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**Chapter 7: Augmenting Traditional Water Supply Through Water Reuse and Recycling.**

*Lecture 7.1: Constructed Wetlands and Managed Aquifer Storage, Recovery and Reuse.*
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Peer Review

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Enquires should be directed to:

Augmenting Traditional Water Supply Through Water Reuse and Recycling

Lecture 7.1: Constructed Wetlands and Managed Aquifer Recharge, Recovery and Reuse.

Educational Aim

The aim of this lecture is to overview two important strategies to help adapt to climate change – namely constructed wetlands and managed aquifer storage and recovery. As Lecture 6.1 showed, a major issue with reusing water without treatment is the significant risk of health problems due to the likely presence of at least one of pathogens, chemicals, fine particle sediments or other pollutants.\(^1\) One option discussed in Lectures 5.4, 6.1 and 6.2 was water disinfection by chlorination which can eliminate most water-borne infectious diseases. However, as also discussed, chlorination disinfection processes have costs and can produce unwanted by-products.\(^2\) Thus, new options are needed, designed to reclaim nutrients and water from wastewater for reuse, while also removing pathogens, chemicals and other fine particles. Such systems ideally would also be environmentally sustainable, require low external energy requirements, be cost-effective and have broad community support: constructed wetlands in many cases meet these criteria and hence is explored in detail in this lecture.\(^3\) Increasingly constructed wetlands are being used to provide initial water treatment for managed aquifer recharge and recovery schemes. Storage of water is becoming increasingly important as climate variability impacts on balancing demand with supply. As this lecture will show there is significant potential in Adelaide, Perth and Melbourne to harvest urban stormwater and store it cost effectively in aquifers for reuse. This lecture seeks to provide an overview of the different ways managed aquifer storage and recovery can be used to help adapt to climate change.

Learning Points

1. The field of study into constructed wetlands is well established. The first constructed wetlands were investigated over forty years ago. There are also now increasing numbers of constructed wetlands in Australia\(^4\) and internationally demonstrating the value and effectiveness of constructed wetlands as an integrated part of urban water sensitive design approaches.

2. There are overall about 5000 constructed wetlands in Europe and hundreds of constructed wetlands operating in the following countries: Australia, Austria, Canada, China, the Czech Republic, France, Germany, Ireland, Norway, Poland, Russia, Ukraine, and the USA. Currently, more and more countries are adopting this approach and modifying it to suit their own climatic, geological and botanical conditions.

3. There is increasing interest nationally and globally in constructed wetlands as part of a growing trend to prefering water sensitive urban design approaches to urban water management. Constructed wetlands can treat water from many sources such as stormwater, sewerage, agricultural and food processing wastewater, industrial wastewater, drainage from mines, and landfill leachate. The performance efficiency of constructed wetlands to transform, remove and recycle nutrients has been studied and is well understood. Constructed wetlands also provide suitable conditions for pathogen removal. Wetlands remove pathogens and harmful bacteria through physical–chemical factors such as solar irradiation (UV light), filtration,

References:


Prepared by The Natural Edge Project 2009 Page 4 of 22 Water Transformed: Sustainable Water Solutions
adsorption and sedimentation.\textsuperscript{23} Constructed wetlands can also remove metals from the main water body.\textsuperscript{24}

4. Thus the main water treatment processes operating in a constructed wetland are as follows;

- **Suspended Solids and BOD** - Sedimentation is aided by the presence of vegetation as fine particles adhere to the bio-film surfaces of the vegetable or gravel substrate and microbes break down organic particulates.

