URBAN WASTEWATER TREATMENT: PAST, PRESENT AND FUTURE

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Summary

The chapter traces the history of water and wastewater management, starting from the

hunter-gatherer days of human existence. It divides the evolution of water industry into four phases. It describes traditional wastewater treatment technologies developed as the second generation water management option. Crystal ball view of the future of wastewater treatment technologies is also given, highlighting the novel approaches currently in the pipe-line.

1. Water Management Systems: A Brief History

As their intellectual and social capacities advanced over the past hundred thousand years, hunter-gatherers homo-sapiens expanded across the globe, building on a legacy of tool making and exploration. During the last ten thousand years, homo-sapiens became cultivators, thereby allowing a great increase in population to occur. One of the essential factors in this metamorphosis of hunter-gatherers into cultivators was the management of water supply through storage and distribution (Chanan & Simmons, 2002). In essence, unlike hunter-gatherer days, water was brought to the place of occupation rather than the community moving to reliable water supplies. The drive for water security has grown from there and has become a significant component of human endeavor. Table 1 provides a broad pattern of human water access and use.

Time Period years ago	**Type of Community**	**Example of location**	**Pattern**
10,000+	Hunter-gatherer	Worldwide	Community moved to water
10,000-7,000	Agricultural City States	Mesopotamia Indus Valley	Water brought (carried) to the community
7,000-1,500	Agricultural Empires	Greece, Rome	Water brought to the community by engineered structures from remote sources
1,500-200	Agricultural Protected	Medieval Europe	Water collected and stored on site
200-100	Industrial	Europe	Large collection and distribution systems
100-0	Industrial	Worldwide	Development of large dams – centralised systems
0-50	Managerial	Worldwide	Total Water Cycle Management Soft Path for water

Table 1: Broad patterns of community water access and disposal

The earliest civilisations, such as in the Indus Valley which flourished 4,000 years ago, showed a sophisticated appreciation of water-related health needs (Edwards, 2000). Domestic water supply in these ancient civilisations appeared to be obtained from wells and was simply carried to wherever it was needed. In ancient Egypt for instance, the purest water for consumption was obtained from wells, whereas the Nile River provided water for irrigation (P&M Magazine, 1989). Similarly ancient Jerusalem relied upon underground springs, streams, tunnels and cisterns. This was more reliable than rainfall and offered safety from enemy destruction. The first sewerage systems in Japan were built during the Yayoi Period, approximately 2,200 years ago (Japan Sewage Works Association, 2002).

The earliest water management systems were developed to cater for contemporary small settlements, relying on locally suitable water supply sources and were decentralised in nature.

1.1 Greco-Roman Influence on Water Management

The Greek and Roman civilisations (Chanan & Simmons, 2002) achieved the next level of urban water management. Until then, cities and towns were largely constructed adjacent to rivers and streams, to ensure a continuum of water supply and waste transport. The security of the Roman political system, in particular, allowed for the development of water transport systems from remote sources. With the formation of new centres, and the expansion of existing ones, new supplies had to be identified, captured, transported and stored (Landels, 1998; cited in Chanan & Simmons, 2002). Figure 1 shows an aqueduct built during the Roman Empire at Nimes, France. Similar aqueducts were built across Europe to transport water over long distances.

Water management and technology, however, declined in Europe after the fall of the Roman Empire. Political and military insecurity and insufficient state wealth meant that the building of large-scale water supply and sewerage schemes was not attempted in Europe, and dependence on decentralised options continued until the 18th century.

1.2 Water Supply and the Industrial Revolution

Figure 1: Roman Aqueduct, Nimes, France

The Industrial Revolution saw significant growth in wealth, population, scientific knowledge and technology; and the size of cities grew rapidly. The large amount of water needed and the sewage generated, as well as the increased stormwater from vast urban areas, needed a new management approach.

Technical advancements resulting from the Industrial Revolution removed some barriers to urban water infrastructure development. By the end of the 18th century, all major northern European cities had built, or were building new systems to distribute water and evacuate liquid wastes (Reid, 1991). The realisation that many diseases, such as cholera, were passed on by contaminated water was primarily behind the development of this "big pipe engineering approach" - for bringing drinking water into the city and for removing wastewater and stormwater from the city. Big pipe engineering became the standard water management technique (Newman, 2007).

A metaphor for this stage in water management is the First Generation – it began to formalise water infrastructure, but human and environmental health were still seriously challenged by the waste products of growing cities (Davis, 2008)

1.3 Water Engineering in the 20th Century

According to Chanan & Simmons (2002), the 20th century could best be described as the century of applying big engineering solutions to water management. During this period, extensive networks of canals, dams and reservoirs were designed and constructed worldwide. Since 1950, the number of large dams (15 metres or taller) has grown from 5,000 to about 45,000. More than 85 per cent of those were built in the last 35 years (World Commission on Dams, 2000).

