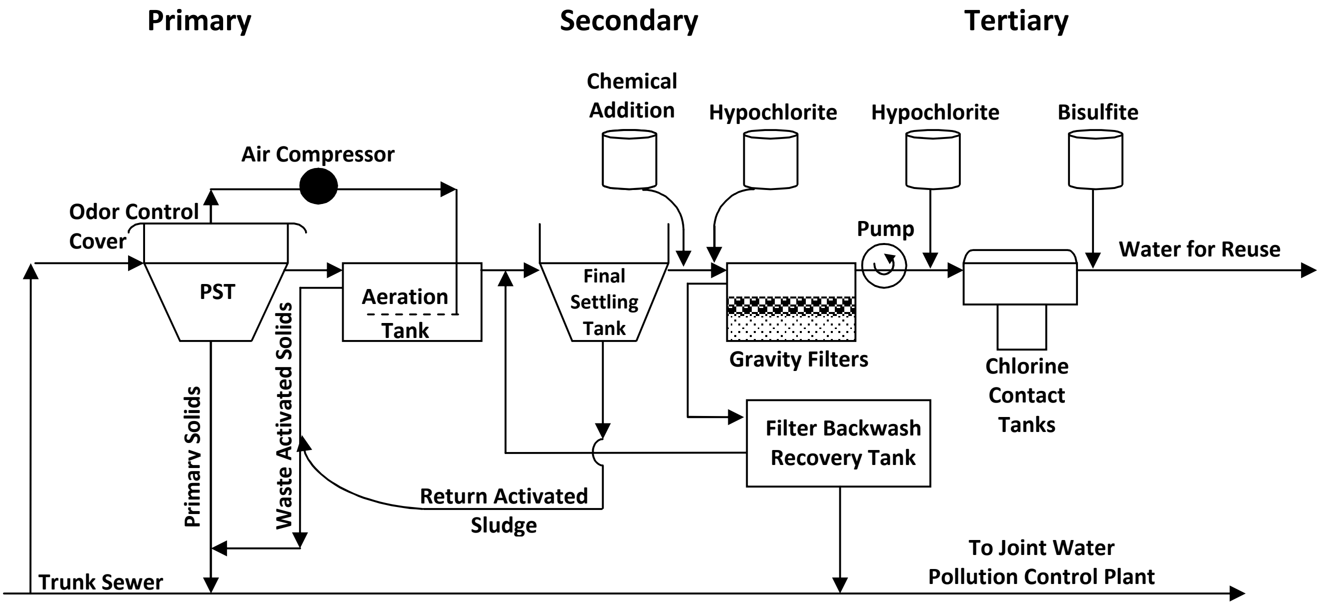


Figure 5: Flow diagram of the Pomona Water Reclamation Plant (WRP), Los Angeles County, California, USA

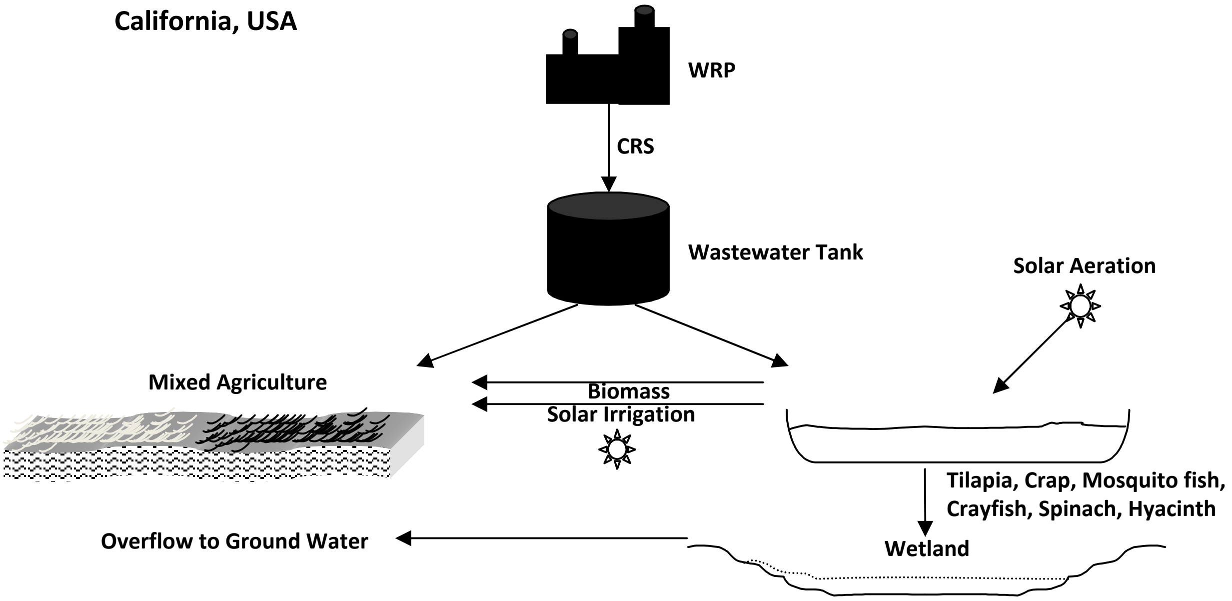


Figure 6: Flow Diagram of the Integrated Aquaculture-Wetland Ecosystem (AWE)

The wetland is a simple bowl-shaped depression where waters are impounded by a rock dam. The wetland develops a *Typha*–water hyacinth–duckweed (*Lemna* sp.) aquatic plant community on its own, with the emergent plants and duckweed comprising about 50% of the surface area of the wetland, and the water hyacinths occupying the remainder. Reclaimed wastewater is pumped from the Pomona TSTP to the storage tank located on a hill. Ponds are filled initially by gravity with a mixture of 50% potable water: 50% reclaimed water to allow water hyacinths to get established, thereafter they are flushed 20% per week with reclaimed water. A polyculture species stocking is used which defined 'target' and 'janitor' species. The target species are hybrid, all male, sex-reversed tilapia (*Oreochromis mossambicus_O. hornorum*). Janitor fish species stocked are common carp (*Cyprinus carpio*) and mosquitofish (*Gambusia affinis*). Water hyacinths (*Eichhornia crassipes*) are added to all ponds at 10–20% of the pond area and maintained at about 50% of the pond surface area by use of floating booms and manual harvesting every 2 weeks. The AWE accomplishes aquatic food production and almost complete removal of inorganic nitrogen from wastewater, functioning as a 'quaternary' wastewater treatment/food production ecosystem. The case study demonstrates that the concept of using tertiary-treated wastewater for aquatic food production may be attractive in the peri-urban areas of many mega-cities like Los Angeles, both for fish markets and to stem the growing discharges of wastewaters that are causing coastal pollution.

Reference:

Costa-Pierce, B.A., 1998. Preliminary investigation of an integrated aquaculture - wetland ecosystem using tertiary-treated municipal wastewater in Los Angeles County, California. Ecol. Eng. 10, 341–354.

LACSD, 2010. Ponoma Water Reclamation Plant, Sanitation Districts of Los Angeles County (LACSD). In Website:http://www.lacsd.org/about/wastewater_facilities/joint_outfall_system_water_reclamation_plants/pomona.asp (Accessed on January 02, 2010).

3.7 Florida Water Reuse Program, Florida, USA

Title of Case Study: Florida Water Reuse Program, Florida, USA

Type of Case Study: Reuse of domestic wastewater for the purposes of land application and residential irrigation, groundwater recharge and indirect potable reuse and industrial use of reclaimed water.

Objective of Case Study: To encourage and promote water reuse in Florida in compliance with the state objective for conserving freshwater supplies and preserving rivers, streams, lakes, and aquifers.

Background of Case Study: Florida is the fourth most populous state in the USA and population is projected to grow from about 16 million in 2000 to about 21 million in 2020. While Florida receives a large amount of rainfall every year compared to other states, the distribution is not even throughout the year and across the state. As the state continues to grow, demand for fresh water also will increase. In 1995, Florida used about 7.2 billion gallons of water each day (27,288 MLD). By 2020, water use is forecast to grow to 9.1 billion gallons per day (34,489 MLD). Florida is the largest user of irrigation water east of the Mississippi River. In 2020, agriculture is expected to account for about 46 percent of Florida's total demand for fresh water. Public water supply will account for about 34 percent of the total. The remaining 20 percent of water use will be associated with industrial/commercial/electric generation, recreational irrigation, and domestic self supply. In 2001, Florida's domestic wastewater treatment plants had a total capacity of about 2,220 MGD (8414 MLD) and actually treated about 1,486 MGD (5,632 MLD). In 2020, it is estimated that wastewater flows to be treated will reach 1,950 MGD (7,390 MLD). This represents 1,950 MGD (7,390 MLD) of a water resource that can and should be reclaimed and reused for beneficial purposes. Periodic droughts combined with increased demand for fresh, clean surface and groundwater for public consumption have resulted in periodic and prolonged water shortages. Conservation measures such as irrigation and groundwater recharge with reclaimed water are viewed as the plausible ways to reduce the use of existing potable water supplies and tackle the water shortages.

Salient Features: The Florida Department of Environment Protection (DEP) began looking at ways to promote reuse of reclaimed water in 1987. Reuse systems serving Tallahassee and St. Petersburg significantly influenced reuse in Florida and paved the way for today's multitude of excellent, innovative reuse projects. Table 3 shows the different types of reuse systems in Florida and a brief description of the treatment and disinfection requirements for each. As per the Florida Water Reuse 2009 inventory, a total of 484 domestic wastewater treatment facilities (WWTF) with permitted capacities of 0.1 MGD (0.379 MLD) or above that make reclaimed water available for reuse are there in the Florida state. These facilities have WWTF capacity totaling 2,287 MGD (8,668 MLD) and treated 1,421 MGD (5,386 MLD) of domestic wastewater in 2009. These treatment facilities serve 433 reuse systems. Approximately 673 MGD (2,551 MLD) of reclaimed water from these facilities is reused for beneficial purposes. The total reuse capacity associated with these systems is 1,559 MGD (5,909 MLD). Figure 7 shows the percentage of reclaimed water utilization by flow for each reuse type as per the Florida Water Reuse 2009 inventory. Irrigation of areas accessible to the public like residential areas, golf courses, athletic fields, parks, etc. represented about 56 percent of the 673 MGD (2,551 MLD) of reclaimed water reused. Reclaimed water from these systems was used to irrigate 276,471 residences, 533 golf courses, 873 parks, and 306 schools. Following public access areas, the next largest uses are industrial uses (14%) such as cooling water in power plants and groundwater recharge (13%). Most of the reclaimed water used for agricultural irrigation is used to grow feed, fiber, or other crops that are not for direct human consumption. Over 12,750 acres of edible crops on 75 farms are reported to be irrigated with reclaimed water. A demonstrative video on the Florida Water Reuse Program is available and can be viewed at: http://www.dep.state.fl.us/water/reuse/

In addition to the Florida Water Reuse Program, the Hazen and Sawyer in partnership with another national firm the Miami-Dade Water and Sewer Department are currently designing 21 MGD (79.6 MLD) South District Water Reclamation Plant (SDWRP), the largest advanced wastewater reclamation plant of its kind in the State of Florida, for replenishment of the Biscayne Aquifer via rapid infiltration, in which the domestic wastewater that has been treated to meet drinking water standards percolates through the soil down to the groundwater level. The SDWRP is planned to upgrade the South District Wastewater Treatment Plant (SDWWTP) and will treat secondary effluent from the SDWWTP which adds High Level Disinfection (HLD) to the existing pure oxygen secondary treatment plant. The first step in the treatment process will be strainers followed by microfiltration (MF) or ultrafiltration (UF) to minimize suspended solids from the secondary effluent. The RO treatment process at the SDWRP will remove organic carbon (TOC), total organic halides (TOX), and significantly reduce nitrogen and phosphorus to satisfy potable reuse and environmental application requirements. Microconstituents and emerging pollutants of concern (EPOC) will also be reduced in the final step of the process which includes advanced oxidation processes (AOP) like ultraviolet light (UV) application and hydrogen peroxide (H_2O_2) addition to form hydroxyl radicals (OH^-) which oxidize most organic compounds.

Table 3: Different Type of Reuse Systems under Florida Water Reuse Program

Reuse System Type	Reuse Activities	Treatment and Disinfection Requirements
Slow-rate land application systems; restricted public access	• Irrigation of pastures, trees, feed, fodder, fiber, or seed crops	Secondary treatment and basic disinfection
Slow-rate land application systems; public access areas, residential irrigation, and edible crops	• Residential, golf course, and other landscape irrigation • Toilet flushing • Fire protection • Dust control • Aesthetic features (ponds and fountains) • Irrigation of edible crops (direct contact only with crops that will be peeled, skinned, cooked, or thermally processed)	Secondary treatment, filtration, and high-level disinfection
Rapid-rate land application systems	• Rapid Infiltration Basins (RIBs) • Absorption Fields	Secondary treatment, basic disinfection, < 12 mg/L NO_3-N
Groundwater recharge and indirect potable reuse	• Salinity barriers • Augmentation of surface waters	Principal treatment and disinfection or full treatment and disinfection (depending on use)
Industrial uses of reclaimed water	• Cooling water • Wash water • Process water (not to include food processing for human consumption)	Secondary treatment and basic disinfection (additional treatment may be needed to meet needs of a particular application)

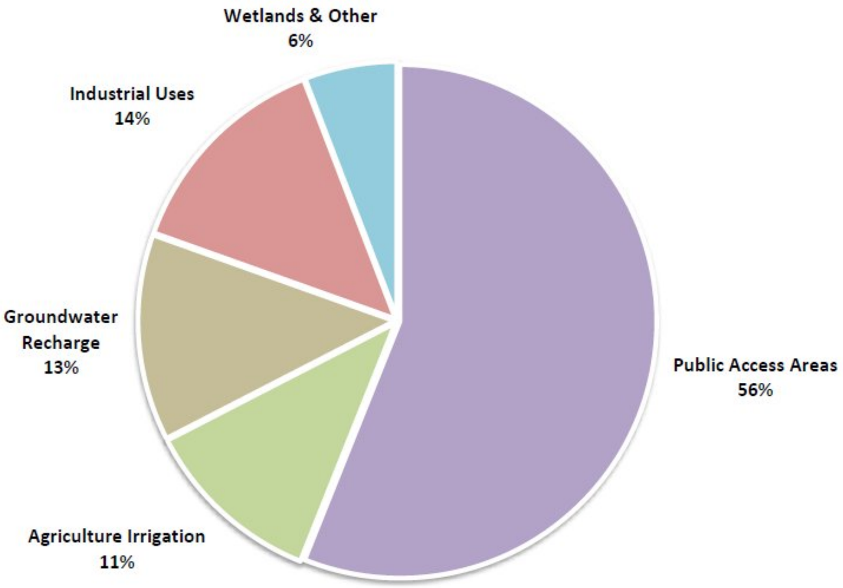


Figure 7: Reclaimed Water Utilization by Flow in Florida as per Water Reuse 2009 Inventory

Reference:

FDEP, 2007. Reuse of Reclaimed Water and Land Application: Rule 62-610 Florida Administrative Code (FAC), Florida Department of Environmental Protection (FDEP), 2007. In Website: http://www.dep.state.fl.us/legal/rules/wastewater/62-610.pdf (Accessed on January 05, 2011).