- **Nutrients**: Nutrients can be directly taken up by plants and micro-organisms. Microbial processes facilitate the removal and transformation of nutrients. The literature demonstrates the ability of constructed wetlands to reduce nutrient loads to treat agricultural runoff, effluent or sewerage.\textsuperscript{25}

- **Pathogens**: Pathogens can be removed through natural UV disinfection over time. Careful choice of a diverse array of plant species and the design of the wetland can improve the effectiveness of a wetland in removing nutrients and pathogens. Natural UV disinfection processes can be enhanced through incorporating lagoons and designing shallow-water wetlands. Studies in Australia show that constructed wetlands can remove 95% of pathogen and indicator organisms.\textsuperscript{26}

- **Metals**: Metals are taken out of the main water body by being adsorbed and captured onto sediments or through plant uptake and bioaccumulation.\textsuperscript{27}

Thus, as Greenway has shown “**Constructed-wetland technology presents itself as a viable option for reducing nutrients and performing the function of disinfection.**”\textsuperscript{28}

5. The potential is significant in most countries, including Australia, to increase the levels of wastewater treatment and reuse through constructed wetlands.\textsuperscript{29} In Australia, currently very little sewage effluent or stormwater runoff is reclaimed and reused. For instance, less than three per cent of urban stormwater runoff in Australia is currently re-used.\textsuperscript{30} Wastewater typically provides both nutrients and water upon which agriculture, horticulture, forestry, golf courses, parks and gardens depend. Sewerage and stormwater harvesting, treatment and reuse can thus both return water and nutrients to the land and in so doing create additional sources of water supply to help adapt to climate change.


6. As mentioned above, there is an increasing number of urban wetlands operating and being constructed in Australia. One example of this is in the city of Salisbury, Adelaide. The Salisbury “Stormwater to Potable Water Project” firstly harvests urban stormwater from residential and industrial sources, then treats this water in a “reed-bed wetland” before the water is injected into wells in a limestone aquifer below ground for storage and further purification. The water recovered from this managed aquifer storage and recovery system was found to meet drinking water quality standards.

7. In many countries, including Australia, the potential to store harvested stormwater using “Managed Aquifer Recharge” (MAR) techniques is significant. In Sydney, Perth, Brisbane, and Cairns, where annual rainfall is greater than 800mm, the volume of urban stormwater runoff is larger than the volume of water supplied by mains water. Large scale and cost effective water storage options have been the main barrier to reusing these high volumes of stormwater. MAR is emerging as the most cost effective solution where suitable aquifers are present. Much research is currently underway mapping the potential for managed aquifer recharge and recovery in Australia. Where urban aquifers have been mapped in Perth, Adelaide and Melbourne such studies show significant potential storage capacity with Perth at 100–250 GL/year, Adelaide at 20–80 GL/year and Melbourne at 100 GL/year.

8. The Water Services Association of Australia forecasts a shortfall in water supplies to Australian cities and towns of around 800 GL/year by 2030. MAR may provide significant opportunities to close this gap, not only in many of Australia’s capital cities but in many of its coastal towns as well. According to CSIRO, “Substantial opportunities for MAR are expected, but not yet assessed, in rural catchments where water has not been over-allocated, particularly in coastal catchments with unconfined aquifers.” CSIRO also found that urban stormwater stored in an aquifer for a year met all the human health drinking water quality requirements. In a demonstration of the quality of the water produced by MAR, the water was further purified by carbon filtration, microfiltration and ultraviolet disinfection to meet the aesthetic guidelines and bottled as high quality drinking water.

9. Hence, much of the supply-demand gap forecast by the Water Services Association of Australia will be able to be met cost effectively by investing in water efficiency and demand management (Module B, Lectures 2.1-4.3 and Module C, Lectures 5.1-5.2), combined with investments in stormwater harvesting, water treatment with managed aquifer recharge, storage and recovery (Lectures 6.3 and 7.1).

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32 Ibid.
33 Ibid.
10. Managed aquifer recharge also provides a strategy to reduce the risk of coastal aquifer salinisation, which may result from climate change. In the south eastern and south western parts of Australia climate change is forecast to reduce rainfall. This will result in reduced quantities of freshwater flowing into coastal aquifers. Combined with sea level rises, this increases the risk of coastal aquifers becoming salinised. Managed aquifer recharge could be used to ensure adequate levels of freshwater flow into the aquifer, helping to maintain the freshwater and saltwater lens of coastal aquifers. (See Lecture 5.4 for more details)

11. Managed aquifer recharge and reuse is emerging as one of the lowest cost options to adapting to climate change in the water sector. CSIRO has found that

If 200GL of the Water Services Association of Australia projected 800GL shortfall in water in Australian cities by 2030 were met from stormwater aquifer storage and recovery the cost savings in comparison with seawater desalination would be AUD$400million per year in addition to significant environmental benefits.