The resulting centralised system that has now been inherited is based on sourcing large quantities of water from one location (often a different catchment), adding a number of nutrients to it during its once-only use, and finally disposing the waste stream at another point location. Such a system not only results in receiving waters becoming more polluted, it also causes water sources to become scarce and nutrients such as nitrogen and phosphorus to be diluted and removed from where they could potentially be reused (Livingstone et al, 2004).

Returning to the generation metaphor – this was the Second Generation of water management. The Second Generation lasted till late 20th century, consequently water and wastewater technologies developed during this phase are predominant throughout the world. These technologies are now commonly referred to as the 'conventional' techniques.

2. Conventional Sewage Treatment Techniques

Treatment of sewage is required to protect both public health and that of the receiving water or user. A treatment system has to remove suspended material, dissolved organic material, pathogens and, sometimes, dissolved inorganic material.

There are basically two types of wastewater treatment processes, (a) unit operations where physical processes dominate the removal of contaminants e.g. screening, sedimentation, filtration, etc., and (b) unit processes where removal or conversion of contaminants takes place either by addition of chemicals or by biological action e.g. biological breakdown, disinfection etc. Preliminary treatment (e.g. screens and grit chambers) removes most of the coarse and heavy inorganic (typically garbage and grit) and organic solids (coarse food particles), whereas a large fraction of total suspended solids and a fair proportion of the organic matter in suspended solids can be removed by gravity in a primary sedimentation tank. The biodegradable organics (mainly in dissolved form, but also as fine particles) are removed in some sort of biological reactor. Since feeding bacteria with degradable material results in a net growth of bacterial biomass, it is common for a secondary clarifier tank to separate the biomass. Polishing to remove fine particles and disinfection are typically carried out in filtration and chlorination or UV disinfection reactors respectively.

As outlined in Figure 2, a typical conventional treatment plant consists of a train of individual unit processes set in a series, with the effluent of one process becomes the influent of the next inline process. The sewage treatment processes can be classified as four groups: preliminary treatment, primary treatment, secondary treatment and tertiary treatment. The treatment level is subjective, meaning that there is no quantitative value which defines the effluent standards for each level of treatment. For example, a particular primary treatment method may produce effluent comparable to a secondary treatment of another method. While this classification was useful in older style treatment plants, it has less utility today, when there are a wider variety of processes, used in different combinations, and especially when more *natural* approaches are used, which rely on the same fundamental mechanisms, but which are also combined in different ways. Conventional wastewater treatment is further discussed in Chapter 9 and 11.

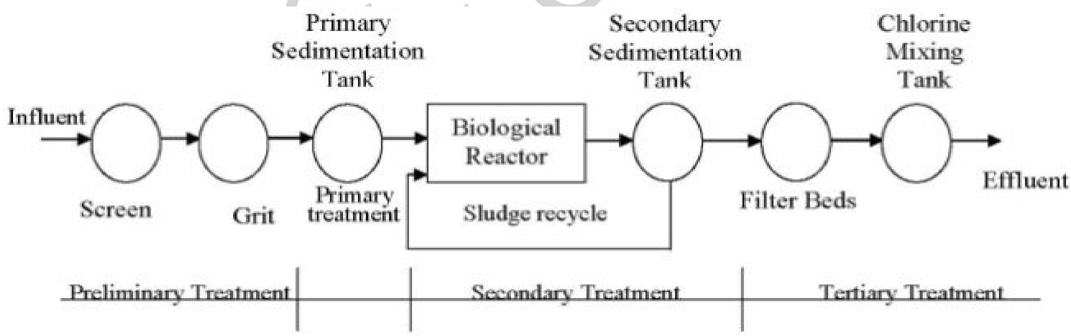

Figure 2: Process diagram of a typical conventional sewage treatment plant

Table 2 shows various treatment classes and some of the units in conventional and natural treatment systems.

Class/Level	Conventional system	Natural/low cost system
Preliminary Treatment	Screens Grit chamber Grease trap	Screens Grit chamber Grease trap
Primary Treatment	Primary sedimentation tanks Enhanced clarifiers	Anaerobic/facultative ponds Facultative ponds

	CEPT (chemically enhanced primary treatment) Lamella separators	Partially aerated ponds
Secondary Treatment	Trickling filter Rotating biological contactor Anaerobic filter Fixed film process Sequencing batch reactor	Wetlands Oxidation ponds Oxidation ditches Aerated ponds
Tertiary Treatment	Chlorine disinfection Membrane Filtration Sand filtration Ozone treatment Ion-exchange Activated carbon adsorption Membrane process Chemical oxidation Granular media filtration Ultraviolet disinfection	Wetlands Land treatment UV disinfection Maturation ponds Slow sand filter

Table 2: Treatment classes and their various optional units

3. Third Generation Wastewater Treatment Systems

Driven by increased environmental awareness amongst the community, water and wastewater management entered into the Third Generation phase in late 20th Century. One of the most significant outcomes of this short-lived phase in water management was the realization that the conventional treatment systems contribute to environmental degradation by excessive extraction of nonrenewable resources, and through disposal of by-products/final products of these technologies, such as biosolids and sludge. Therefore, the Third Generation wastewater treatment techniques were focused on cost-effective sustainable approach that often revolved around using natural components rather than mechanical devices that use energy.