FDEP, 2010. 2009 Reuse Inventory, Florida Water Reuse Program, Florida Department of Environmental Protection (FDEP), September 2010. In Website: http://www.dep.state.fl.us/water/reuse/inventory.htm (Accessed on January 05, 2011).

Florida Council of 100, 2003. Improving Florida’s Water Supply Management Structure: Ensuring and Sustaining Environmentally Sound Water Supplies and Resources to Meet Current and Future Needs, Florida Council of 100, September 2003. In Website: http://www.fc100.org/reports/waterreportfinal.pdf (Accessed on January 05, 2011).

Hazen and Sawyer, 2011. Wastewater Reuse Project Will Boost Florida’s Water Sustainability, Hazen and Sawyer, P.C., New York, USA, 2011. In Website: http://www.hazenandsawyer.com/news/wastewater-reuse-project-will-boost-floridas-water-sustainability/ (Accessed on January 05, 2011).

3.8 Singapore Water Reclamation Study (Newater Study), Singapore

Title of Case Study: Singapore Water Reclamation Study (NEWater Study), Singapore

Type of Case Study: A joint initiative between the Public Utilities Board (PUB) and the Ministry of the Environment (ENV) of Singapore to demonstrate the suitability of using NEWater (advanced treated wastewater) as a source of raw water to supplement Singapore's water supply.

Objective of Case Study: (i) To design, construct, commission and operate an advanced water reclamation plant for production of drinking water from wastewater for planned indirect potable reuse (IPR), (ii) to conduct a Sampling and Monitoring Programme (SAMP) for comprehensive physical, chemical and microbiological sampling and analysis of reclaimed water to assess its suitability as a source of raw water for planned IPR, and (iii) to run a Health Effects Testing Programme (HETP) to complement the comprehensive SAMP to determine the safety of reclaimed water.

Background of Case Study: Singapore has a population of 4.4 million people on an island with a land area of 700 km^2. Low land area in combination with high population density lead to consider Singapore to be a water-scarce country. Increased water demand due to population and economic growth, environmental needs, change in rainfall, flood contamination of good quality water and over abstraction of groundwater are all factors that continue to create water shortage problems. Singapore had a long-term agreement with the Malaysian Government to import water to meet its ever increasing water demand of 350 MGD (1,3266 MLD) at a price of less than one Singapore cent per 3,785 L. Due to the conflict related to the price for importing water from Malaysia, Singapore decided to embark on a water reclamation programme in order to ensure self-sufficiency in water.

Salient Features: Singapore has a unique political driver to ensure that its water consumption becomes self-sufficient by promoting wastewater reuse and will not have to rely on sources from Malaysia. In order to become self-sufficient in water and to promote wastewater reuse as an alternative source of raw water, The Public Utilities Board (PUB), a Government-owned utility for managing the country's entire water cycle in association with the Ministry of the Environment (ENV) of Singapore initiated a Water Reclamation Study (NEWater Study) in 1998. The NEWater Plant is a 10,000 m^3/d advanced water reclamation plant employing state-of-the-art dual-membrane (microfiltration and reverse osmosis) and UV disinfection treatment process train. The NEWater Plant treatment process train is shown in Figure 8.

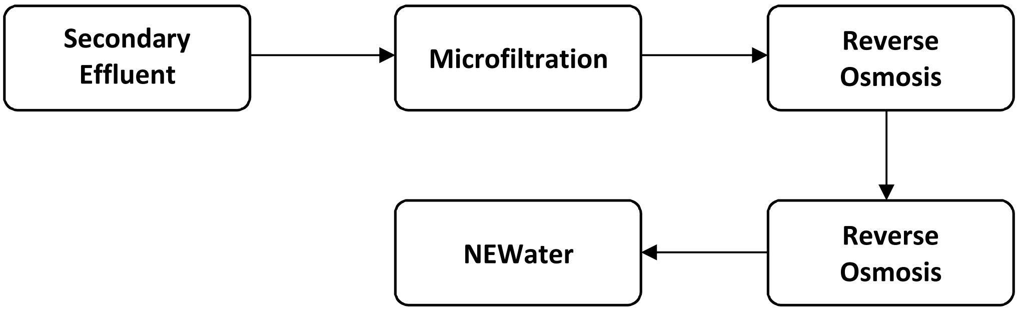


Figure 8: Treatment Process Flow Diagram of the NEWater Reclamation Plant, Singapore

This NEWater plant was built on a compact site downstream of the Bedok Water Reclamation Plant (WRP) (formerly known as Bedok Sewage Treatment Works) as the Bedok WRP receives more than 95% of its wastewater from domestic sources and commenced its operation in May 2000. The NEWater plant receives clarified secondary effluent as feed water from an activated sludge process with typical characteristics: 10 mg/L BOD_5, 10 mg/L TSS, 6 mg/L NH_4^+-N and 400 to 1,600 mg/L total dissolved solids (TDS) including 12 mg/L of total organic carbon (TOC). The secondary effluent is first subjected to micro-screening (0.3 mm) followed by microfiltration (MF) (pore size: 0.2 µm) for removal of fine solids and particles, and then demineralization in two parallel 5,000 m^3/d (5 MLD) reverse osmosis (RO) trains fitted with thin-film aromatic polyamide composite membranes configured for 80 to 85% recovery in a three-stage array. The RO permeate is disinfected by ultraviolet irradiation using three UV units in series equipped with broad-spectrum medium pressure UV lamps delivering a minimum design total UV dosage of 60 mJ/cm^2 as the final step. In order to control the rate of biofouling in the membrane systems, chlorine is added at two points before and after MF. The end product of the reclamation plant is called NEWater. Table 4 presents and compares the original plant design criteria against actual plant performance (monthly averages) since operation in May 2000. NEWater is considered to be safe for potable use as it is evaluated by the comprehensive SAMP and meets the stringent requirements of the USEPA's National Primary and Secondary Drinking Water Standards and the WHO's Drinking Water Quality Guidelines. Also, the findings from the HETP confirms that exposure to or consumption of NEWater does not have carcinogenic (cancer causing) effect on the mice and fish, or estrogenic (reproductive or developmental interference) effect on the fish. The average unit power consumption at NEWater Plant varies in the range of 0.7 to 0.9 kWh/m^3. The successful operation of the NEWater Reclamation Plant is a good example of the unique political will and the government initiative to drive and promote wastewater as an alternative source of water in order to address the country's water scarcity challenge.

Table 4: Design Specifications against the Actual Performance of NEWater Reclamation Plant

Parameter	Design Specification	Actual Performance
pH	None	5.9
TOC Removal (%)	> 97	> 99
NH_4^+-N Removal (%)	> 90	> 94
TDS Removal (%)	> 97	> 97
MF Filtrate Turbidity (NTU)	≤ 0.1	≤ 0.1

The outcome of the NEWater Reclamation Plant led the PUB to embark on new initiatives to supply NEWater to industries for non-potable use. Towards the new initiatives for wastewater reclamation, the PUB in association with the Vivendi Water Systems Asia set up a 40,000 m^3/d dual-membrane high grade water reclamation plant (HGWRP) at Kranji, Singapore and the plant started operation at the end of December 2002. The plant is designed to allow future expansion of capacity up to 72,000 m^3/d. The plant combines Memcor's CMF-S (Microfiltration) with Reverse Osmosis (RO) and UV to produce high purity water from secondary effluent. The CMF-S Submerged Continuous Microfiltration process combines Memcor's proven pressurized CMF product know-how with a submerged configuration to achieve increased product scale and improved operating economies. The multiple barrier approach in the plant ensures pathogen removal in wastewater. The main unit processes in the plant include:

- Secondary effluent pumping combined with chlorine dosing and equalization tank;
- Microfiltration: 6 units of 480S10T CMF-S cells;
- Filtered water storage combined with chlorine dosing;
- 5 units of two-stage (49 vessels 1st stage, 24 vessels 2nd stage, 7 elements/vessel) RO trains;
- 3 units of UV irradiation for disinfection; and
- Product water storage and pumping combined with pH and chlorine control.

Reference:

Durham, B., Koh, W.K., Thompson, G., Biltoft, B., 2002, Membrane Filtration - An Effective Pretreatment to RO in Water Reclamation Experience in the Municipal & Industrial Sectors, In: *Proceedings of the Water / Wastewater Management Conference*, November 20-21, 2002, Shangri-la Hotel, Singapore.

Singapore Public Utilities Board (PUB), 2002, Singapore Water Reclamation Study: Expert Panel Review and Findings Report, Singapore Public Utilities Board (PUB), June 2002. In Website: http://www.pub.gov.sg/water/newater/NEWaterOverview/Documents/review.pdf (Accessed on April 12, 2011).

Thompson, M., Powell, D, 2003, Case Study – Kranji High Grade Water Reclamation Plant, Singapore, In: *Proceedings of the IMSTEC '03*, September 2003, Sydney, Australia.

3.9 Wastewater Treatment Recycling Plants, Bangalore Water Supply and Sewerage Board (BWSSB), India

Title of Case Study: Wastewater Treatment Recycling Plants (60 MLD Vrishabhavathy Valley TTP; 10 MLD Yelahanka TTP), Bangalore Water Supply and Sewerage Board (BWSSB), India
Type of Case Study: Reuse of municipal and industrial wastewaters for non-potable and industrial uses.

Objective of Case Study: Recycling and reuse of wastewater in order to meet the water demands of ever growing population of Bangalore city in view of limited water resource and to reduce the high energy cost for pumping of water from Cauvery River.

Background of Case Study: Bangalore city has limited raw water resources to meet its water demands for ever growing population. City is almost completely depending on the Cauvery River, located more than 100 km away from the city for its requirements. The pumping of water from the river for water supply involves an exorbitantly high energy costs. In view of extremely finite source of raw water and high energy cost for pumping of water, the recycling and reuse of wastewater becomes absolutely imperative in Bangalore city and prompted the Bangalore Water Supply and Sewerage Board (BWSSB) to undertake a major initiative towards the recycling of wastewater. The BWSSB planned and established the two tertiary treatment plants (TTPs) in Bangalore at Yelahanka (capacity: 10 MLD) and another at Vrishabhavathy Valley (capacity: 60 MLD) for water recycling and reuse.

Salient Features: The 10 MLD TTP with recycling facilities at Yelahanka with funding support from KUIDFC/HUDCO under Megacity scheme and through Indo-French protocol has been commissioned in May 2003 for the BWSSB. The Yelahanka TTP has three treatment stages, viz., primary treatment, secondary treatment and tertiary treatment. The collected wastewater from Yelahanka is initially subjected to primary stage treatment (screening, grits and grease removal), followed by the secondary stage using primary settling and activated sludge process. Tertiary filtration (using sand and gravel) along with coagulation with aluminium sulphate are provided to the effluent from the secondary stage for removal of suspended solids. The chlorinated recycle water from the TTP is supplied to the ITC Ltd., Wheel and Axel Plant and the new International Devanahalli Airport to meet the non-potable water requirements. The characteristics of raw influent wastewater and tertiary treated effluent at the Yelahanka plant are shown in Table 5. Representative photographs of 10 MLD TTP at Yelahanka, Bangalore are presented in Figure 9.

Table 5: Characteristics of Raw Wastewater and Tertiary Treated Effluent at Yelahanka TTP

Parameter	Raw Wastewater	Treated wastewater
pH	6.8 – 7.5	7.0 – 8.0
Suspended solids (mg/L)	480	<5
Turbidity (NTU)	N.A.	<2
BOD_5 (mg/L)	380	<5
Fecal coliform (MPN/100 ml)	N.A.	<25

Figure 9: Photographs of 10 MLD Tertiary Treatment Plant (TTP) at Yelahanka, Bangalore

The BWSSB commissioned another 60 MLD capacity tertiary treatment plant (TTP) with recycling facilities at Vrishabhavathy Valley with funding support from KUIDFC/HUDCO under Megacity scheme and through Indo-French protocol in May 2003. The V. Valley TTP provides a combination of biological and physiochemical treatment to the secondary effluent from the existing 183 MLD STP based on conventional bio-filter near Kenchenahally. The treatment chain in the V. Valley TTP consists of trickling filter, DENSADEG high rate clarifier (combination flash mixer, lamella separators and counter current flow thickener), FLOPAC aerobic biological filtration unit and chlorine based disinfection. The chlorinated recycle water from the V. Valley TTP is supplied to M/s Karnataka Power Corporation Ltd. at Bidadi and M/s Pulikeshi

Power Corporation Ltd. at Kumbalgod for their power generation plants. Figure 10 shows the photograph of 60 MLD TTP at Vrishabhavathy Valley, Bangalore.

Figure 10: Photographs of 60 MLD Tertiary Treatment Plant (TTP) at Vrishabhavathy Valley, Bangalore

Reference:

BWSSB, 2005a. Recycling Treatment Plants, Vrishabhavathy Valley Tertiary Treatment Plant, The Bangalore Water Supply and Sewerage Board (BWSSB), 2005. In Website: http://www.bwssb.org/ current_project_recycle_treatment_vvalley.html (Accessed on January 11, 2011).

BWSSB, 2005b. Recycling Treatment Plants, Yelahanka Tertiary Treatment Plant, The Bangalore Water Supply and Sewerage Board (BWSSB), 2005. In Website: http://www.bwssb.org/ current_project_recycle_treatment_yehlenka.html (Accessed on January 11, 2011).