This is because, the average levelised cost of eight urban stormwater aquifer storage and recovery projects of between 75 and 2000 ML/yr was found to be AUD$1.12/kL. This is less than current prices of mains water in capital cities.

For agricultural recharge projects where infiltration basins can recharge unconfined aquifers at high rates the levelised cost of recharge and recovery is more than an order of magnitude less, e.g. in the Burdekin Delta, Queensland, the cost is $0.07/kL. This project has proven to be economic for irrigation of sugar cane and has been operated continuously for 30 years.

Comparisons with alternative urban supplies show levelised costs of stormwater aquifer storage and recovery are 30 to 46 per cent of the costs of seawater desalination and aquifer storage and recovery consumes three per cent of the energy.

Comparative unit costs for urban water storages show that aquifer storage costs are one to four per cent of tank storages and they occupy less than 0.5 per cent of the land surface area of water tanks (for the same volume of water stored). 39

12. Those interested in investigating and implementing managed aquifer recharge, storage, and recovery (ASR) projects have much experience in Australia to draw upon. According to CSIRO, in Australia in 2008, MAR already contributed 45GL/yr to irrigation supplies 40 and 7GL/yr to urban water supplies across Qld, SA, WA and NT. 41 In addition, relatively new Australian guidelines for MAR 42, published in 2009, address the risks to human health and the environment, and thus will bring national uniformity and reduce uncertainties in approval processes for new MAR water supply projects using all sources of water (including recycled water). There is now also a wealth of research and guides for MAR available to also assist practitioners. (see Key References below)

Brief Background Reading

39 Ibid.
**Constructed Wetlands – A Natural Approach to Water Treatment.**

While recognising the progress being made with physico-chemical-biological water treatment technologies and processes, which were outlined in Lecture 6.2, there is renewed interest in biological systems based on wetlands for wastewater treatment as part of water sensitive urban design projects. Constructed wetlands can provide a low cost alternative to tertiary “Biological Nutrient Removal” plants and thus may be more appealing for small communities where the cost of upgrading treatment works can be prohibitive. The treated wastewater from these wetlands (a scarce resource during the dry season and in arid regions) can also be used to irrigate crops, playing fields, parks and gardens or golf courses or stored in aquifers. Thus wetlands, when combined with aquifers, provide a natural, low greenhouse gas emitting strategy, to store rainfall during the wetter months of the year to enable that water to be used during drier months of the year. Constructed wetlands can also provide biodiversity value and improve landscape amenity. As many natural wetlands are only seasonally inundated, during the dry season wildlife has to seek alternative refuges. Wetlands constructed for effluent treatment can mitigate the loss of wetlands that have occurred in the past through ignorance of their importance to natural ecosystems and wildlife.43

Wetland ecosystems are made up of both biotic (aquatic plants – macrophytes; aquatic organisms – macroinvertebrates and vertebrates; and micro organisms) and abiotic components (sediment, water, air). Wetlands support a diverse array of species with microrganisms being the largest in number. Which species are most common depends obviously on the bioregion but also on rainfall patterns and the water depth of the wetland. As Greenway explains

>“Water depth plays a critical role in the distribution of the types and species of aquatic plants in wetlands. In natural wetlands, zonation is common, with emergent seasonally inundated species occurring at the landward interface and submerged species occurring in deeper permanent water. Ephemeral wetlands or wet meadows are dry or waterlogged areas that experience regular inundation which may be seasonal and support emergent macrophytes. Marshes are shallow wetlands, which are typically dominated by emergent macrophytes. However, floating-leaved attached macrophytes such as water lilies, submerged macrophytes and floating macrophytes (e.g. duck weed) may occur, particularly where there is permanent water. Deeper open ponds may support floating-leaved attached macrophytes, floating macrophytes or submerged macrophytes if there is sufficient light for growth. Wetlands and ponds support a diversity of aquatic animals including micro-crustaceans (copepods, ostracods, cladaceans) shrimps, crayfish; insects (dragonfly larvae, water beetles, water boatman); pond snails, tadpoles, frogs and fish. These organisms are a crucial component of wetland and pond ecosystems providing invaluable food web linkages between plants, micro-organisms and other animals. Predator-prey relationships are important in the control of mosquitoes.”44