Some useful Third Generation techniques that will also play significant role into the future of wastewater treatment include:

3.1 Facultative Ponds

Facultative ponds (ones which have a zone of oxygenated water at the surface, but oxygen-deprived water below) are either primary facultative ponds that receive raw wastewater or secondary facultative ponds that receive settled wastewater effluent from anaerobic ponds. They are designed for BOD removal on the basis of a relatively low surface loading (i.e. the mass of organic pollution applied to the surface area, expressed as 100-400 kg BOD/ha.d at temperature between 20°C and 25°C) to permit the development of a healthy algal population. The oxygen for BOD removal by the pond bacteria is mostly generated by algal photosynthesis (Mara and Pearson, 1998). Facultative ponds are referred to in different terms such as oxidation ponds, sewage lagoons and photosynthetic ponds which in the main provide secondary treatment and effluent polishing. In chapter 12 a comparison of the performance of facultative ponds with other types of treatments is given.

The water layer near the facultative pond surface contains dissolved oxygen owing to atmospheric reaeration and algal respiration, a condition suitable for aerobic (need oxygen to respire) and facultative (can respire with or without free oxygen present) organisms. The sludge deposits at the bottom of the pond support anaerobic (can only respire when there is no free oxygen present) organisms while the intermediate anoxic (no free oxygen, but not fully anaerobic either) layer, known as the facultative zone, ranges from the aerobic layer near the top to the anaerobic layer at the bottom. These layers may persist for long periods due to temperature-induced water density variations (US EPA, 2002). Inversions can occur in the spring and autumn when the surface water layer may have a higher density than layers underneath. This higher density water sinks during these unstable periods, creating turbidity, and producing objectionable odours (US EPA, 2002) when anaerobic metabolic products are exposed to the atmosphere. Facultative ponds are further discussed in Chapter 12.

3.2 Constructed Wetlands

Wetland treatment systems use either natural wetlands or purpose-built ones (constructed wetlands) for treatment of wastewater. Depending on the level of water, there are two basic types of constructed wetlands for treatment of wastewater. They are constructed surface flow (SF) wetlands, and constructed sub-surface flow (SSF) wetlands.

In surface flow wetlands the substrate bed is densely vegetated and there is a water column above the surface of the bed. In a sub-surface flow wetland, the substrate bed is constructed with gravel to provide high void space to allow wastewater loaded onto the bed to quickly seep through the bed and to always flow below the surface level of the bed. Treatment of wastewater occurs while flowing through the bed. Through different arrangement for feeding wastewater into wetlands and collection the effluent, the wastewater can flow either horizontally or vertically. The wetland is a vertical flow system or a horizontal flow system depending on whether the flow is predominantly vertical or predominantly horizontal. Chapter 12 provides further details of these configurations.

The four major system components of constructed wetlands for treatment of wastewater are:

- Wetland vegetation or macrophytes - play a major role in treatment of wastewater. The biomass of the plant slows the pathway of wastewater, enhancing the sedimentation of solids. There is also uptake of some pollutants in wastewater by these plants.
- Media or substrate supporting vegetation- comprising coarse and fine gravel, physically supports macrophytes in a constructed wetland and also acts as the principal storage of all biotic and abiotic (non-living) components that exist in a wetland.
- Water column (in or above the media)- pollutants are transported by the water column above and below the substrate to active biological zones of a wetland

system. It also provides the environment for the biochemical treatment reactions to occur and to transmit the resultant products such as gases that are formed during these reactions;

- Living organisms - micro- and macro-organisms form a part of wetlands. The microorganisms attach to the substrate and help assimilate, transform and recycle chemical constituents that are found in wastewater and aid their removal.

Wetlands are effective in removing biological oxygen demand, suspended solids, nitrates and phosphates, as well as reducing the concentrations of metals, organics and pathogens. Removal of pollutants in a constructed treatment wetland can occur in the following ways:

- Direct uptake of pollutants by the plants;
- Plants providing large surface area on which microbial degradation occurs;
- Decreasing velocity of flow to allow sedimentation of solids;
- Filtering-out of large particles through root and reed masses;
- Adsorption of nutrients (such as nitrates and phosphates) by soil/substrate media;
- Allowing detention time for natural die-off of pathogens;
- UV radiation and excretion of antibiotics by plants to remove pathogens.

Pollutant removal processes occur by interaction with the wetland vegetation, the water column, and the wetland substrate. Table 3 sets out details of process types and the pollutants removed. Processes may be physical, chemical or biological. These are discussed in more detail in chapter 9 and 12.