3.10 Sewage Reclamation Plant, The Rashtriya Chemicals and Fertilizers (RCF) Plant, Chembur, Mumbai, India

Title of Case Study: Sewage Reclamation Plant, The Rashtriya Chemicals and Fertilizers (RCF) Plant, Chembur, Mumbai, India

Type of Case Study: Reuse of complex wastewater (municipal sewage polluted with various industrial wastes) for industrial uses.

Objective of Case Study: Recycling and reuse of complex wastewater (municipal sewage polluted with various industrial wastes) for non-potable uses in the industry.

Background of Case Study: Municipal sewage generated in the vicinity of the Rashtriya Chemicals and Fertilizers (RCF) Plant, Chembur, Mumbai is heavily contaminated with various streams of industrial wastes and results into complex wastewater. In order to become water self-sufficient and to meet increasing process water requirements, the RCF plant realizes the importance of recycling and reuse of wastewater for non-potable industrial use and commissioned a sewage reclamation plant for the industry.

Salient Features: The RCF Plant commissioned a 23 MLD capacity sewage reclamation plant involving reverse osmosis in the year 2,000 and treats a complex wastewater comprising of the municipal sewage heavily contaminated with various industries wastes. The sewage reclamation plant at the RCF consists of following treatment units:
Screening → Grit Removal → Activated Sludge System → Clarifier → Sand Filter → Pressure Filter → Cartridge Filters → Reverse Osmosis → Degasser to remove CO_2 → Reuse in Industry.
The detailed flow sheet of the sewage reclamation plant for the RCF plant at Chembur is presented in Figure 11.

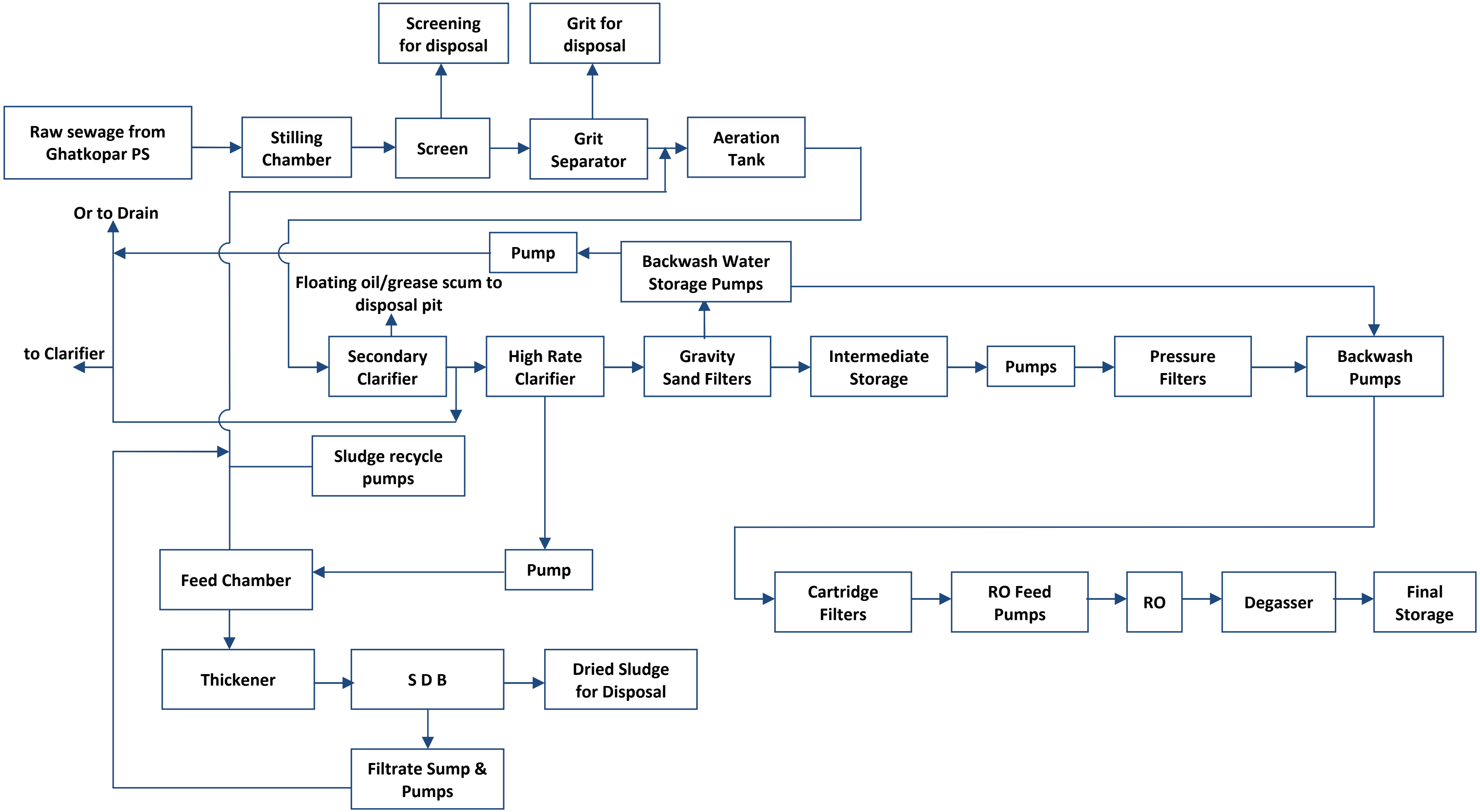


Figure 11: The Detailed Flow Sheet of the 23 MLD Sewage Reclamation Plant for the Rashtriya Chemicals and Fertilizers (RCF) Ltd., Chembur, Mumbai

The plant cost nearly Rs. 40 crores to build in 1998 and the operating cost as reported in 2005 came to Rs. 39/- per m^3. With the passage of time and the success of reuse schemes, the municipal charge levied also became higher at Rs 6/- per m^3 of raw sewage. Some additional treatment steps like use of Ultrafiltration became necessary in order to improve the quality of the water reaching the RO system (keeping the silt density index, SDI < 3.0) owing to the more polluted nature of the influent wastewater.

Reference:

Arceivala, S.J., Asolekar, S.R., 2007. Water Conservation and Reuse in Industry and Agriculture. In: Wastewater Treatment for Pollution Control and Reuse, 2007, Tata McGraw-Hill Publishing Company Limited, New Delhi, pp. 396–425.

3.11 Tertiary Treated Municipal Sewage Reuse, The Madras Refineries Ltd. and The Madras Fertilizers Ltd., Chennai, India

Title of Case Study: Tertiary Treated Municipal Sewage Reuse, The Madras Refineries Ltd. and The Madras Fertilizer Ltd., Chennai, India

Type of Case Study: Reuse of municipal sewage for industrial uses.

Objective of Case Study: Recycling and reuse of municipal sewage for non-potable uses in the refinery and fertilizer plant.

Background of Case Study: Chennai city has perennially finite water resources. Two industries i.e. the Madras Refineries Ltd. (MRL) and the Madras Fertilizer Ltd. (MFL) are the biggest users of water for their process requirements. Both industries commissioned tertiary treatment plant (TTP) for municipal sewage reuse in order to become water self-sufficient and to meet increasing process water requirements.

Salient Features: Since 1991, both the industry i.e. the Madras Refineries Ltd. started reusing municipal sewage producing 12 MLD of reusable water and the Madras Fertilizer Ltd. producing 16 MLD of reusable water. Based on these TTPs, the Chennai Metro Water and Sewerage Board supplies secondary treated sewage (with BOD 120 mg/L even after secondary treatment) and the industries provide the required further treatment depending on their end uses. The TTPs which receive secondary treated wastewater from the Chennai city at the Madras Refineries Ltd. and the Madras Fertilizer Ltd. consist of following treatment units:

Additional Secondary Biological treatment → Chemically-aided Settling + Pressure Filtration + Ammonia Stripping, Carbonation, Clarification, Pressure Filtration → Chlorination → Sodium Bisulfate Dosing → Multimedia Filtration → Cartridge Filtration → Reverse Osmosis → Permeate for Reuse.

Figure 12 presents the detailed flow sheet of the 12 MLD TTP at the Madras Refineries Ltd.

The rejects containing high TDS are disposed to the sea through a submerged outfall. As per the 1991 estimate, the capital cost for building the MRL plant was around Rs. 24 crores. The treatment costs for the MRL plant are reported to be about Rs. 35/- per 1,000 liters of water, which is much less in comparison to the charge of Rs. 60 per liters for fresh water supplied to industries. The Chennai Metro Water and Sewerage Board also charges a much higher tariff rate of Rs. 5.2/- per 1,000 liter of water to cover its treatment costs up to secondary stage.

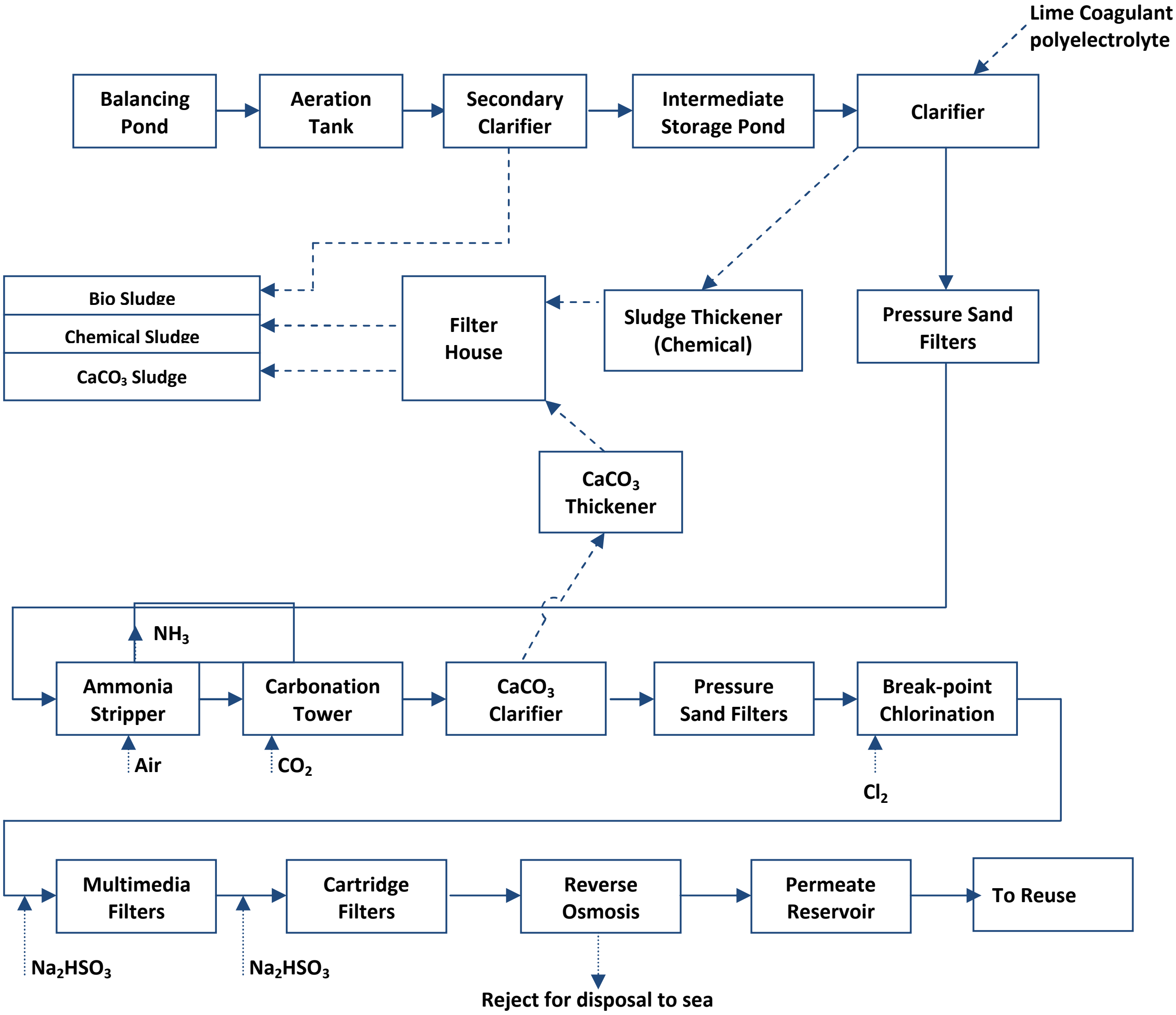


Figure 11: **The Detailed Flow Sheet of the 12 MLD Tertiary Treatment Plant (TTP) for the Madras Refineries Ltd., Chennai**

Reference:

Arceivala, S.J., Asolekar, S.R., 2007. Water Conservation and Reuse in Industry and Agriculture. In: Wastewater Treatment for Pollution Control and Reuse, 2007, Tata McGraw-Hill Publishing Company Limited, New Delhi, pp. 396–425.

3.12 Reverse Osmosis Plant for Wastewater Reuse, Vadodara, Gujarat, India

Title of Case Study: Reverse Osmosis Plant for Wastewater Reuse, Vadodara, Gujarat, India

Type of Case Study: Reuse of highly polluted wastewater for industrial uses.

Objective of Case Study: Recycling and reuse of highly polluted industrial wastewater for non-potable industry uses.

Background of Case Study: The reverse osmosis-based wastewater reuse plant was established in order to demonstrate the plausibility of reuse of highly polluted complex wastewater consisting of various industrial effluent streams for non-potable uses in the industry.

Salient Features: The reverse osmosis-based wastewater reuse plant uses highly polluted wastewater from an effluent disposal channel into which several industries viz. refineries, fertilizers, petrochemicals discharge their raw wastes. The successful operation of the plant demonstrated that at least 75% of the wastewater could be made available for reuse at treatment cost of Rs. 36/- per 1,000 liters as per the 1999 estimates. The remaining 25% constituted of the rejects and sludge from the reverse osmosis plant and needs to be disposed of separately. The treatment chain for the 3 MLD capacity reverse osmosis plant for wastewater reuse at Vadodara comprises of following units:

Wastewater from Effluent Channel → Chemical Feeding (Lime, Polyelectrolyte, Soda Ash) → Clarification → HCl Addition → Press Filtration → Sodium Bisulfate → Cartridge Filtration → Reverse Osmosis → Degasser to remove CO_2 → For Reuse.

The detailed flow diagram of the 3 MLD reverse osmosis plant for wastewater reuse at Vadodara is shown in Figure 13.

Reference:

Arceivala, S.J., Asolekar, S.R., 2007. Water Conservation and Reuse in Industry and Agriculture. In: Wastewater Treatment for Pollution Control and Reuse, 2007, Tata McGraw-Hill Publishing Company Limited, New Delhi, pp. 396–425.