**Wetland design is critical to optimising nutrient and pathogen removal.**

Wetland design and choice of plant species is important to improve the effectiveness of the constructed wetland removing nutrients and pathogens. If we take Queensland, as an example,

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research there shows that in order to maximise nutrient removal, a range of plant types should be used, including\textsuperscript{45}

- duckweed and submerged species (e.g. \textit{Ceratophyllum} and \textit{Potamogeton}), to remove nutrients directly from the water column;
- rooted species, to remove nutrients from the sediment and aerate the rhizosphere zone for nitrification.
- plants with large surface area to ensure Periphyton attachment. Periphyton is a complex mixture of algae, cyanobacteria, heterotrophic microbes, and detritus that is attached to submerged surfaces in most aquatic ecosystems. It serves as an important food source for invertebrates, tadpoles, and some fish. It can also absorb contaminants; removing them from the water column and limiting their movement through the environment.

In order to maximise pathogen removal, both open-water areas and densely vegetated zones are needed. The densely vegetated zones ensure high levels of filtration and sedimentation of particles to which pathogens will be adsorbed, while the open-water areas enable natural UV disinfection to work as effectively as possible. Ensuring the wetland encourages and supports large populations of natural-wetland microbes (bacteria and viruses) will enable predation, lysis and competition with pathogenic human microbes. Ensuring that water spends at least 5 days passing through a wetland will ensure time for natural UV disinfection to work as effectively as possible. Proponents of constructed wetlands also recommend “a final subsurface filtration through gravel or sand to maximise both nutrient and pathogen removal.”\textsuperscript{46}

The Mosquito Issue

One of the barriers to wider adoption has been the perception that constructed wetlands may be potential breeding sites for mosquitoes.\textsuperscript{47} Wetland design can be used to reduce the potential for mosquitoes to breed. Aggressive species which die off in winter to produce a thick interwoven mat of stems should not be used. Nor should species that produce dense floating rafts be used, nor aquatic creepers. With respect to minimising mosquito breeding, wetland design should include both shallow marsh and at least 30 per cent deep open-water ponds. A 2002 study by the South Australian EPA concluded that

“Wetlands with open waterbodies, steep edges and little emergent vegetation had no or very low numbers of mosquitoes. Wetlands and drains producing high numbers of mosquitoes were shallow, protected waterbodies, with isolated pools of water that limited predator access and contributed to poor water quality.”\textsuperscript{48}

Greenway et al\textsuperscript{49} have shown that predation of mosquito larvae by aquatic invertebrates controls the larvae and prevents the development of pupae.\textsuperscript{50} Greenway et al have shown that “Surface-flow

wetlands can also be designed to minimise mosquito breeding by increasing macro-invertebrate predators, thereby alleviating community concerns about potential health risks." Thus, there is minimal health risk in terms of these wetlands being breeding grounds for mosquitoes, if designed and managed to maximise macro-invertebrate predators and minimise breeding sites. Minimising breeding sites is important, as Walton noted "in the arid south-western United States, constructed treatment wetlands can increase mosquito production if there is poor water quality and dense coverage of submerged dead vegetation." Hence these issues need to be managed and mosquito breeding sites need to be minimised.

While most mosquitoes are opportunistic breeders, they will only deposit eggs if a suitable body of water is available. In aquatic ecosystems, mosquito larvae are an integral component of aquatic food webs. Mokany and Shine found that the presence of existing mosquito larvae was a strong attractant to further egg laying and that female mosquitoes use both chemical and biological cues to assess what sites they choose to breed. Thus, if constructed wetlands are designed to function and maximise the predator–prey mix to control mosquito breeding then this will minimise the chances of mosquito breeding progressing from the larval stage. Predator–prey relationships are thus important in the control of mosquitoes. Wetland plant diversity is important for determining macro-invertebrate associations and wildlife diversity to ensure adequate predators for mosquitoes' because of the creation of habitat and food resources. Wetzel noted that the most effective wetland ecosystems "are those that possess maximum biodiversity of higher aquatic plants and periphyton associated with the living and dead plant tissue." The key to mosquito management is to ensure a well-balanced ecosystem supporting a diversity of aquatic organisms.