Processes	**Pollutants removed**
Biological degradation, sedimentation, microbial uptake	Organic material (measured as BOD)
Adsorption, volatilisation, photolysis and biotic/abiotic degradation	Organic contaminants such as pesticides
Sedimentation, filtration	Suspended solids
Sedimentation, nitrification/denitrification, microbial uptake, plant uptake, volatilization	Nitrogen
Sedimentation, filtration, adsorption, plant & microbial uptake	Phosphorus
Natural die-off, sedimentation, filtration, predation, UV degradation, adsorption	Pathogens
Sedimentation, adsorption, plant uptake	Heavy metals

Table 3: Pollutant removal processes in constructed wetlands (modified from Mitchell, 1996)

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Bibliography

Adams, C., Wang, Y., Loftin, K. and Meyer, M. (2002). Removal of antibiotics from surface and distilled water in conventional water treatment processes. Journal of Environmental Engineering, 123, 253-260. [This paper highlights the deficiency of flocculation in removing smaller organics molecules]

Al-Malack, M.H. and Anderson, G.K. (1996). Coagulation crossflow micro filtration of domestic wastewater. Journal of Membrane Science, 121(1), 59-70. [Paper describing the importance of pretreatment in membrane filtration used for water reuse]

Ahmaruzzaman, M. and Sharma, D.K. (2005). Adsorption of phenols from wastewater. Journal of Colloid and Interface Science, 287, 12-24. [Paper describing a physico-chemical process in water treatment]

Anderson J. (1996), 'The potential for water recycling in Australia - expanding our horizons', *Desalination*, Vol. 106, pp. 151-156. [Paper describing the opportunities for wastewater reuse in Australia]

Australian Bureau of Statistics (2001), *Environmental Issues, People's Views and Current Practices*, Australian Bureau of Statistics, catalogue number 4602.0, Canberra. [This report gives useful information on contemporary views and practices on environmental issues]

AWWA (1999). Water Quality and Treatment: A handbook of community water supplies. AWWA, McGraw-Hill, New York. [A book giving a good overview on water supply and treatment]

Ayuso E.A., Sanchez A.G., Querol X. (2003) Purification of metal electroplating waste waters using zeolites. Water Research 37, 4855–4862. [This presents approaches to the study of water purification using zeolites]

Bellona C., Drewes J.E. (2007) Viability of a low-pressure nanofilter in treating recycled water for water reuse applications: A pilot-scale study. Water Research, 41, 3948-3958. [This presents approaches to the study low-pressure nanofilter]

Binks P. (2007) Nanotechnology & water: opportunities and challenges. Victorian Water Sustainability Seminar, May 15 2007. [This presents approaches to the study of nanotechnology for water issues]

Bruggen B.V.D., Manttari M., Nystrom M. (2008) Drawbacks of applying nanofiltration and how to avoid them: A review. Separation and Purification Technology, 63, 251-263. [This presents review approaches to the application of nanofiltration]

Boyer, T.H. and Singer, P.C. (2005). Bench-scale testing of a magnetic ion exchange resin for removal of disinfection by-product precursors. Water Research, 39 (7) 1265-1276.

Cakir, F. Y., Stenstrom, M. K. (2005) 'Greenhouse gas production: A comparison between aerobic and anaerobic wastewater treatment technology'. *WaterResearch*, 39, 4197-4203. [A paper analysing the green house implications of different forms of wastewater treatment]

Cavaco, S.A., Fernades, S., Quina, M.M. and Ferraira, L.M. (2007). Removal of chromium from electroplating industry effluents by ion exchange resins. Journal of Hazardous Materials, 144, 634-638. [Paper describing the ion exchange process in industrial wastewater treatment]

Chanan A. and Simmons B. (2002), '*Dams to Demand Management: A Journey Through Development of Urban Water Supply*', Proceedings River Symposium 2002, Brisbane, September 2002. [A paper describing the paradigm shift in water management]

Chang, S., Waite, T.D. and Fane, A.G. (2005). A simplified model for trace organics removal by continuous flow PAC adsorption/submerged membrane processes. Journal of Membrane Science, 253(1), 81-87. [Paper describing the membrane hydrid system and its optimisation]

Chen, Y., Dong, B.Z., Gao, N.Y. and Fan, J.C., (2007), Effect of coagulation pre-treatment on fouling of an ultrafiltration membrane, Desalination, 204, pp. 181-188 [Paper describing the importance of flocculation as a pretreatment to membrane processes]

Cho M., Chung H., Choi W., Yoon J. (2005) Different inactivation behaviours of MS-2 phage and Escherichia coli in TiO_2 photocatalytic disinfection. Applied and Environmental Microbiology, 71, 270-275. [This presents approaches to the study of bactericidal effect of TiO_2]