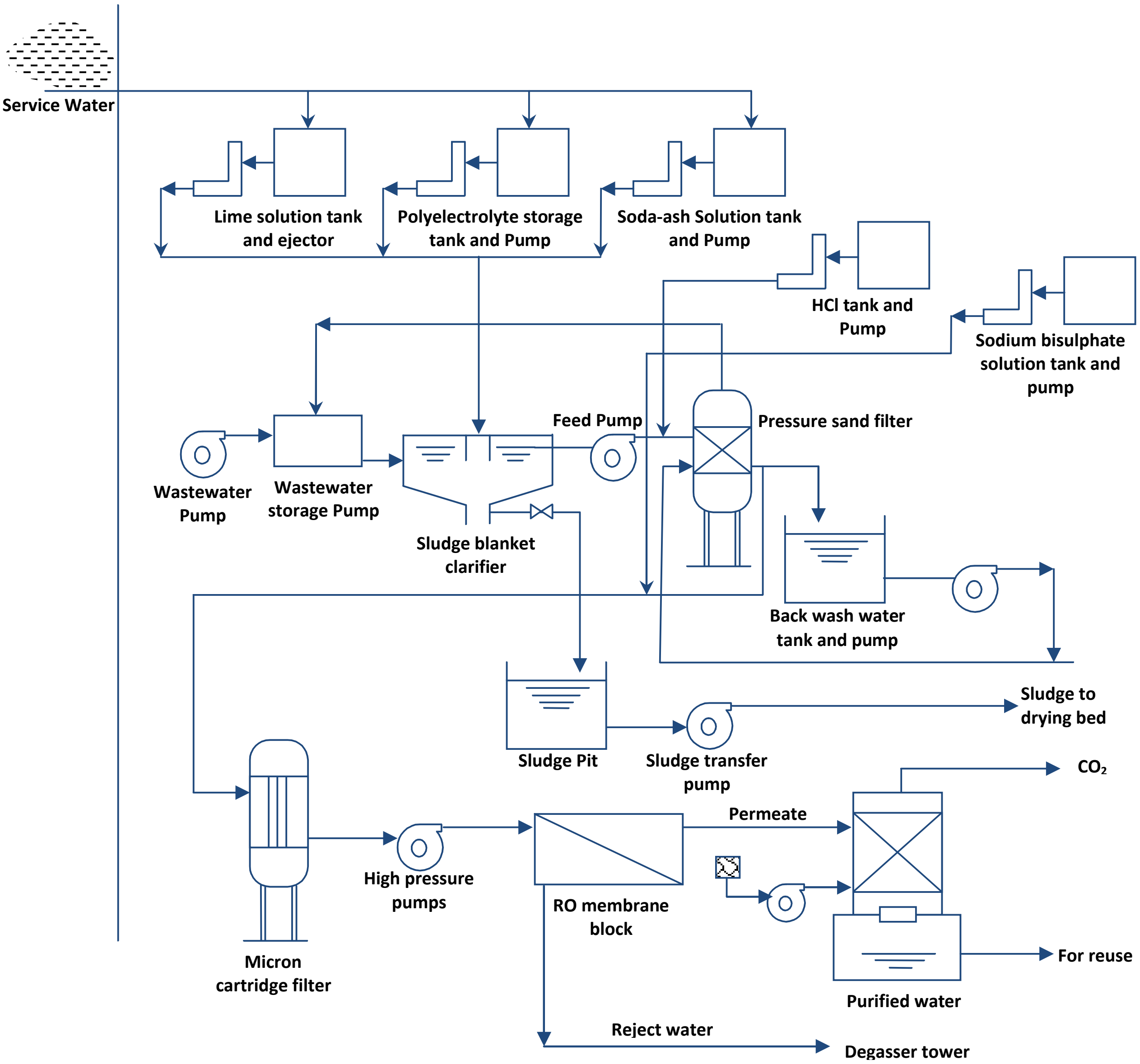


Figure 13: The Detailed Flow Diagram of the 3 MLD Reverse Osmosis Plant for Wastewater Reuse at Vadodara, Gujarat

3.13 Greywater Reuse System in Residential School, Ganganagar, Dhar District, Madhya Pradesh, India

Title of Case Study: Grey-water Reuse System in Residential School, Ganganagar, Dhar District, Madhya Pradesh, India

Type of Case Study: Reuse of treated grey-water for toilet flushing and irrigating the food crops.

Objective of Case Study: Treatment and reuse of grey-water from residential school for toilet flushing and irrigating the food crops.

Background of Case Study: The Central Indian state of Madhya Pradesh has a population of 28,928,245 spanning 308,245 km^2. The infrastructure for ensuring proper wastewater and its reuse is currently inadequate in the state with a third of the rural, and a quarter of urban, households with no wastewater drainage system. Therefore, there is a necessity to implement wastewater reuse system in the state. Towards the implementation of wastewater reuse, a grey-water reuse system has been initiated in one Girls boarding school in Ganganagar, District Dhar of Madhya Pradesh. The school has following characteristics:

No. of girl inmates: 300
School period: July 1 to April 30
Water requirement: 10,000 L
Grey-water generation: 4000 – 6000 L.

Salient Features: The National Environmental Engineering Research Institute (NEERI), Nagpur, Public Health Engineering Department (PHED), NGO partners and UNICEF, Madhya Pradesh have developed and implemented a grey-water reuse system in the residential school to provide sufficient water for flushing of toilets, cleaning of school floors and small-scale irrigation. The grey-water is treated using following primary, secondary and tertiary treatment technologies:

- ***Primary treatment:*** absorption of soap suds using a synthetic sponge, *sedimentation* baffled/graded settlement tank,
- ***Secondary treatment*****:** involves filtration of the reuse water using gravel (10–60 mm size) and sand roughing filtration, and
- ***Tertiary treatment*****:** the effluent is treated using aeration and chlorination before being pumped to an overhead tank for toilet flushing.

The techno-economical feasibility of the grey-water reuse system reveals that the system is performing exceedingly well and the internal and external benefits of the system are substantially higher than the internal and external costs. The reuse of grey-water has resulted in no occurrence of diarrhoea annually. The public perception study of the reuse system concluded that the grey-water reuse system is acceptable to the community and school children. Considering the successful operation of the grey-water reuse system in the residential school, Government of Madhya Pradesh has allocated funds for construction of 412 grey-water reuse systems in April 2006 and about 200 systems are already built in schools in Madhya Pradesh, India.

Reference:

Godfrey, S., Labhasetwar, P., Wate, S., 2009. Greywater reuse in residential schools in Madhya Pradesh, India – A case study of cost-benefit analysis. Resour. Conserv. Recycling. 53, 287–293.

3.14 Water Reuse Facility, Indian Institute Technology, Madras, Tamil Nadu, India

Title of Case Study: Water Reuse Facility, Indian Institute Technology, Madras, Tamil Nadu, India

Type of Case Study: Reuse of campus wastewater for toilet flushing and gardening.

Objective of Case Study: Treatment, storage and reuse of wastewater from hostels, residential apartments and the institution for toilet flushing in the hostels and gardening.

Background of Case Study: The Indian Institute of Technology Madras (IITM) campus has thirteen hostels, two guest houses and many residential apartments and bungalows with a total population of nearly 10,000 people. The total water consumption in the IITM campus is around 1.5 MLD and the total quantity of wastewater generated including the institute section varies from 1.0 to 1.2 MLD. Till 2004, the wastewater generated in the campus was treated in two oxidation ponds of capacity 136 m x 136 m x 2.5 m and the characteristics of the treated effluent from the pond was: 200-250 mg/L of BOD_5 (total) and 35-40 mg/L of BOD_5 (soluble), which is highly unsuitable for discharge into existing water bodies as per the Tamil Nadu Pollution Control Board (TNPCB) norms. In order to reuse the water, to prevent the formation of marshy area and to discharge the treated effluent to existing water bodies (Buckingham canal) there was a need to improve the existing treatment system. Moreover, the marshy area existing in and around the wastewater treatment system used to overflow during rainy season and contaminate the lake water as well as the swimming pool water in the campus. On the backdrop of these problems and in order to conserve water in water-starved place like Chennai and to reduce the procurement of water from outside, water reuse is viewed as essential in the campus.

Salient Features: A preliminary investigation to come up with a feasible treatment option for the campus suggested that a water reuse facility consisting of aerated lagoon followed by tertiary treatment is the best option for the existing condition with a possibility of around 0.2-0.4 MLD of wastewater reuse for toilet flushing and gardening in the hostel zone. The water reuse facility designed and installed to treat 1.4 MLD of wastewater and comprises of aerated lagoon, clariflocculator, chlorination, pressure filter, storage unit and sludge drying bed. There are two units of aerated lagoon with volume of 2600 m^3 each and take care of organic matter in the wastewater. The detention time provided in the aerated lagoon is relatively high compared to conventional ASP and thereby ensuring negligible sludge production. The effluent from the aerated lagoon is subjected to clariflocculation in order to remove colloidal and suspended solids. Alum and poly-electrolytes are being used as coagulant and coagulant aid respectively. The clariflocculator is also designed for a capacity of 1.4 MLD. After the clariflocculator, about two-third of the water (1 MLD) is send to the storage tank which was an oxidation pond earlier. The remaining one-third water (0.4 MLD) is chlorinated and filtered through a pressure filter. The pressure filter improves the quality of the water considerably by further removing the colloidal and suspended solids. Chlorination helps to reduce the pathogenic organisms substantially and keeps the filter relatively free from the microbial growth. The last unit in the reuse facility is the storage tank of water for further distribution.

The performance characteristics of various treatment units of the reuse facility are presented in Table 6. The highly treated effluent is reused for toilet flushing and gardening in the hostel zone alone. The sludge generated in the whole system is disposed off on the sludge drying bed. The schematic of the water reuse facility system is shown in Figure 14. This case study is a good example of sustainable water management and a notable initiative towards the reuse of wastewater from residential as well as from the institution sectors in India.

Table 6: Performance Characteristics of Various Treatment Units of the Water Reuse Facility

Treatment Unit		Parameter			
		Quantity, m^3/d	**BOD, mg/L**	**SS, mg/L**	**MPN/ml**
Aerated Lagoon	Influent	1400	200	100	N.A.
	Effluent	1428	20	49	N.A.
Clariflocculator	Influent	1428	20	49	N.A.
	Effluent	1358	10	29.45	100
Pressure Filter	Influent	400	10	29.45	100
	Effluent	400	4.0	5.0	50

Reference:

Philip, L., 2011. Water reuse facility at Indian Institute of Technology, Madras, Personal Communication.

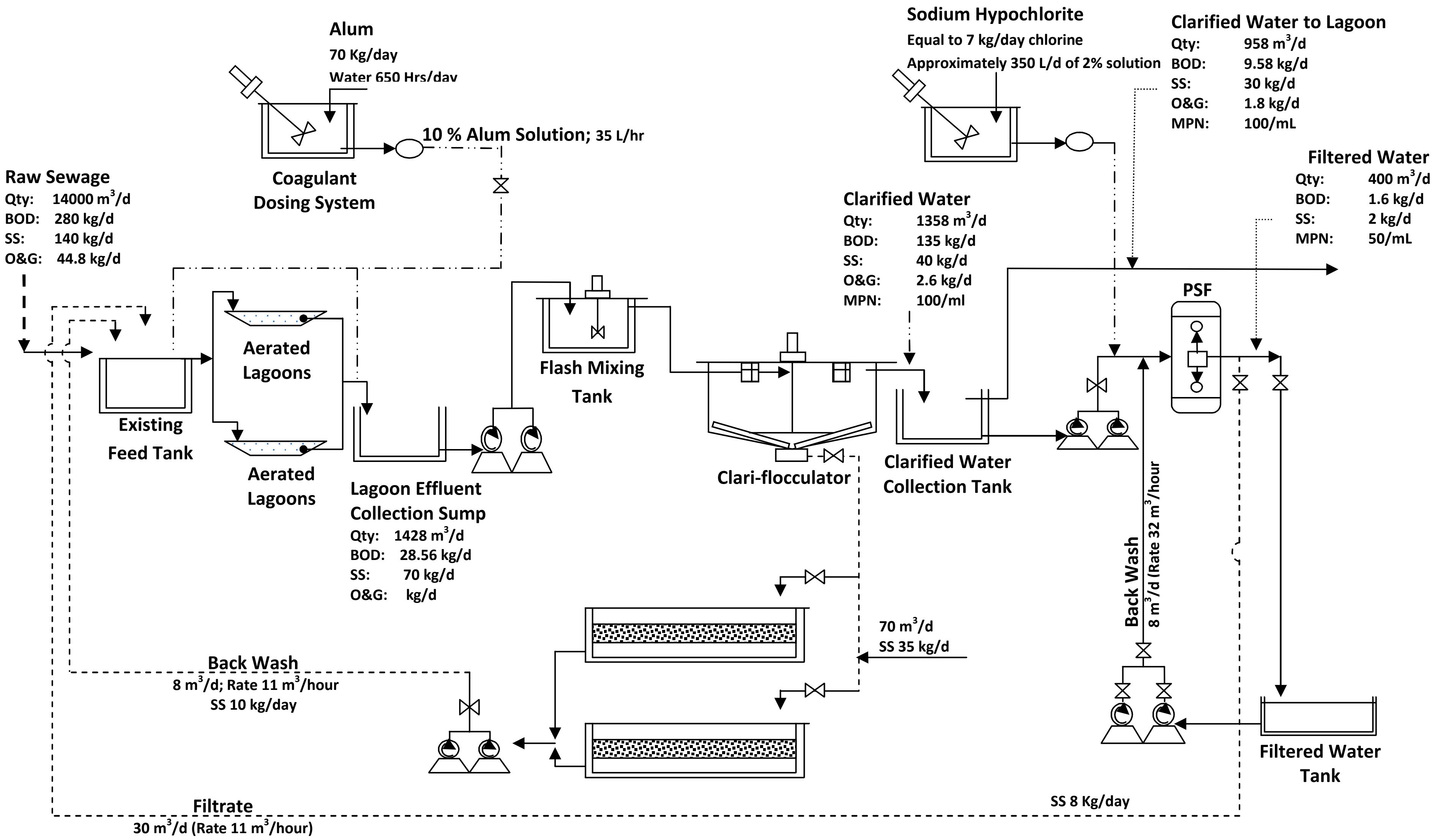


Figure 14: The Detailed Flow Schematic of the Water Reuse Facility at Indian Institute of Technology, Madras, Tamil Nadu

4. Environmental Impacts of Wastewater Reuse

The wastewater reuse is the most promising alternative to augment water supply and means of alleviating the anthropogenic impacts on the environment: it reduces the volume of wastewater discharged to receiving waters, and its substitution for freshwater leaves more water for the environment. Wastewater can be reused for a variety of purposes, including agricultural irrigation, heavy industry, urban and landscape irrigation, groundwater recharge, and wetland creation (Hartling and Nellor, 1998; Radcliffe, 2004). The wastewater reuse schemes have the potential to extend existing water supplies, lessen the demand on sensitive water bodies, lower the cost of developing new water supplies, reduce disposal costs, lessen the discharge of pollutants to the environment, and provide water to serve a variety of beneficial uses (Atwater, 1998). Wastewater, treated, partially-treated or untreated, is most widely reused for irrigation in an agricultural setting in developing countries as well as the water-scarce regions of the developed countries. There are many ill effects of reusing untreated or partially treated wastewater for irrigation like groundwater pollution, soil contamination, and the adverse effect on farmers and consumers of wastewater products. The environmental impacts of reuse of highly reclaimed wastewater using advanced or tertiary treatments have only been considered in this section. The potential environmental benefits of reuse of highly reclaimed wastewater are as follows.