Where were Constructed Wetlands First Built and in which Countries are They Used Today?

The use of higher aquatic plants and constructed wetlands for the treatment of polluted water and wastewater is not new. There is a long history of practice and research upon which practitioners can further build. The first constructed wetland was built in the 1960s, when the Max Planck Institute in Germany began to study the treatment properties of higher aquatic plants. In the 1970s, researchers in the Netherlands developed this approach of using plants for wastewater treatment. They called this the "Lelystad process". In the 1970s and 1980s, this research continued in countries such as the USA, Denmark, the UK, Russia and Ukraine, and in the 1990s, research and implementation of constructed wetlands continued in many European countries and the rest of the world. Different terms are used for these systems around the world such as "constructed wetlands" (USA), "reed beds" (UK) or "bioengineering systems" (Ukraine). The term "constructed wetlands" in recent times has become the one most commonly used.

The USA, with more than 1000 wetlands constructed, and the UK, with nearly 500 wetlands constructed currently lead the world in numbers of constructed wetlands. There are overall about

5000 constructed wetlands in Europe. Dozens to hundreds of wetlands have also been constructed throughout Australia, Austria, Canada, China, the Czech Republic, France, Germany, Ireland, Norway, Poland, Russia and Ukraine. Currently, more and more countries are adopting this approach and modifying it to suit their own climatic, geological and botanical conditions.

There are now increasing numbers of constructed wetlands in Australia demonstrating the value and effectiveness of constructed wetlands as part of a water sensitive design approach to stormwater harvesting and water treatment in urban water management. Examples of constructed wetlands being used today include Bridgewater Lifestyle Village Wetland, Erskine, City of Mandurah, Timbers Edge Village Wetland, Dawesville, City of Mandurah; Liege Street Wetland, Cannington, Perth, and Ikerman Oasis, Aurora Estate, and Lynbrook Estate Development all in or near Melbourne. Other famous examples include Olympic Park, Sydney and Mawson Lakes Wetland, Adelaide. In South Australia, for instance, treated sewage effluent after pre-treatment in constructed wetlands is stored in previously unused brackish aquifers for irrigation of parks during dry weather. Recycled water from the Bolivar Wastewater Treatment Plant is being trialled for irrigation of market gardens. Again, wetlands can be used to improve water quality, with savings in water and infrastructure costs as well as providing economic, environmental and social benefits. Constructed wetlands are also used to process and treat industrial waters in Australia at, for instance, Kwinana, WA and Lake Pillans, NSW.

A number of constructed wetlands have been built in South East Queensland and northern rivers, NSW. For instance, in 1995, two large-scale wetlands (Cooroy and Rosewood) were constructed in...
south-east Queensland. Cooroy consists of a lagoon and a series of shallow, densely vegetated marshes and small deep-water ‘ponds’, and treats secondary effluent. Rosewood consists of a lagoon, two surface-flow wetlands and a subsurface-flow wetland, and treats primary settled effluent. More recently a constructed wetland was built as part of the Rocks Riverside Park development in Brisbane.

Another example of utilising constructed wetlands is the Salisbury “stormwater to potable water project” in Salisbury, Adelaide. This project uses urban stormwater harvested from a residential and industrial catchment, which is treated in a reedbed wetland before injecting into wells in a limestone aquifer 160 to 180m below ground there it is stored and then recovered for water reuse. As part of the proof of concept, water recovered after 12 months storage met drinking water requirements.