Crittenden, J.C., Trussell, R.R., Hand, D.W; Howe, K.J, and Tchobangoglous, G. (2005). Water Treament: Principles and Design, John Wiley & Sons, Inc., New Jersey. [a good overview on different treatment process for water]

Cheryan M. (1998). Ultrafiltration and Microfiltration Handbook, Technomic Publishing Co., Lancaster, PA. [This book presents detailed information of UF and MF]

Chuang, C. L., Fan, M., Xu, M., Brown, R.C., Sung, S., Saha, B. and Huang, C.P. (2005). Adsorption of arsenic (V) by activated carbon prepared from oat hulls. Chemosphere, 61, 478-483. [Paper describing the arsenic removal by adsorption]

Crites, R. W., E. J. Middlebrooks and S. C. Reed (2006). Natural Wastewater Treatment Systems. CRC, Taylor & Francis, Boca Raton, Florida. [This book provides good information on natural treatment systems including wetlands]

Davis C. (2008), *Fourth Generation Water Systems*, A paper for the Local Government and Shires Association of NSW, February 2008, University of Technology Sydney.[A paper describing the evolution of water management systems that forms the basis of this chapter]

Devi, R. and Dahiya, R.P. (2007). COD and BOD removal from domestic wastewater generated in decentralised sectors. Bioresource Technology, 99, 344-349. [given information on the pollutant removal during wastewater treatment]

Dillon, P. (2001). 'Water Reuse in Australia: Current, Future and Research', *Water*: Journal of Australian Water Association, 28 (3), 18-21. [A paper on status and opportunities of water recycling in Australia]

DLWC (1998). *The Constructed Wetlands Manual*. Department of Land and Water Conservation New South Wales ISBN 07313 1329 6 [Comprehensive manual on the construction, operation and maintenance on constructed wetlands.]

Edwards, M. (2000) 'Indus Civilisations', *National Geographic*. 197, No.6 [A article on the Indus civilisation]

EPA Victoria (2000) *Environmental Guidelines for Reducing Greenhouse Gas Emissions from Landfills and Wastewater Treatment Facilities*. EPA Victoria, Report 722, ISBN 0 7306 7590 4. [This report provides figures on the greenhouse emissions form solid waste landfills]

Ernst M., Sachse A., C. Steinberg E. W. and Jekel M. (2000) Characterization of the DOC in nanofiltration permeates of a tertiary effluent. Water Research, 34, 2879-2886. [This presents approaches to the study of characterization of organic matter after NF]

Fane S. (2005), '*Planning for Sustainable Urban Water: System Approaches and Distributed Strategies*', Institute for Sustainable Futures, University of Technology Sydney, PhD Thesis. [this thesis gives details on planning and policy aspects on urban water systems]

Guida, M., Mattei, M., Rocca, C.D., Melluso, G. and Meric, S. (2007). Optimization of alum-coagulation/flocculation for COD and TSS removal from five municipal wastewater. Desalination, 211, 113-127. [This paper highlights the pollutant removal results by flocculation of wastewater]

Guo, W.S. (2005). Microflitration Hybrid System in Wastewater Treatment for Reuse. Faculty of Engineering, University of Technology Sydney, PhD Thesis. [This thesis gives good information on membrane bioreactor and related hybrid systems with extensive experimental information]

Guo, W.S., Shim, W.G., Vigneswaran, S. and Ngo, H.H. (2005). Effect of operating parameters in a submerged membrane adsorption hybrid system: experiments and mathematical modeling. Journal of Membrane Science, 247(1), 65-74. [Paper describing the membrane hydrid system in wastewater treatment]

Greenfield, P.F. & Batstone, D. J. (2005). Anaerobic digestion: impact of future greenhouse gases mitigation policies on methane generation and usage. *Water Science and Technology*, 52 (1-2), 39-47. [A paper analysing the green house implications of anaerobic digestion used in wastewater treatment]

Hakim (2002). *Water Demand and Pollution Control: Key to securing and safeguarding the water supplies for the MENA in the 21st century.* WHO Regional Centre for Environmental Health Activities, Amman, Jordan [discusses concepts for water and wastewater management in the future]

Hartley, K., Lant, P. A., Leinster, D. G. (2003) 'EnRec-Energy recovery sewage treatment technology'. *Proc AWA QLD Branch Reg. Conf*, Caloundra, QLD, Australia. [A paper highlighing the issue of greenhouse gas emissions resulting from sewage treatment and possible energy recovery]

Hartley, K., and Lant, P. (2006). 'Eliminating non-renewable CO_2 emissions from sewage treatment: an anaerobic migrating bed reactor pilot plant study'. *Biotechnology and Bioengineering*, 95 (3), 384-398. [A paper highlighting the issue of greenhouse gas emissions resulting from sewage treatment and possible solutions]

Hu J., Chen G., Lo I.M.C. (2005) Removal and recovery of Cr(VI) from wastewater by maghemite nanoparticles. Water Research, 39, 4528-4536. [This presents approaches to the study of wastewater remediation by maghemite]