Prevention of Over-extraction and Conservation of Freshwater Resources: Over-extraction of freshwater resources, mainly for municipal and agricultural activities, has led to significant degradation of rivers, lakes, aquifers, and dependent systems, such as wetlands. Wastewater reuse provides a renewable and alternative source of water supplies for municipal and agriculture purposes and it decreases the pressure on freshwater resources. Liberation of freshwater for the environment through substitution with wastewater reuse has been widely promoted as a means of prevention of over-extraction of freshwater resources and reduction of anthropogenic impacts (Anderson, 2003; Hamilton et al., 2005).

Pollution Reduction of Receiving Water Bodies and Associated Habitats: The other major environmental benefit to be garnered from reusing wastewater is diminution in pollution of waters receiving discharge of sewage and the restoration of ecosystem health. The wastewater reuse eliminates discharge of effluent into surface water and thereby decreases the associated pollution loads in terms of organics, nutrients and coliforms. Major environmental pollution in surface water bodies such as dissolved oxygen depletion, eutrophication and algal blooms, foaming, fish kills and destruction of floral and faunal biodiversity can be avoided. The wastewater reuse for the water recycling projects in the Costa Brava area demonstrated reduction in nutrient discharges to the environment, which accounted for 25 tons of nitrogen and 6 tons of phosphorus recycled every year (Nieto et al., 2001), and the marked improvement in the microbiological quality of the bathing waters of the beach at the mouth of the Muga river in Castelló d'Empúries. Planned reuse of wastewater for irrigation prevents pollutions and reduces the resulting damage that if quantified, can partly offset the costs of the reuse scheme.

Stabilizing Groundwater Table and Restoration of Surface Water Bodies: Wastewater reuse has played a major role in matching demands and available raw water supplies. It has been highly emphasized in various developed countries that the high quality reclaimed wastewater should be returned to stream of origin unless applied to beneficial reuse. As a result, recycled water is used in substantial proportion to maintain the base flow or ecological flow in many rivers and replenishing and stabilizing the groundwater through seasonal storage in surface reservoirs. For example, reclaimed wastewater is reused to supplement about 50% of the inflow into Hartbeespoort Dam which supplies water to Pretoria and Johannesburg in South Africa (Odendaal et al., 1998). It has also been demonstrated that wastewater reuse for irrigation has resulted in an increase in groundwater recharge in the Mezquital Valley in Mexico City including the creation of a new shallow aquifer and an increase in the base flow of local streams (Jimenez et al., 1998). Recovery and restoration of rivers and streams with the reclaimed wastewater in arid and semi-arid countries like Israel have also been demonstrated (Friedler and Juanico, 1995; 1996; 1997; Juanico and Friedler, 1999). There are also various other instances like Whittier Narrows in Los Angeles, Orange County in California, and Upper Occaquan reservoir in North Virginia where high quality reclaimed wastewater has been reused for direct groundwater recharge (Anderson, 2003).

Creation and Enhancement of Wetlands and Riparian (Stream) Habitats: Wetlands are the natural systems which help to provide wildlife habitat, improve water quality, result in flood diminishment, and support fisheries breeding grounds. For wetlands that have been impaired or dried due to water diversion, water flow can be augmented with wastewater reuse to sustain and improve the aquatic and wildlife habitat. Examples of wetland environmental restoration projects where water flow has been augmented using reclaimed water are Empuriabrava, Girona (7 hectare), Granollers, Barcelona (1 hectare) and Prat de Llobregat, Barcelona (18 hectare) in the region of Catalonia, Spain (Sala *et al*., 2004).

Increased Crop Yield and Agricultural Products: The reuse of wastewater for agricultural irrigation reduces the amount of water that needs to be extracted from natural water sources (USEPA, 1992; Gregory, 2000). It has been demonstrated in many instances that the wastewater reuse for irrigation can significantly increase crop growth and yield, and associated agricultural products. The reuse of reclaimed wastewater for irrigation has greatly increased crop yields in the Mezquital Valley in Mexico City (Anderson, 2003). The paddy rice irrigation with reclaimed wastewater from waste stabilization pond followed by a constructed wetlands in a decentralized rural area with conventional fertilization resulted in about 50% greater average rice yield than that of control, indicating that the reclaimed water can increase the crop yield substantially (Ham *et al*., 2007). Cultivating rice with reclaimed wastewater has shown no adverse effects on crop growth or yield; instead, the average yield for the rice plots irrigated with the reclaimed wastewater (6,680 kg/ha) resulted in about 19%

greater yields than the control plots irrigated with natural groundwater and it also showed more than the national average yield (4,500 kg/ha) in Korea (Jang *et al*., 2010). The wastewater reuse facilitates in effective use of nutrients contained in reclaimed wastewater for irrigation leading to reduction in uses of chemical fertilizer (Lazarova and Asano, 2005). Soil microorganisms have been observed to have increase metabolic activity when reclaimed wastewater is reused for irrigation (Meli *et al*., 2002; Ramirez-Fuentes *et al*., 2002).

Energy Savings: Wastewater reuses on-site or nearby reduces the energy needed to transport and distribute water longer distances or pump water from deep within an aquifer. The energy needed to treat wastewater also reduces by tailoring water quality to a specific water reuse. For example, the water quality required for flushing a toilet is less stringent than that for drinking water purposes and requires less energy to achieve. Reuse of reclaimed wastewater with lower quality for specific purposes that don't require high quality water saves energy and money by reducing treatment requirements.

In summary, the environmental benefits of reuse of highly reclaimed wastewater include: (a) Freshwater resources and quality benefits such as - (i) displace the need for over-extraction of freshwater resources, (ii) reliable, secure, and drought-proof water source, (iii) freshwater conservation by closing the water cycle, (iv) reduction in freshwater diversions and more river flow for downstream users, (v) reduced impacts of developing new water retaining structures like dams, reservoirs, (vi) reduction in pollution loads and better downstream water quality, (vii) reduced environmental impact and improved river aesthetics, (viii) reduced impacts on fisheries and aquatic life, (ix) improved public health for downstream users, (x) improved recreational values of waterways; (b) Agricultural benefits such as - (i) reduced diversion costs, (ii) value of a secure drought-proof supply of reclaimed water, (iii) increased crop growth and yield, farm production, (iv) increased food production, and (iv) savings in fertiliser applications by virtue of value of reclaimed water nutrients.

There have been a number of adverse environmental effects identified for reusing wastewater for non-potable purposes. Some effects are short term and vary in severity depending on the potential for environmental contact, while others have longer term impacts which increase with continued use of recycled water. The potential adverse environmental effects of high quality reclaimed wastewater reuse are as follows:

Adverse Environmental Effects of Heavy Metals and Emerging Contaminants: High quality reclaimed wastewater may contain various emerging contaminants like pharmaceutically-active compounds (PhAC), endocrine disrupting compounds (EDC) and hormones apart from heavy metals. These PhACs and EDCs originate either from industrial or domestic sources. Very little is mentioned regarding the potential presence of these trace contaminants apart from heavy metals and some brief mention on PhACs (USEPA, 1992). There is concern about the potential environmental impact by the emerging contaminants if they survive treatment processes, and are able to accumulate in the environment and enter the food chain. Heavy metals are easily and efficiently removed during common treatment processes and the majority of heavy metal concentrations in raw sewage end up in the biosolids fraction of the treatment process with very low heavy metal concentrations present in the treated effluents (Sheikh *et al*., 1987). Thus, heavy metals are of little concern for irrigation of crops using reclaimed wastewater. Ofosu-Asiedu *et al*. (1999) examined the uptake of heavy metals by crops irrigated with reuse of sewage and found that the levels in the crops irrigated with reuse of sewage was similar to background environmental levels and thus posed no environmental risks. Angelova *et al*. (2004) observed that fibre crops such as flax and cotton did take up heavy metals when grown in heavily contaminated soils, however the concentrations detected in the leaves and seeds were only a small percentage of the concentration present in the soil. Apart from heavy metals, most of the environmental concerns regarding the wastewater reuse revolve around the trace emerging contaminants. The endocrine disrupting compounds (EDCs) are compounds outside of an organism which can impact on the structure and function of an organism's endocrine system causing effects on the organism or its progeny (Lim *et al*., 2000). Known EDCs that can be found in wastewaters include the estradiol compounds commonly found in the contraceptive pill, phytoestrogens, pesticides, industrial chemicals such as bisphenol A and nonyl phenol, and heavy metals (Lintelmann *et al*., 2003). It has been demonstrated that wildlife (e.g., alligators in Florida and riverine fish in the UK) that are in constant or near constant contact with reclaimed water containing EDCs can have potential adverse effects like problems relating to the size and development of male gonads in Juvenile male alligators and increase in intersexuality of riverine fish (Guillette *et al*., 1994; Jobling *et al*., 1998). Sewage effluent usually contains a variety of hormones which increase the endogenous production of hormones (phyto-hormones) in legumes like alfalfa when the effluent is reused for irrigation. These phyto-hormones can then cause fertility problems in sheep and cattle that eat the forage (Colborn *et al*., 1993; Shore *et al*., 1995; Guan and Roddick, 1998). The pharmaceutically-active compounds (PhACs) are drugs used for a variety of therapeutic uses for both humans and animals. The PhACs detected in reclaimed water include analgesics such as Ibuprofen, caffeine, antiepiletics, cholesterol reducing drugs such as atorvastatin (common brand name Lipitor), antibiotics and antidepressants. One of the major concerns relating to PhACs is the development of antibiotic resistance in soil and water microorganisms due to the reuse of wastewater for irrigation (Guardabassi *et al*., 1998).

Adverse Effects of Salinity of Recycled Water on Soil Properties and Crop Growth: The physical characteristics of recycled water can have an impact on the environment in which it is used. The most important physical characteristics of recycled water to be used for irrigation purposes is the salinity, particularly in forms of sodium and chloride and can have a deleterious effect on soil properties and certain sensitive plants, thereby impairing the usefulness of recycled water. The most reliable index of the sodium hazard of irrigation water is the sodium adsorption ratio (SAR). The threshold value of SAR of less than 3 indicates no restriction on the use of recycled water for irrigation, while severe damage could be observed when SAR is over 9, in particular for surface irrigation (Lazarova *et al*., 2005). At a given SAR, the infiltration rate increases as salinity increases and vice versa. Recycled water is often high in sodium, and the resulting high SAR is a major concern in planning water reuse projects. The adverse effects of salinity are usually associated with an increase in soil salinity and the osmotic pressure in the soil solutions, and thereby with adverse effects on both crop and soil. Sodium and other forms of salinity are the most persistent in recycled water and difficult to remove from water as it requires the use of expensive cation exchange resins or reverse osmosis membranes. For some sensitive crops and landscape ornamentals, the presence of boron and trace element toxicity in the recycled water for irrigation could be of major concern. Salinity in the form of sodium can directly affect soil properties like soil permeability through the phenomena of swelling and dispersion due the interaction of positively charged sodium with the negatively charged layers (known as platelets) of clay particles (Halliwell *et al.*, 2001). The salinization of soil through the reuse of wastewater with high salinity for irrigation purposes affects clay particles in the soil and thereby reduces the hydraulic conductivity. The interaction of dissolved organic matter present in the reclaimed water with the soil profile also reduces the hydraulic conductivity of soil (Tarchitzky *et al.*, 1999). High salinity in the reclaimed water can lead to a decrease in productivity for certain crops, destabilizing the soil structure. Salinity also affects crop transpiration and growth (fewer and smaller leaves) (Bouwer, 2005). Higher salinity in the root-zone of plant leads to decrease in the osmotic potential of the soil-water solution and retards the water uptake rate of the plant. The plant expends considerable energy trying to extract water by osmotically adjusting and accumulating ions at the expense of plant growth and yield (Maas and Grattan, 1999).

The reuse of high quality reclaimed wastewater for various purposes has a numbers of genuine environmental benefits. Using recycled water as an alternative source of water reduces the pressures on the environment by reducing the use of freshwater resources. However, proper care and precautions must be taken in the haste to reap these benefits, as wastewater reuse itself also has the potential to be environmentally detrimental. There are certain issues that need to be properly resolved including the adverse environmental effects of presence of emerging contaminants as well as salinity on soil properties and crop growth in order to convince stakeholders for wide acceptability of wastewater reuse.

Reference:

Anderson, J., 2003. The environmental benefits of water recycling and reuse. Water Sci. Technol.: Water Supply 3(4), 1–10.

Angelova, V., Ivanov, R., Delibaltova, V., Ivanov, K., 2004. Bio-accumulation and distribution of heavy metals in fibre crops (flax, cotton and hemp). Ind. Crops Prod. 19, 197–205.

Atwater, R., 1998. Urban water recycling feasibility assessment handbook. Bookman-Edmonston Engineering Inc., California Urban Water Agencies, pp. 1–2.

Bouwer, H., 2005. Adverse effects of sewage irrigation on plants, crops, soil, and groundwater, In: Lazarova, V., Bahri, A., (eds.), *Water Reuse for Irrigation: Agriculture, Landscapes, and Turf Grass*, pp. 235–263.