![Figure 7.1.1 Salisbury ASTR stormwater to drinking water project.](image)

(Source: photograph courtesy of United Water cited in Dillon et al, 2010)

The potential for stormwater harvesting to be reused, as in Salisbury, Adelaide is significant because where urban aquifers have been mapped in Perth, Adelaide and Melbourne, there are known prospects for managing the storage of 300-500 GL/yr urban supplies. Recharged water may be sourced from rainwater, stormwater, reclaimed water, or other aquifers. The amount of potential water for aquifer recharge and reuse is significant as less than three per cent of urban stormwater runoff is currently harvested and treated for re-use in Australian cities. Managed aquifer recharge and recovery (MAR) is being increasingly used around the world to address this opportunity. MAR is actively and successfully used in the USA, Europe, South Africa, India, China and the Middle East. UNESCO and the International Association of Hydrogeologists (IAH) are co-ordinating efforts in this

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area through a range of initiatives. We now look at MAR in more depth to consider the technical options, cost effectiveness and potential energy savings from using MAR more in Australia to help us adapt to climate change by creating more additional sources of urban and rural water.

**Managed Aquifer Recharge, Storage and Recovery – A Low Emissions Approach to Water Storage and Reuse**

CSIRO defines “Managed aquifer recharge (MAR)” is the purposeful recharge of water to aquifers for subsequent recovery or environmental benefit. Aquifers, permeable geological strata that contain water, are replenished naturally through rain soaking through soil and rock to the aquifer below or by infiltration from streams.” Aquifer recharge can be intentionally enhanced through mechanisms such as injection wells, infiltration basins and galleries for rainwater, stormwater, and reclaimed water. Figure 7.1.2 provides examples of how managed aquifer recharge can be done for both confined and unconfined aquifers.

MAR can store water from various sources enabling this water to be reused when needed. With appropriate pre-treatment before recharge and sometimes post-treatment on recovery of the water, it may be used for drinking water supplies, industrial water, irrigation, toilet flushing, and on parks and gardens and otherwise sustaining ecosystems. It is important to note that the actual process of aquifer storage itself also contributes to the water treatment process. As CSIRO explains

> As the treated water infiltrates the soil and aquifer natural biological, chemical and physical processes occur to remove pathogens, chemicals and nutrients from the water. This ‘filtering’ process continues while the water infiltrates and resides in the aquifer.

> The following water quality improvements occur during the process: attenuation of nutrients such as inorganic phosphates and nitrogen as well as most organic compounds, degradation of trace chemicals such as disinfection by-products and pathogen die-off.

> The majority of this treatment occurs through the activity of naturally occurring micro-organisms in the aquifer. As long as these micro-organisms remain active the process remains sustainable. The ability to remove contaminants from the water significantly reduces the health and environmental risks that may be associated with secondary treated wastewater, leaving the reclaimed water in similar quality to that of the surrounding groundwater.

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75 UNESCO and IAH have initiated, for instance, the International Groundwater Resources Assessment Centre (IGRAC) which has drawn together a database of Managed Aquifer Recharge at a global scale via the IGRAC portal, ([http://www.igrac.nl/](http://www.igrac.nl/))


77 Piezometric level is the level of water in a well if a well were constructed. For an unconfined aquifer this is the watertable. During recharge levels rise and near recovery wells levels fall.

There are a large number and growing variety of methods used for MAR internationally (see Figure 7.1.3). The different types are covered in more detail in the national guidelines for MAR. A sample of some of the main methods currently in use in Australia include:

**Aquifer storage and recovery (ASR)**

ASR consists of injecting water down a well into an aquifer for storage, and then recovering that water later on from the same well. This method can be applied to aquifers that are confined or unconfined. The Salisbury, Adelaide example discussed above uses this method. This method is also used in the schemes in Grange, Tea Tree Gully, and other suburbs of Adelaide.

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**Aquifer storage, transport and recovery (ASTR)**

ASTR involves injecting water into a well for storage in an aquifer, and then recovery from the aquifer from a different well. The Salisbury, South Australian case study also uses this approach.  

**Percolation tanks and recharge weirs**

Percolation tanks and recharge weirs are dams built in seasonal streams (i.e., stream channels that contain water only after rainfall or snowmelt) to detain water that infiltrates through the bed, increasing storage in unconfined aquifers. The water is extracted down-valley. Examples are found in the Callide Valley, Queensland.