Intergovernmental Panel on Climate Change (2007) *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [This is an authoritative report by leading experts on climate change]

IPCC – see Intergovernmental Panel on Climate Change

Japan Sewage Works Association c. 2002, *Making Great Breakthroughs - All about the Sewage Works in Japan*, p. 47, accessed at http://www.sewerhistory.org/articles/whregion/japan_waj01/ index.htm (Accessed Feb 2008) [an internet article describing early sewerage systems in Japan]

Jarusutthirak C. (2002) Fouling and flux decline of reverse osmosis (RO), nanofiltration (NF) and ultrafiltration (UF) membranes associated with effluent organic matter (EfOM) during wastewater reclamation/reuse. Ph. D. Dissertation, University of Colorado at Boulder. [This thesis presents fouling and flux decline of RO, NF and UF]

Jiuhui Q. (2008) Research progress of novel adsorption processes in water purification: A review. Journal of Environmental Sciences, 20, 1-13. [This presents a review for approaches to the study of water purification by adsorption processes]

Jung, C.W., Son, H.J. and Kang, L.S. (2006). Effects of membrane material and pretreatment coagulation on membrane fouling: fouling mechanism and NOM removal. Desalination, 197(1-3), 154-164. [Paper describing the impostance pretreatment in reducing the membrane fouling and natural organic matter removal]

Keller, A., and Sakthivadivel R., (2000), Water Scarcity and the Role of Storage in Development. in *Wastewater Management Policy.* International Water Management Institute. Sri Lanka. [This report gives useful information on policy aspects related to water security and wastewater management]

Keller, J. and Hartley, K. (2003). 'Greenhouse gas production in wastewater treatment: process selection is the major factor', *Water Science and Technology*, 47(12), 43-48. [A paper analysing the green house implications of different forms of wastewater treatment]

Kim, S.H., Moon, S.Y., Yoon, C.H., Yim, S.K. and Cho, J.W., (2005), Role of coagulation in membrane filtration of wastewater for reuse, Desalination, 173, pp. 301-307 [Paper describing the pretreatment of coagulation prior to membrane application in water reuse]

Kuramitz, H., Saitoh, J., Hattori, T. and Tanaka, S. (2002). Electrochemical removal of p-nonylphenol from dilute solutions using a carbon fiber anode. Water Research, 36, 3323-3329. [Paper describing the advanced oxidation processes]

Lebeau, T., Lelievre, C., Buisson, H., Cleret, D., Van de Venter, L.W. and Cote, P. (1998). Immersed membrane filtration for the production of drinking water: combination with PAC for NOM and SOCs removal. Desalination, 117(2), 219-231. [This paper gives experimental results on organic removal by membrane-adsorption hybrid system]

Livingston D., Stenekes N., Colebatch H., Ashbolt N. and Waite T. D. (2004), '*Water Recycling and Decentralised Management: The Policy and Organisational Challenges for Innovative Approaches*', In Proceedings of WSUD 2004 – Cities as Catchments Conference, Adelaide, South Australia, 21-25 November 2004. [A paper describing decentralised approaches for recycle water management].

Lopez, A., Bozzi, A., Mascolo, G. and Kiwi, J. (2003). Kinetic investigation on UV and UV/H_2O_2 degradation of pharmaceutical intermediates in aqueous solution. Journal of Photochemistry and Photobiology A: Chemistry, 156, 121-126. [this paper highlights the application of advanced oxidation in industrial wastewater treatment]

Manttari M., Viitikko K., Nystrom M. (2006) Nanofiltration of biologically treated effluents from the pulp and paper industry. Journal of Membrane Science, 272, 152-160. [This presents approaches to the study of water remediation by nanofiltration]

Mara, D. (1987). Design Manual for Waste Stabilisation Ponds in India. Leeds: Lagoon Technology International. www.leeds.ac.uk/civil/ceri/water/tphe/publicat/pdm/india/india.html. [Comprehensive guideline for designing of waste stabilisation ponds with special emphasis on India]

Mara, D. and H. Pearson (1998). Design Manual for Waste Stabilisation Ponds in Mediterranean Countries. Leeds: Lagoon Technology International. www.leeds.ac.uk/civil/ceri/water/tphe/publicat/pdm/med/medman.html. [Comprehensive guideline for designing of waste stabilisation ponds]

Mara, D., H. Pearson, J. Oragui, H. Arridge and S. A. Silva (2001). Development of a new approach to waste stabilisation pond design. Research Monographs in Tropical Public Health Engineering, School of Civil Engineering, University of Leeds, ISSN: 1351 - 1378. [Explains the new approaches to designing WSP]

Mitchell C. (1996) Pollutant Removal Mechanism in Artificial Wetlands. Unpublished course notes for the International Winter Environment School (IWES), July, Gold Coast, 1996. [course notes describing the pollutant removal in constructed wetlands]