Colborn, T., Vomsaal, F.S., Soto, A.M., 1993. Developmental effects of endocrine disrupting chemicals in wildlife and humans. Environ. Health Perspect. 101, 378–384.

Friedler, E., Juanico, M., 1995. Policy of water sources and quality management in the Alexander River. In: Brandais, A. (Ed.), *Master plan for the recovery of the Alexander River: Report to the Administration for the Recovery of Israeli Rivers*, pp. 104–133, 271–279.

Friedler, E., Juanico, M., 1996. Water allocations for the recovery of selected rivers in Israel: Report to the Administration for the Recovery of Israeli Rivers, p. 150.

Friedler, E., Juanico, M., 1997. Master plan for the recovery of the Sorek River - water quantity and quality: Report to the Administration for the Recovery of Israeli Rivers, p. 65.

Gregory, A., 2000. Strategic direction of water recycling in Sydney. In: *Proceeding of the First Symposium Water Recycling*, Australia, Adelaide, 19–20 October, 2000, pp. 35–41.

Guan, M., Roddick, J.G., 1998. Comparison of the effects of epibrassinolide and steroidal estrogens on adventitious root growth and early shoot development in mung bean cuttings. Physiol. Plant. 73, 426–431.

Guardabassi, L., Petersen, A., Olsen, J.E., Dalsgaard, A., 1998. Antibiotic resistance in *Acinetobacter* spp. Isolated from sewers receiving waste effluent from a hospital and a pharmaceutical plant. Appl. Environ. Microbiol. 64, 2499–3502.

Guillette, L.J., Gross, T.S., Masson, G.R., Matter, J.M., Percival, H.F., Woodward, A.R., 1994. Developmental abnormalities of the gonad and abnormal sex hormone concentrations in juvenile alligators from contaminated and control lakes in Florida. Environ. Health Persp. 102, 680–688.

Halliwell, D.J., Barlow, K.M., Nash, D.M., 2001. A review of the effects of wastewater sodium on soil properties and their implications for irrigation systems. Aust. J. Soil Res. 39, 1259–1267.

Ham, J.H., Yoon, C.G., Jeon, J.H., Kim, H.C., 2007. Feasibility of a constructed wetland and wastewater stabilisation pond system as a sewage reclamation system for agricultural reuse in a decentralised rural area. Water Sci. Technol. 55(1–2), 503–511.

Hamilton, A.J., Boland, A.M., Stevens, D., Kelly, J., Radcliffe, J., Ziehrl, A., Dillon, P.J., Paulin, R., 2005. Position of the Australian horticultural industry with respect to the use of reclaimed water. Agricultural Water Management 71, 181–209.

Hartling, E.C., Nellor, M.H., 1998. Water recycling in Los Angeles County. In: Asano, T. (Ed.), *Wastewater reclamation and reuse*, CRC Press, pp. 1163–1192.

Jang, T., Lee, S.B., Sung, C.H., Lee, H.P., Park, S.W., 2010. Safe application of reclaimed water reuse for agriculture in Korea. Paddy Water Environ. 8, 227–233.

Jobling, S., Nolan, M., Tyler, C.R., Brighty, G., Sumpter, J.P., 1998. Widespread sexual disruption in wild fish. Environ. Sci. Technol. 32, 2498–2506.

Juanico, M., Friedler, E., 1999. Wastewater reuse for river recovery in semi-arid Israel. Water Sci. Tech. 40(4–5), 43–50.

Lazarova, V., Asano, T., 2005. Challenges of sustainable irrigation with recycled water, In: Lazarova, V., Bahri, A., (eds.), *Water Reuse for Irrigation: Agriculture, Landscapes, and Turf*

Grass, pp. 1–30.

Lazarova, V., Bouwer, H., Bahri, A., 2005. Water quality considerations, In: Lazarova, V., Bahri, A., (eds.), *Water Reuse for Irrigation: Agriculture, Landscapes, and Turf Grass*, pp. 31–60.

Lim, R., Gale, S., Doyle, C., Lesjean, B., Gibert, M., 2000. Endocrine disrupting compounds in sewage treatment plant (STP) effluent reused in agriculture–is there a concern? In: *Proceeding of the First Symposium Water Recycling*, Australia, Adelaide, 19–20 October 2000, pp. 23–28.

Lintelmann, J., Katayama, A., Kurihara, N., Shore, L., Wenzel, A., 2003. Endocrine disruptors in the environment. IUPAC Technical Report. Pure Appl. Chem. 75, 631–681.

Maas, E.V., Grattan, S.R., 1999. Crop yields as affected by salinity. In: Skaggs, R.W., van Schilfgaarde, J. (Eds.), *Agricultural Drainage. Agronomy Monograph 38,* ASA, CSSA, SSSA, 1999, 55–108.

Meli, S., Maurizio, M., Belligno, A., Bufo, S.A., Mazzatura, A., Scopa, A., 2002. Influence of irrigation with lagooned urban wastewater on chemical and microbial soil parameters in a citrus orchard under Mediterranean condition. Sci. Total Environ. 285, 69–77.

Nieto, C., Serra, M., Sala, L., 2001. Water savings in the Costa Brava derived from wastewater reclamation and reuse. In: *Proceedings of the XIII Workshop on Water Savings in Industry and Municipalities*, ICAEN, 5 February 2001, Barcelona.

Odendaal, P.E., van der Westhuizen, J.L.J., Grobler, G.J., 1998. Wastewater reuse in South Africa, In: Asano, T. (Ed.), *Wastewater Reclamation and Reuse*. Water Quality Management Library Vol. 10, Technomics Publishing.

Ofosu-Asiedu, K., Oteino, D.A., Omolo, J.O., Etiegni, L., 1999. Sewage re-use for irrigation in Athi River Town Kenya: its implications on public health. Water Sci. Technol. 39, 343–346.

Radcliffe, J.C., 2004. Water recycling in Australia, Australian Academy of Technological Sciences and Engineering.

Ramirez-Fuentes, E., Lucho-Constantino, C., Escamilla-Silva, E., Dendooven, L., 2002. Characteristics, and carbon and nitrogen dynamics in soil irrigated with wastewater for different lengths of time. Bioresour. Technol. 85, 179–187.

Sala, L., Serra, M., Huguet, A., Colom, J., Carré, M., de Tejada S.R., Marquès, E., 2004. Multiple benefits of the environmental reuse Project at the Aiguamolls de l'Empordà Natural Reserve (Costa Brava, Girona, Spain), In: *Proceedings of the 9th International Conference on Wetland Systems for Water Pollution Control*, Vol. 2, Avignon, France, pp. 481–487.

Sheikh, B., Jaques, R.S., Cort, R.P., 1987. Reuse of tertiary municipal wastewater effluent for irrigation of raw-eaten food crops: a 5 year study. Desalination 67, 245–254.

Shore, L.S., Kapulnik, Y., Gurevich, M., Wininger, S., Badamy, H., Shemesh, M., 1995. Induction of phytoestrogen production in *Medico sativa* leaves by irrigation with sewage water. Environ. Exp. Botany 35, 363–369.

Tarchitzky, J., Golobati, Y., Keren, R., Chen, Y., 1999. Wastewater effects on montmorillonite suspensions and hydraulic properties of sandy soils. Soil Sci. Soc. Am. J. 63, 554–560.

USEPA, 1992. Guidelines for water reuse, Offices of Water and Wastewater and compliance USEPA, Washington.

5. Public Health Impacts of Wastewater Reuse

Recycling of highly reclaimed wastewater for various beneficial purposes has been perceived as a possible solution and an alternative source of water for an anticipated ever-growing water shortage problem in many parts of the world. Currently, there is considerable interest and apprehension for the potential health effects associated with the wastewater reuse. The possible risk to public health due to wastewater reuse is essentially depends on the degree of treatment provided to the wastewater. Depending on the extent of treatment received before reuse, the public health concerns related to the wastewater reuse can be classified in two categories: (i) Biological risks due to presence of microbial pathogens and indicators like enteric bacteria, virus and protozoa and helminths, and (ii) Chemical risks due to presence of various emerging contaminants like pharmaceutically-active compounds (PhAC), endocrine disrupting compounds (EDC) and hormones. Biological risks related to wastewater reuse have been recognized since the very beginning of this reuse practice. On the other hand, the considerations related to chemical risks have been developed recently following improvements in analytical capabilities. Additionally, biological risks have a relatively immediate outcome (illnesses develop in a short period of time), while chemical risks are translated into time-delayed illnesses (carcinogens, long-term toxicity, etc.). The public health concerns related to the reuse of untreated and partially-treated wastewater have been reviewed and summarized (Frerichs, 1984; Cooper, 1991). This section reviews the potential public health concerns due to the reuse of highly reclaimed wastewater only.

Biological Risks due to Presence of Microbial Pathogens and Indicators: The most common human microbial pathogens found in recycled water are enteric in origin. Enteric pathogens enter the environment in the faeces of infected hosts and can enter water either directly through defecation into water, contamination with sewage effluent or from run-off from soil and other land surfaces (Feachem *et al*., 1983). Enteric viruses are the smallest of the pathogens found in reclaimed water and most enteric viruses have a narrow host range meaning that most viruses of interest in recycled water only infect humans (Haas *et al*., 1999). This means that only human faecal contamination of water needs to be considered as a concern for viral infection of humans. Bacteria are the most common of the microbial pathogens found in recycled waters (Toze, 1999). Like other enteric pathogens, a common mode of transmission is via contaminated water and food and by direct person to person contact (Haas *et al*., 1999). A number of these bacterial pathogens can also infect, or be carried by wild and domestic animals. Enteric protozoan pathogens are unicellular eukaryotes, which are obligate parasites. There are several protozoan pathogens sometimes found in recycled water like *Entamoeba histolytica*, *Giardia intestinalis* (formerly known as *Giardia lamblia*), and *Cryptosporidium parvum* (Gennaccaro *et al*., 2003). Infection from all three of these protozoan pathogens can occur after consumption of food or water contaminated with the oocysts or through person to person contact (Carey *et al*., 2004). Helminths (nematodes and tape worms) are common intestinal parasites which are transmitted the faecal-oral route and require an intermediate host for development prior to becoming infectious for humans (Toze, 1999). Helminth parasites that are of significant health risk due to the presence in reused waters include the round worm (*Ascaris lumbricoides*), the hook worm (*Ancylostoma duodenale* or *Necator americanus*), and the whip worm (*Trichuris trichiura*).

The presence of microbial pathogens like enteric bacteria, virus and protozoa and helminthes in recycled water, particularly when sourced from sewage effluent is arguably the major concern for health regulators, farmers and the general public. Tertiary treated recycled water is a common treatment level where close contact with the water is considered a possibility. It has been shown that pathogens can still be detected in tertiary treated recycled water (Rose *et al*., 1996; Gennaccaro *et al*., 2003) and that some pathogens are resistant to disinfection processes. Examples of notable disinfectant-resistant pathogens are: *Cryptosporidium* is resistant to chlorination (Finch and Belosevic, 2002) and adenovirus is resistant to UV radiation (Meng and Gerba, 1996). It has been observed that infection rates, particularly for adults, decreased with treatment of the sewage effluent with infection rates decreasing at a rate that could be linked to the level of treatment (Lazarova *et al*., 2005). Epidemiological studies conducted to date have not established definitive adverse health impacts attributable to the use of appropriately treated recycled water for irrigation (Lazarova *et al*., 2005). There have been indications that the greatest health risk is associated with spray irrigation of recycled water when concentrations of nematode eggs are over 1 egg/L, particularly for children who eat vegetables irrigated with such water (Lazarova *et al*., 2005). No strong evidence has been found to suggest that population groups residing near wastewater recycling plants or recycled water irrigation sites are subject to increased risk from pathogens resulting from aeration processes or sprinkler irrigation (Blumenthal *et al*., 2000). A 5-year field pilot study in the Monterey Wastewater Reclamation Study for Agriculture (MWRSA) in Monterey, California indicated that there was an absence of microorganisms of concern for food safety in the water and on the edible and residual plant tissues of raw-eaten food crops, including lettuce, broccoli, and celery irrigated with recycled water having received tertiary treatment followed by disinfection (Sheikh *et al*., 1999). Some experts have concluded that the annual risk of enteric virus and bacterial ingestion from eating lettuce irrigated with recycled water meeting WHO guideline levels ranges from 10^{-5} to 10^{-9} (Blumenthal *et al*., 2000). The findings from the Health Effects Testing Programme (HETP) of NEWater Study in Singapore confirms that the reclaimed water is safe for potable use and exposure to or consumption of reclaimed water does not have carcinogenic (cancer causing) effect on the mice and fish, or estrogenic (reproductive or developmental interference) effect on the fish (SPUB, 2002). A more specific study (Vigneswaran and Sundaravadivel, 2004) of the city of St. Petersburg, Florida to estimate the potential risk to the exposed population concluded that: (i) there is no evidence of increased enteric diseases in urban regions housing areas irrigated with treated reclaimed wastewater, and (ii) there is no evidence of significant risks of viral or microbial diseases as a result of exposure to effluent aerosols from spray irrigation with reclaimed water. Another study on a grey-water reuse system in one Girls boarding school in Ganganagar, District Dhar of Madhya Pradesh showed that the occurrence of water-borne and water-washed diseases like diarrhoea have reduced substantially with implementation of the water reuse system (Godfrey et al., 2009). However, the potential presence of microbial pathogens in recycled water, even at very low numbers, must be considered a real biological risk and public health concern and the wastewater must be reused with due regard to this risk.

Chemical Risks due to Presence of Emerging Contaminants: Owing to the impressive improvement in analytical capacity, it has been made possible to discover various emerging contaminants like pharmaceutically-active compounds (PhAC), endocrine disrupting compounds (EDC) and hormones in natural water, raw and recycled wastewater capable of exerting negative public health impacts. Public health-related concerns pertaining to these emerging contaminants in recycled water are receiving increased attention. These chemicals tend to be present at very low concentrations in treated recycled water (usually in the range of ng/L) as well as require the ingestion of large doses over long time periods to produce any clinical effect (Durodié, 2003). Even if very long exposure occurs, it has been concluded that the actual concentration of compounds consumed would have minimal, if any, impact on a person or their offspring (Durodié, 2003). Due to the paucity of information on environmental persistence and potential health impacts due to the presence of emerging contaminants in recycled water, however, it is an area that currently remains a concern for health regulators and the public and potential fertile field for research. The current large number of known EDCs and PhACs present in reclaimed wastewater, as well as the possible existence of other potential and as yet unknown chemicals-of-concern, pose as barrier towards the promotion of wastewater reuse. Therefore, proper care and precautions must be taken in selecting advanced treatment techniques in water reclamation schemes for the removal of these emerging contaminants which are usually present in very low concentrations in the reclaimed water. It has been demonstrated that the tertiary treatment of wastewater like sand filtration, advanced oxidation processes (AOP) like ultraviolet light (UV) disinfection, ozonation and hydrogen peroxide (H_2O_2) addition can reduce these emerging contaminants in reclaimed water to below detection limits (Moore and Chapman, 2003).