**Infiltration galleries**

Infiltration galleries make use of buried water pipes in permeable soil/rock. Water is pumped through these pipes so that it seeps out through the holes in the pipes into the permeable rock where it then infiltrates down into an unconfined aquifer. Floreat Park in Western Australia uses this method.

**Rainwater harvesting**

In ‘rainwater’ harvesting, water from roof run off is diverted into a well or sump filled with sand or gravel. The water is further purified by percolating down into the watertable. It is then, later on, recovered from the aquifer by pumping the water back up from a well. Examples are common in Perth, Western Australia.

**Dune filtration**

In dune filtration, water is infiltrated from ponds constructed in dunes, and extracted from wells or ponds at lower elevation. The filtration improves water quality and helps to balance supply and demand. Examples are found in Amsterdam, The Netherlands.

**Infiltration ponds**

Infiltration ponds and channels are constructed off-stream, with surface water then diverted into them whereupon the water infiltrates down to the underlying unconfined aquifer. The Burdekin Delta, Queensland has been using this method for over thirty years.

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Figure 7.1.3 Schematic of types of managed aquifer recharge.

(Source, EPHC, NHMRC and NRMMC, 2009)

Already many of these methods of MAR are being used in Australia. (See Figure 7.1.4)

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Selection of Recharge Method

The nature of the site, permeability of the rock structures and type of aquifers present determine which managed aquifer recharge method is chosen. For instance, for confined aquifers, well-injection methods, such as aquifer storage and recovery (ASR) and aquifer storage, transport and recovery (ASTR) are the recommended options. If infiltration is restricted then it is necessary to penetrate the low permeable upper layer using methods such as infiltration galleries or wells. According to the national guidelines, the chosen configuration and size will also depend on:

- the thickness of the low-permeability layer
- the required infiltration rate
- land availability and cost
- compatibility with other land uses
- ease of traffic access
- the need to avoid insect pests, or even to prevent the attraction of birds (eg at airports).

The high land values in urban areas also are a significant factor affecting the choice of method. In urban areas methods such as aquifer storage and recovery are thus highly competitive from a cost benefit point of view with other forms of urban water treatment and reuse. This is less of an issue in rural areas where the lower land prices enable greater use of infiltration ponds and soil aquifer treatment.

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87 Ibid.
Source water quality may also play a role in method selection. This is addressed in detail in Chapter 6 of the national guidelines for managed aquifer recharge and recovery.88

**Benefits of Managed Aquifer Recharge for Recycling**

Managed aquifer recharge makes it possible to harvest and reuse urban and coastal town stormwater in significant quantities that currently flows out to sea. The scale of water currently being wasted means that managed aquifer recharge systems could play a key role this century in ensuring water security for many capital cities and coast towns where over 90 per cent of Australians live. There are also significant water quality benefits from using managed aquifer recharge systems. The underground storage increases the treatment time resulting in improved water quality. If sampling exposes any problems with water quality, managed aquifer storage provides much more time to ensure such issues can be addressed before recovering the water for different uses. There are numerous indirect benefits from using managed aquifer recharge systems such as

- stormwater capture, harvest and MAR systems mitigate flooding of downstream urban and coastal town areas thus helping to address risks from climate change. This could result in insurance premiums being reduced.
- positive impact on coastal water quality by reducing the amount of nutrients, pollutants and pathogens flowing into the ocean through stormwater.
- improving the price of real estate by having water features such as wetlands and irrigated parks.
- providing protection against aquifer depletion and salinisation (See Lecture 5.4)
- financial savings from deferring the need to build new dams, desalination plants or other water supply infrastructure.

To conclude, managed aquifer storage combined with minimal external energy water treatment systems like constructed wetlands now provide the water supply sector and water planners with innovative and effective options to adapt to climate change.

**Key References**

**Constructed Wetlands**

*Guidelines*


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**Best Practice Case Studies**


**Managed Aquifer Storage**


The International Association of Hydrogeologists Commission on Managed Aquifer Recharge at [www.iah.org/recharge](http://www.iah.org/recharge)