Mo, L. and Huanga, X. (2003). Fouling characteristics and cleaning strategies in a coagulation-microfiltration combination process for water purification. Desalination, 159(1), 1-9. [Detailed information on flocculation-microfiltration hybrid systems]

Monteith, H.D., Sahely, H.R., MacLean H.L., Bagley, D.M. (2005). A rational procedure for estimation of greenhouse-gas emissions from municipal wastewater treatment plants, Water Environment Research. 77 (4), 390–403. . [A paper describing the calculation of green house gas production from wastewater treatment plants]

Newman P. (2007), '*Sustainability and the Urban Water System*', Case Study, Institute for Sustainability and Technology Policy, Murdoch University. [A report on the development of Western Cities and accompanying development of the water supply systems]

P& M Magazine (1989). Ancient Plumbing. *Plumbing and Mechanical Magazine*. October 1989. [A article on the Nile civilisation and diversion of water form the Nile]

Pinkham R. (2004), 21st Century Water Systems: Scenarios, Visions, and Drivers, Rocky Mountain Institute, Snowmass, Colorado, February 2004. [This report provides emphasise the merits of decentralised systems]

Radcliffe, J. (2003). An Overview of Water Recycling in Australia – Results from the recent ATSE study. Water Recycling Australia, 2nd National Conference 1-3 September, 2003 Brisbane. Australian Water Association, Sydney. [A report on status of water recycling in Australia]

Reed, S. C., R. W. Crites and E. J. Middlebrooks (1995). Natural Systems for Waste Management and Treatment (second edition), McGraw Hill Book Co., New York, NY, 1995. [This book gives very good information on wetlands]

Reid, D. (1991). *Paris Sewers and Sewermen*, IBT Global London. [A book describing the Parisian sewer system]

Satyawali Y., Balakrishnan M. (2008) Wastewater treatment in molasses-based alcohol distilleries for COD and color removal: A review. Journal of Environmental Management, 86, 481-497. [This presents approaches to the study of industrial wastewater treatment]

Schafer A.I. (2001) Natural organics removal using membranes: principles, performance, and cost. Technomic Publishing Company, Inc., Pennsylvania, USA. [This book presents approaches to the study of the characteristics of different membranes for removal of NOM]

Shizas, I, and Bagley, D. M. (2004). Experimental determination of the energy content of unknown organics in municipal wastewater streams ASCE. *Journal of Energy Engineering*, 130(2), 45-53. [A paper describing outlining the energy content available in municipal wastewater]

Shon, H.K. (2006) Ultrafiltration and nanofiltration hybrid systems in wastewater treatment and reuse. Thesis, Doctor of Philosophy, Faculty of Engineering, University of Technology Sydney, Australia. [This thesis provides detailed information on the physico-chemical process and membrane filtration in organic removal from wastewater]

Shon, H. K., Vigneswaran, S., Kim, I.S., Cho, J. and Ngo, H.H. (2004). Effect of pretreatment on the fouling of membranes: application in biologically treated sewage effluent. Journal of Membrane Science, 234, 111-120. [This paper discusses the capability of different physico-chemical processes in removing organic matter for Wastewater]

Shon H.K., Vigneswaran S., Ben Aim R., Ngo H. H., Kim In S. and Cho J. (2005) Influence of flocculation and adsorption as pretreatment on the fouling of ultrafiltration and nanofiltration membranes: application with biologically treated sewage effluent. Environmental Science & Technology, 39, 3864-3871. [This presents approaches to the study of the influences of pretreatment methods on the fouling of UF/NF using BTSE]

Smith A. (2006) Nanotech – the way forward for clean water? Filtration and Separation, 43(8), 32-33. [This presents approaches to the study of nanotechnology applications for water treatment]

Stenekes N., Livingston D., Colebatch H. K., Waite T. D., and Ashbolt, N. J. (2004), *Sustainable water management in Australia: an institutional analysis*, In Proceedings of Good Water Governance for People and Nature: Water Roles for Law, Institutions & Finance Conference, Dundee, Scotland, August 29-September 2, 2004. [A paper describes institutional aspects related to water management in Australia].

Sundaravadivel, M and Vigneswaran, S (2001). Constructed Wetlands for Wastewater Treatment. Critical Reviews in Environmental Science and Technology, 31(4):351-409 (2001). [An excellent comprehensive review of constructed wetlands for wastewater treatment]

Suty, H., De Traversay, C. and Coste, M. (2003). Applications of advanced oxdiation processes: present & future. In: *proceedings of the 3rd Conference on Oxidation Technologies for Water and Wastewater Treatment*, Goslar, Germany, May 18-22, 8. [This paper highlights the relative merits of advanced oxidation]

Tchobanoglous, G., Burton, F.L. and Stensel, H.D. (2003). Wastewater Engineering: Treatment and Reuse, Metcalf and Eddy, Inc., McGraw-Hill Book Company, New York. [This book details the treatment and reuse of wastewater]