Reference:

Blumenthal, U.J., Peasey, A., Ruiz-Palacios, G., Mara, D.D., 2000. Guidelines for wastewater reuse in agriculture and aquaculture: Recommended revisions based on new research evidence. WELL Study, Task no. 68, Part 1, p. 67.

Carey, C.M., Lee, H., Trevors, J.T., 2004. Biology, persistence and detection of *Cryptosporidium parvum* and *Cryptosporidium hominis* oocyst. Water Res. 38, 818–862.

Cooper, R.C., 1991. Public health concerns in wastewater reuse. Wat. Sci. Tech. 24(9), 55–65.

Durodié, B., 2003. The true cost of precautionary chemicals regulation. Risk Analysis 23, 389–398.

Feachem, D.G., Bradley, D.J., Garelick, H., Mara, D.D., 1983. Sanitation and Disease: Health Aspects of Excreta and Wastewater Management. John Wiley and Sons, Bath.

Finch, G.R., Belosevic, M., 2002. Controlling *Giardia* spp. and *Cryptosporidium* spp. in drinking water by microbial reduction processes. J. Environ. Eng. Sci. 1, 17–31.

Frerichs, R.R., 1984. Epidemiologic monitoring of possible health reactions of wastewater reuse. Sci. Total Environ. 32, 353–363.

Gennaccaro, A.L., McLaughlin, M.R., Quintero-Betancourt, W., Huffman, D.E., Rose, J.B., 2003. Infectious *Cryptosporidium parvum* oocysts in final reclaimed effluent. Appl. Environ. Microbiol. 69, 4983–4984.

Godfrey, S., Labhasetwar, P., Wate, S., 2009. Greywater reuse in residential schools in Madhya Pradesh, India – A case study of cost-benefit analysis. Resour. Conserv. Recycling. 53, 287–293.

Haas, C.N., Rose, J.B., Gerba, C.P., 1999. Quantitative Microbial Risk Assessment. John Wiley and Sons, New York.

Lazarova, V., Bouwer, H., Bahri, A., 2005. Water quality considerations, In: Lazarova, V., Bahri, A., (eds.), *Water Reuse for Irrigation: Agriculture, Landscapes, and Turf Grass*, pp. 31–60.

Meng, Q.S., Gerba, C.P., 1996. Comparative inactivation of enteric adenoviruses, poliovirus and coliphages by ultraviolet irradiation. Water Res. 30, 2665–2668.

Moore, M., Chapman, H.F., 2003. Endocrine disruptors in western society - Are there any health risks in effluent reuse? In: Proceedings of the 2nd National Conference of Water Recycling Australia, Brisbane.

Rose, J.B., Dickson, L.J., Farrah, S.R., Carnahan, D.P., 1996. Removal of pathogenic and indicator microorganisms by a full-scale water reclamation facility. Water Res. 30, 2785–2797.

Sheikh, B., Cooper, R., Israel, K., 1999. Hygienic evaluation of recycled water used to irrigate food crops - a case study. Wat. Sci. Techn. 40(4–5), 261–268.

SPUB, 2002. Singapore Water Reclamation Study: Expert Panel Review and Findings Report, Singapore Public Utilities Board (PUB), June 2002. In Website: http://www.pub.gov.sg/water/newater/NEWaterOverview/Documents/review.pdf (Accessed on April 12, 2011).

Toze, S., 1999. PCR and the detection of microbial pathogens in water and wastewaters. Water Res. 33, 3545–3556.

Vigneswaran, S., Sundaravadivel, M., 2004. Recycle and reuse of domestic wastewater, In: Wastewater Recycle, Reuse, and Reclamation, In: Vigneswaran, S. (Ed.), *Encyclopedia of Life Support Systems (EOLSS),* Developed under the Auspices of the UNESCO, Eolss Publishers, Oxford, UK.

6. Economics of Wastewater Reuse

Financial and economic analyses are generally concerned with the identification, valuation, and comparison of costs and benefits with a view to judging whether a proposed activity is worthwhile or not. Costs play an important part in determining the practicability of wastewater reuse schemes. However, the costs incurred for any wastewater reuse scheme alone do not necessarily determine the economic desirability of any such scheme. It is important to have a clear view on the purpose of the valuation of the costs of a wastewater recycling and reuse installation whether the purpose is to determine overall financial feasibility, to determine charges to water users, to determine the need for borrowing to finance the project, or whether the purpose is to assess the wider economic performance of the investment, including the value of any environmental impact. Costs must be compared to the overall benefits of the scheme in evaluating the economics of wastewater reuse. The economic analyses of wastewater reuse must consider whether a particular wastewater reclamation installation is absolutely worthwhile in itself, that is, whether the overall benefits are greater than the costs incurred. Generally, the type and scale of benefits and costs of wastewater recycling and reuse are very location-specific, such that generalizations are difficult and can be misleading. A wide variation in recycled water unit pricing exists depending on the type of reuse, flow rates, and local conditions, ranging from USD 0 to 0.52/m^3 (INR 0 to 23.1 per m^3; USD1.0 = INR44.4) (Morris *et al.*, 2005). Almost 50% of 34 wastewater reuse projects assessed by the Water Environment Research Foundation (WERF) ranged from USD 0.15 to 0.52/m^3 (INR 6.7 to 23.1 per m^3; USD1.0 = INR44.4) (Mantovani *et al.*, 2001). Among existing wastewater reuse projects, the prices of recycled water appear consistently lower than those of potable water. The Durban Water Recycling (DWR) Scheme, run by Vivendi Water in association with the Durban Metro, supplies high quality reclaimed water to the Mondi Paper Mill and SAPREF Refinery at a cost 25% lower than potable water (MED WWR WG, 2007). Radcliffe (2003) argues that the costs and pricing mechanisms for wastewater reuse schemes are not transparent, as the true cost of irrigation, potable and recycled water is not reflected in the current prices. The disparities in pricing water from recycling schemes ranged from AUD7 to 83 cents per kL (INR3.4 to 40.25 per kL), compared to the true cost of reclaimed water that ranged from AUD1.45 to 3.00 per kL (INR 70.3 to 145.5 per kL; AUD1 = INR48.5) and can be attributed to unaccounted costs and the fact that environmental externalities are not considered and internalized. According to Muir (2006) price signals from the use of recycled water should be set at the long run marginal costs of supply. If this is done then appropriate decisions on existing stand alone schemes or the comparison of different proposals can be made. The existing managed potable water supply with heavy subsidy by municipal or regional authorities can lead to inefficient use of already scare water resources and market inefficiencies for wastewater reuse initiatives. Subsidized prices not only tend to discourage proper use of water among those who often could afford to pay more, but may also reduce the incentive for investment in wastewater treatment and reuse. When recycled water is provided for non-potable uses, especially irrigation, it is often offered at a lower price than potable water to encourage its use. The subsidized price combined with undervaluing of potable water has led the recycling projects fail to recover full cost and thereby fail to attain financial sustainability. The subsidized and real costs of recycled water for some recycled water schemes in Australia have been compared and presented in Table 7. Also, a survey of 79 wastewater recycling projects found that only 5 in the United States and 7 elsewhere recovered full costs (Mantovani *et al*, 2001). For the other U.S. projects, operating revenues covered between 0 and 80% of the full cost, implying a high level of subsidy. However, the failure to recover costs due to subsidized cost of recycled water does not imply that wastewater reuse schemes are uneconomic: the costs of wastewater reuse schemes may be justified in terms of broad economic, social, and environmental objectives where the overall target is wise use of available water supplies in support of local, regional, or national development objectives. Wastewater recycling improves the economic conditions of any region by creating employment and increasing the property values. For example, the social advantages in employment and populations were identified in the Lockyer Valley Water Recycling Scheme in South East Queensland by using reclaimed water and the financial gains for individual property owners through increase in property value (Mekala *et al*., 2008). The cost-benefit analyses of a grey-water reuse system in one Girls boarding school in Ganganagar, District Dhar of Madhya Pradesh showed that the internal and external benefits of grey-water reuse are substantially higher than the internal and external costs (Godfrey *et al*., 2009). The construction cost (material and labour costs) and the O&M cost of the system are INR 50,300 and INR 5725 per year, respectively. Internal benefits of the system are estimated to be INR 30,000 per year due to the reduction in fresh water supply. The external benefits in terms of the environmental and health benefits of the system are estimated as INR 44,000 and INR 793,380 respectively.

Table 7: Comparison of Subsidized and Real Costs of Recycled Water for Some Recycled Water Schemes in Australia (Source: Mekala *et al*., 2008)

Location	Use of Recycled Water	Subsidized Cost of Recycled Water/kL	Real Cost of Recycled Water/kL	Drinking Water Price/kL
Springfield, Queensland	Residential: toilet flushing, gardening	AUD43 cent	AUD1.45	90 cent per quarter for 100-150 kL
Rouse Hill, New South Wales	Residential: toilet flushing, gardening	AUD28 cent	AUD3.00-AUD4.00	98 cent
Olympic Park, New South Wales	Residential: toilet flushing, gardening, laundry	AUD83 cent	AUD1.60 (operating costs only)	98 cent
Mawson Lake, South Australia	Residential: toilet flushing, gardening	AUD77 cent	Not Available	AUD1.03 for >125 kL

AUD1.0 = INR48.50

Most of the existing wastewater reuse schemes worldwide use effluent from the secondary processes for further purification in advanced or tertiary treatment units and the additional costs involves in installing and operating the advanced or tertiary processes. Therefore, it is utmost necessary to review and discuss the costs involved in providing additional tertiary or advanced treatment in the context of the economics of the wastewater reuse. The distribution of capital and O&M costs of additional tertiary treatment for wastewater reuse varies from one project to another and depends on the type of the treatment processes used. Other major factors and local constraints like price of the building site, distance between the production site and the consumers, and necessity to install a dual distribution system or retrofitting also highly influence the capital and O&M costs of additional treatment. The latter two constraints are of major importance since the major capital investment concerns the distribution system in many wastewater reuse schemes and can reach 70–200% of the overall costs depending on site-specific conditions (Lazarova, 2005). Storage, mainly seasonal storage in form of surface reservoirs, represents significant part of investment. The cost of retrofitting of existing networks is comparatively higher than the installing new systems. Among the tertiary treatments, polishing pond treatment is the most simple and unsophisticated but has proven to be a competitive, efficient solution for small communities. This technology is the cheapest solution for flows under 3000 m^3/d (15,000 population equivalent) with average total annualized cost of about USD 5–7 cents/kL (INR2.22–3.11/kL; USD1.0 = INR44.4) (Lazarova, 2005). As the project size increases, polishing pond treatment becomes less and less competitive compared to other solutions, not taking its storage function into account. The construction of filtration as tertiary treatment unit results in a two- to three-fold increase in the capital and operating costs as compared to the disinfection processes. For project sizes more than 7500 m^3/d (50,000 population equivalent), the cost for UV treatment or chlorination becomes comparable to maturation ponds within the error margin of the cost estimation. For small and medium-size wastewater reuse schemes (<50,000 population equivalent), chlorination and UV irradiation are more competitive than ozonation, with average total annualized cost of about USD 2.2–8.0 cents/kL (INR0.98–3.55/kL; USD1.0 = INR44.4) (Lazarova, 2005). The cost difference between UV irradiation and ozonation decreases with plant size. The competitiveness of ozonation appears clear for large recycling plants (>100,000 population equivalent), where total costs are in the typical range of USD 0.8–2.5 cents/kL (INR0.35–1.11/kL; USD1.0 = INR44.4), and in some cases could be less than UV irradiation (Lazarova, 2005). Ozonation is generally considered and recommended as a viable option for large plants since ozonation improves the visual aspect of the recycled water and sometimes lessens its odor. The costs of membrane filtration (micro- and ultra-filtration) are significantly higher compared to the other disinfection processes and typically reach USD 0.40–0.70/kL (INR17.8–31.1/kL; USD1.0 = INR44.4) for plant capacity in the range of 20,000–500,000 population equivalent (Lazarova, 2005). The cost difference decreases when compared with combined sand filtration and UV or ozone disinfection. The widespread application of membrane bioreactors (MBRs) despite all the process advantages is constrained by the high cost of membranes apart from high O&M cost for fouling tendency. Compared to the conventional ASP, the overall costs for MBR remain up to 20% and 50% higher than the conventional ASP depending on plant size. Reported MBR costs typically vary from USD 0.095 to 0.20/kL (INR4.22–8.88/kL; USD1.0 = INR44.4) for treatment plant size up to 50,000 population equivalent (Lazarova, 2005). The operating costs are about 45–50% of the total annual costs for UV irradiation and increase up to 50–70% for chlorination and ozonation, respectively for small to large wastewater reuse schemes (Lazarova, 2005). Operation and maintenance costs incurred by chlorination and ozonation are primarily those associated with chemical costs. Higher reagent costs up to 60% of the operating costs are characteristic for chlorination. Operating costs for UV systems consist mostly of lamp replacement and cleaning.

Treatment of wastewater to a high level, using secondary to tertiary processes, for reuse and recycling can be very energy intensive and the economics of the wastewater reuse schemes is directly related to the energy consumption. Energy costs are about 2–5% of the operating costs for chlorination. Energy costs for UV irradiation and ozonation are between 15 and 35% of the operating costs respectively, depending on plant size. Water reclamation from wastewater with less total dissolved solids than seawater has lower energy costs for reverse osmosis. The comparative energy consumption for various technologies for per kL of potable water production is presented in Table 8.

Table 8: Comparative Energy Consumption for Various Technologies for Potable Water Production

Technology	Energy Consumption, kWh/kL	Reference
Reverse Osmosis of Seawater	3.2 – 3.5	Sanz and Stover (2007)
Brackish Reverse Osmosis	0.7 – 1.2	Swinton (2005)
Conventional Water Treatment	0.4 – 0.6	Swinton (2005)
Wastewater Reclamation	0.7 – 0.9	Singapore Public Utilities Board (2002)
	0.8 – 1.0	Swinton (2005)

Reference:

Godfrey, S., Labhasetwar, P., Wate, S., 2009. Greywater reuse in residential schools in Madhya Pradesh, India – A case study of cost-benefit analysis. Resour. Conserv. Recycling. 53, 287–293.

Lazarova, V., 2005. Wastewater treatment for water recycling, In: Lazarova, V., Bahri, A., (eds.), *Water Reuse for Irrigation: Agriculture, Landscapes, and Turf Grass*, pp. 163–234.

Mantovani, P., Asano, T., Chang, A., Okun, D.A., 2001. Management practices for non-potable water reuse, WERF Project Report 97-IRM-6, Water Environment Research Foundation, Alexandria, VA.

MED WWR WG, 2007. Mediterranean Wastewater Reuse Report, Mediterranean Wastewater Reuse Working Group (MED WWR WG), November 2007.

Mekala, G.D., Davidson, B., Samad, M., Boland, A.M., 2008. Wastewater reuse and recycling systems: A perspective into India and Australia, IWMI Working Paper 128, International Water Management Institute, Colombo, Sri Lanka, 35p.

Morris, J., Lazarova, V., Tyrrel, S., 2005. Economics of water recycling for irrigation, In: Lazarova, V., Bahri, A., (eds.), *Water Reuse for Irrigation: Agriculture, Landscapes, and Turf Grass*, pp. 265–283.

Muir, R., 2006. The economics of recycling, In: *Proceedings of the Water Recycling and Infrastructure Summit*, 6 December, 2006, Synergies Economic Consulting, Sydney.

Radcliff, J., 2003. An overview of water recycling in Australia-Results of a recent ATSE study, In: *Proceedings of Water Recycling Australia: Second National Conference*, Brisbane, 1-3 September, 2003.

Sanz, M.A., Stover, R.L., 2007. Low Energy Consumption in the Perth Seawater Desalination Plant, In: *Proceedings of the IDA World Congress*, Maspalomas, Gran Canaria, Spain, October 21-26, 2007.

Singapore Public Utilities Board (PUB), 2002, Singapore Water Reclamation Study: Expert Panel Review and Findings Report, Singapore Public Utilities Board (PUB), June 2002. In Website: http://www.pub.gov.sg/water/newater/NEWaterOverview/Documents/review.pdf (Accessed on April 12, 2011).

Swinton, B., 2005. Membrane technology, Water, May 2005, 36–41.

7. Community and Public Perception and Participation towards Wastewater Reuse

The wastewater reuse in any context can quite understandably be a source of concern for general public and communities at large who have no previous direct experience of similar schemes. Irrespective of what conclusions scientific enquiry leads to, the impressions and attitudes that the public holds can speedily and effectively bring a halt to any reuse scheme. The central dilemma for anybody attempting to understand how individuals respond to change is that people interpret their surroundings in a highly personal manner. Not only is interpretation individualistic, it is also dynamic (i.e., changes over time) and as such is extremely difficult to monitor. The psychological factor is essential for initiating, implementing and sustaining a long-term wastewater reuse program. The general community has openly acknowledged that there is a “yuck” factor or a psychological barrier to using recycled water on many occasions (Melbourne Water, 1998). In psychological terminology, the “yuck” factor or disgust is defined as the emotional discomfort generated from close contact with certain unpleasant stimuli. Any neutral object through brief contact with another object may acquire disgusting properties as per the law of contagion (Rozin and Fallon, 1987). People may still perceive the wastewater reuse to be disgusting because the water has been in contact with human wastes which results in disgusting stimuli irrespective of the highest degree of treatment provided to the wastewater. Therefore, the development of sustainable water recycling schemes needs to include an understanding of the social and cultural aspects of wastewater reuse. A wastewater reuse project may fail in absence of social support. The public attitude plays an important role even for non-potable reuse purposes including the perception of water quality, willingness to pay or to accept any wastewater reuse project (Lazarova et al., 2000). It has to be kept in mind while studying on the public as well as on the community acceptance that wastewater reuse has different driving forces: (i) It is a supplemental water supply in water scarce regions, and (ii) It can be a viable alternative to the disposal of treated effluents in rivers and other surface water bodies and there with a driving force also for regions with humid climate. Hence, the particular issue of public and community perception and participation require complex and complicated understanding since it is related to the beliefs, attitudes, and trust.

Studies of public and community attitudes to wastewater reuse have been carried out since the late 1950s (originally in the United States, but more recently in Europe, Central America, and Africa). A summary of such studies reported that individuals who consider their potable supplies to be under threat (in terms of either quality or quantity) or perceive an economic benefit are generally more positive towards the idea of recycling water (Bruvold and Crook, 1989). Other study has demonstrated that acceptance of water recycling schemes in general is influenced by the degree of human contact associated with the reuse application (Bruvold, 1985). Uses such as garden irrigation and toilet flushing are consistently preferred over uses such as food preparation and cooking. Faby *et al*. (1999) criticize the very stringent restrictions which are even much higher than the WHO (1994) guidelines concerning reuse in agriculture in some parts of the world. This is detrimental to the public acceptance of wastewater reuse schemes. A study about the industrial sector in Thailand and its willingness to adopt wastewater reuse practices indicates that only 10.5% of the industries included in survey reuse their treated effluent (Visvanathan and Cippe, 2000). Furthermore, the tendency of the industries is directed into non-adoption of industrial wastewater reuse. Another study has considered other determinants of attitudes to reuse schemes, including the scale of the scheme (e.g., single house/multiple house) and the context of the scheme (e.g., domestic, commercial, or public premises) (Jeffrey, 2002). The sources of recycled water as well as the environment in which it is to be used are likely to influence attitudes towards the system as a whole. However, the communities and societies at large also differ just like individuals vary in their attitudes towards water reuse. The dangers inherent in ignoring cultural (ethnic/historical/religious) norms have been recently demonstrated (Mancy *et al*., 2000), and the benefits provided by public education have been pointed out (Sbeih, 1996; Crites, 2002). Po *et al*. (2004) suggested that people may perceive reusing wastewater too risky because (i) the source of this water is not natural, (ii) it may have potential to harm people, (iii) there might be unknown future consequences of reusing wastewater, (iv) their decision to recycle water may be irreversible, and (v) the quality and safety of the water is not within their control. The major findings from various surveys conducted in France, Italy, and the United Kingdom in order to identify the major barriers to water reuse across a range of reuse project types and cultural contexts are as follows (Jeffrey, 2005):

- Communities are sensitive to water reuse issues, although this is more evident in the northern part of the continent than in the south.
- Many corporate stakeholders are nervous about supporting reuse projects in the absence of clear and legally binding water quality guidelines.
- Use of a water recycling system where the source and application are located within their own household is acceptable to the vast majority of the population as long as they have trust in the organization that sets standards for water reuse. Using recycled water from second party or public sources is less acceptable, although half the population show no concern, irrespective of the water source.

- Water recycling is generally more acceptable in non-urban areas than in urban areas. (This disparity is most pronounced for systems where the source and use are not within the respondent's own residence).
- Willingness to use recycled water, particularly from community sources, is higher among metered households than among non-metered households, and higher among those households that take water conservation measures than among those who do not.
- The use of recycled waters for irrigation is widely accepted by farmers who believe them to be safer than river waters.
- There are strong concerns over the sale of products that have been irrigated with reclaimed wastewater, especially vegetables. Farmers can overcome resistance through positive evidence from the consumers and the retailers that there will be a market for the products cultivated with the reclaimed water.
- The establishment of standards for the reuse and management of monitoring programmes promote confidence in reuse schemes.

Studies conducted by Bruvold (1988) and ARCWIS (2002) showed that closer the recycled water is to human contact or ingestion, the more people are opposed to reuse the wastewater. Therefore, introducing recycled water for non-potable non-human contact uses and gradually moving along the contact continuum and wastewater reuse awareness programmes through public education are expected to increase the acceptability of recycled water.

Reference

ARCWIS, 2002. Perth domestic water use study: Household appliance ownership and community attitudinal analysis, 1999-2000. Australian Research Centre for Water in Society, Sydney: CSIRO Urban Water Programme.

Bruvold, W.H., 1985. Obtaining public support for reuse water. J. Am. Water Works Assoc. 77(7), 72–77.

Bruvold, W., 1988. Public opinion on water reuse options. Journal WPCF 60(1), 45–49.

Bruvold, W.H., Crook, J., 1989. What the public thinks: Reclaiming and reusing wastewater. J. Am. Water Works Assoc. 77, 10–17.

Crites, R., 2002. Regional water reuse in California, In: *Proceedings of the Hawaii Water Reuse Conference*, Kauaii, Hawaii, November 7–8, 2002.

Faby, J.A., Brissaud, F., Bintoux, J., 1999. Wastewater reuse in France: Water quality standards and wastewater treatment technologies. Water Sci. Technol. 40(4–5), 37–42.

Jeffrey, P., 2002. Influence of technology scale and location on public attitudes to in-house water recycling in England & Wales. J. CIWEM 16(3), 214–217.

Jeffrey, P. 2005. Community and institutional engagement in agricultural water reuse projects, In: Lazarova, V., Bahri, A., (eds.), *Water Reuse for Irrigation: Agriculture, Landscapes, and Turf Grass*, pp. 285–307.

Lazarova, V., Levine, B., Sack, J., Cireli, G., Jeffrey, P., Muntau, H., Brissaud, F., Salgot, M., 2000. Role of water reuse in enhancement of integrated water management in Europe and Mediterranean Countries, In: *Proceedings of the 3rd International Symposium on Wastewater Reclamation, Recycling and Reuse*, France, 3-7 July, 2000.

Mancy, K.H., Fattal, B., Kelada, S., 2000. Cultural implications of wastewater reuse in fish farming in the Middle East. Water Sci. Technol. 42(1–2), 235–239.

Melbourne Water, 1998. Exploring community attitudes to water conservation and effluent reuse. A consultancy report prepared by Open Mind Group. St. Kilda, Victoria.

Po, M., Kaercher, J. Nancarrow, B.E., 2004. Australian Water Conservation and Reuse Research Program: Literature review of factors influencing public perceptions of water reuse. Australian Water Association, April 2004, pp. 1–27.

Rozin, P., Fallon, A.E., 1987. A perspective on disgust. Psychological Reports 94, 23–41.

Sbeih, M.Y., 1996. Recycling of treated water in Palestine: Urgency, obstacles and experience to date. Desalination 106(1–3), 165–178.

Visvanathan, C., Cippe, A., 2000. Strategies for Development of Industrial Wastewater Reuse in Thailand, In: *Proccedings of the 3rd International Symposium on Wastewater Reclamation, Recycling and Reuse*, France, 3-7 July, 2000.

8. Concluding Remarks and Recommendations

The implementation of treated wastewater reuse is underdeveloped in India. This is based on the total degree of water scarcity (which has forced the other parts of the world including the US and Australia to take a more comprehensive approach to water resources management), but also because urban treated wastewater reuse is not well understood compared with the high priority water management activities of potable water production to protect public health and wastewater treatment to protect the environment. Reuse can be more difficult to implement due to the large number of end users, the vicinity to the public, relatively high cost due to complex distribution and treatment systems as well as potential risks of accidental public exposure in the case of cross-connections in dual supply systems and irrigation of public spaces. Factors such as the increased demand for water, coupled with increased water stress, water scarcity and the compliance measures towards environmental legislation, are likely to increase the drive towards the use of treated wastewater.

The benefits of treated wastewater reuse are very evident even though some risks have to be taken into account. Treated wastewater reuse is vital in the widely promoted concept of “integrated urban water management”. Treated wastewater reuse alternatives should be included as part of the demand driven river basin management plans like the Ganga River Basin Management to maximize water management efficiency. In this context, the total closure of the river basin water cycle needs to be adopted in India as common practice following the reported case studies where treated wastewater is used to recharge the ground water in order to maintain integrated water resources management. Moreover, the concept of zero discharge municipality/city by integrating the reuse of highly treated wastewater adopting tertiary-level advanced treatment techniques needs to be promoted in the Ganga Basin. Therefore, following general recommendations can be made based on the review presented in this report towards the promotion of wastewater reuse in the Ganga River Basin:

- Highly reclaimed wastewater reuse schemes should be included and promoted as an alternative source of water for non-potable non-human contact uses (except food industry) as part of the demand driven river basin management plans like the Ganga River Basin Management to conserve freshwater resources and to maximize water management efficiency.
- Groundwater recharge should be encouraged in the entire Ganga Basin for replenishing and stabilizing the groundwater using highly reclaimed water through seasonal storage in surface reservoirs in order to maintain the base flow or ecological flow in the rivers.
- Zero discharge municipality/city concept (i.e. completely prohibit the disposal of treated or untreated wastewater into surface water bodies) needs to be promoted in the Ganga Basin by reusing entire wastewater generated within the municipality/city adopting tertiary level advanced treatment techniques. Emphasis should be given on natural treatment systems like wetlands and pond systems. Separate distinct treatment chain should be adopted based on the water quality requirements for each of the intended purpose of wastewater reuse.
- A proper water quality standard or guidelines pertaining to wastewater reuse for each of the various beneficial purposes should be developed and strictly enforced as law/regulation in India through peer or public monitoring protocols.
- Irrigation with highly reclaimed water should be promoted in the entire Ganga Basin in order to prevent excessive extraction of surface water and groundwater. For this purpose, separate storage and distribution systems need to be installed completely detached from the distribution systems of other types of water, especially from potable water in order to prevent any contamination.
- Research is warranted on the potential public health impacts due to the presence of microbial pathogens and emerging contaminants, if any, in highly reclaimed wastewater before reuse. Risk assessment studies should also be conducted for the possible public health impacts due to the presence of microbial pathogens and emerging contaminants. Proper surveillance and monitoring of water quality for wastewater reuse should be performed frequently.
- Awareness campaign, workshops, conferences on the potential benefits of wastewater reuse should be conducted in order to promote wastewater reuse and educate people for changing the wrong notion/perception and remove any psychological barrier about wastewater reuse and ensuring the public and community participation towards wastewater reuse. School and college curricula should be appropriately modified to educate next generation on conservation and reuse/recycle of water.