Theron J., Walker J.A., Cloete T.E. (2008) Nanotechnology and Water Treatment: Applications and Emerging Opportunities. Critical Reviews in Microbiology, 34, 43-69. [This presents approaches to the application of nanotechnology for water remediation]

Thomsen, M., Lyck, E. (2005) *Emission of CH_4 and N_2O from wastewater treatment plants* (6B). NERI Technical Notes Number 208, National Environmental Research Institute, Ministry of Environment, Denmark. [This report provides details on the green house emission estimates in wastewater treatment plants]

Ullah R., Dutta J. (2008) Photocatalytic degradation of organic dyes with manganese-doped ZnO nanoparticles. Journal of Hazardous Materials, 156, 194-200. [This presents approaches to the study of organic dye decomposition by manganese doped ZnO nanoparticles]

USEPA (2002) Wastewater Technology Fact Sheet: Rock Media Polishing Filter for Lagoons, Unted States Environmental Protection Agency. [This presents approaches to the study of rock media polishing filter uses and applications for Lagoons]

USEPA (2007). *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2000*, Office of Policy, Planning and Evaluation, Washington, D. C., Report No. EPA-600/R-97-091. [This report provides details on the green house emission estimates in wastewater treatment plants]

Velicu, M., Fu, H., Suri, R.P.S. and Woods, K. (2007). Use of adsorption process to remove organic mercury thimerosal from industrial process wastewater. Journal of Hazardous Materials, 148, 599-605. [This paper highlights the use of adsorption in heavy/toxic metal removal]

Volgelpohl (2003). *Proceedings of the 3rd Conference on Oxidation Technologies for Water and Wastewater Treatment*, Goslar, Germany, May 18-22. [a good overview on advanced oxidation process]

Wang, G. S., Hsieh, S.T. and Hong, C.S. (2000). Destruction of humic acid in water by UV light - catalyzed oxidation with hydrogen peroxide. Water Research, 34, 3882-3887. [the paper describes the application of advanced in natural organic matter]

World Commission on Dams (2000). *Dams and Development: A New Framework For Decision Making*, United Nations. [A comprehensive review of long term impact of dams on the natural environments].

Biographical Sketches

Mr Chris Davis is a. Chris Davis is UTS's Sustainability Business Development Manager, a role he has been in since July 2007. Before taking up that position, Chris was CEO of the Australian Water Association for 15 years, having had a career in local government, consulting and process contracting for water. Chris has a BSc in Civil Engineering from the University of the Witwatersrand (Johannesburg), a Masters Degree in Civil Engineering from the University of Texas at Austin and an MBA from the University of New England. In addition to his UTS role, Chris serves on several advisory committees, panels and boards, relating to the water industry.

Dr Saravanamthu Vigneswaran has been working on water and wastewater treatment and reuse related research since 1976. During the last twenty years, he has made significant contributions in physico-chemical water treatment related processes such as filtration, flocculation, membrane-filtration and adsorption. His research activities both on new processes development and mathematical modeling are well documented in reputed international journals such as Water Research, American Institute of Chemical Engineers Journal, Chemical Engineering Science, Journal of American Society of Civil Engineers, and Journal of Membrane Science. He has also been involved in a number of consulting activities in this field in Australia, Indonesia, France, Korea, and Thailand through various national and international agencies. He has authored two books in this field at the invitation of CRC press, USA, and has published more than 230 papers in journals and conference's proceedings. Currently a Professor of the Environmental Engineering Group at the University of Technology, Sydney, he was the founding Head of and the founding Co-ordinator of the University Key Research Strength Program in Water and Waste Management. He is coordinating the Urban Water Cycle and Water and Environmental Management of the newly established Research Institutes on Water and Environmental Resources Management and Nano-scale Technology respectively.

Dr J. Kandasamy is Senior Lecturer in the Faculty of Engineering University of Technology, Sydney, Australia. He obtained his PhD from University of Auckland., New Zealand where is also obtained his Bachelor in Civil Engineering and Masters in Civil Engineering. He has worked in the New South Wales Government as a Senior Engineer for 15 years and has wide industry knowledge.

Mr Amit Chanan is General Manager of Strategic Assets, State Water Corporation. State Water is New South Wales' rural bulk water delivery corporation, annually delivering more than 5,500GL of water to regional NSW. It manages and operates 20 dams and more than 280 weirs and regulators to deliver water for town water supplies, industry, irrigation, stock and domestic use, riparian and environmental flows. Amit is currently a Member of the International Water Association's (IWA) Australian Management Committee. In 2008 Amit was appointed by the NSW Minister for the Environment and Climate Change to the NSW Load Based Licensing Technical Review Panel. The Load-based Licensing Technical Review Panel advises the EPA on the development of site-specific emission factors and related techincal issues. Amit is also a member of the NSW Government's Science Agencies Group.