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3 : Wastewater Systems and Treatment

Figure 3.0 Horizontal flow subsurface constructed wetland (foreground) and greenhouse housing a staged planning wetland at the Old Trail School, Bath, Ohio, USA. Image courtesy of Living Machine®.
3.1 Introduction

Wastewater wetlands are merely a piece in the puzzle of a city's complex water infrastructure. When dealing with complex IWRM systems it is important to take an "integrated or systematic approach to water system design [which] gears all water-related activities to one another, thereby recognizing the interconnected nature of water and wastewater." (Spataro & Sisolak, p. 30 – 31, 2011). The natural water cycle is a closed loop system and the research contained in this thesis seeks to close the loop in urban water system. This chapter will introduce the many factors that need to be considered when developing wastewater options in an IWRM system.

Urban wastewater conveyance, treatment and disposal/reintroduction technologies are complex systems that link several components to one ultimate goal, the safe management of a city's wastewater. Conventional wastewater systems convey the entire city's wastewater through a large network of pipes and pumps to a centralised treatment facility that combines mechanical and biological processes to treat wastewater to a standard suitable for dispersal/reintegration. Ecological treatment technologies such as wetlands have in recent years been recognised as being "highly energy efficient as they rely strictly on natural biodegradation and do not require extensive electrical input. Many conventional systems use significantly greater electrical inputs and produce greater quantities of sludge that must be removed off-site," (Margolis & Robinson 2007, pg. 112). The unsustainability of conventional wastewater systems is proving to be a burden on the economies and ecologies of many urban environments internationally. This has spawned a surge in the research and development of more sustainable and natural systems.

“Demand for (natural) systems will grow as scientists and engineers find that land-based root-zone systems clean wastewater better than conventional wastewater systems even in colder regions. At the same time, municipalities increasingly favour decentralised solutions that treat effluents at their source.” (Steinfeld & Del Porto, 2006 p. 44). Landscape architects are in an authoritative position to design these land-based systems as landscape architects have an understanding of the many layers of landscape systems and the spatial and aesthetic characteristics of place and experience (Steinfeld & Del Porto 2006). In order for landscape architects to stake a claim in the evolving field of land-based wastewater systems they must have an understanding of the myriad components and processes that make these complex systems safe, efficient, effective and acceptable.

All the components of a city's water infrastructure and how they link to the greater network and system must be considered in order to establish the role of any individual component such as wastewater wetlands. The ebb and flow of a city's water cycle starts with the fresh water resource which is delivered to the public, consumed and/or used as a medium to transport waste. Water then becomes classified as wastewater (see 3.3 for definitions of wastewater). This wastewater joins a stream of conveyance to a treatment facility which removes contaminants to a standard set out by environmental policy according to the ultimate dispersal/reintegration or reuse of the effluent. This chapter will give a brief synopsis of these components and assess them against sustainability criteria and their ability to provide increased resilience in Christchurch.
3.2 Freshwater resource

Cities get their fresh water from a single source or combined sources of ground water, surface water or desalinated water.

- **Surface water** resources include rainwater, stormwater, springs, rivers, streams, lakes, and natural wetlands. Many cities collect and store surface waters in reservoirs. Rainwater can also be collected from roofs and used for potable or non-potable uses.

- **Groundwater** resources come from water stored in the pore spaces of soil and rock under the surface of the earth, called aquifers. Groundwater was at one time surface water that has been pulled by gravity, through the earth's soil, sand, gravel or rock until it has reached a point where the ground is saturated. The top of this saturation point is known as the water table. Aquifers can be classified as confined or unconfined. Confined aquifers generally have an impermeable layer of rock or clay between the aquifer and the surface while unconfined aquifers do not have an impermeable layer and exist close to the surface. Unconfined aquifers are more susceptible to cross-contamination from polluted surface waters.

Christchurch sits atop confined and unconfined aquifers (Fig 6.4). The city sources its freshwater from confined aquifers directly below it. Fresh water is pumped from 167 wells and stored in 34 reservoirs located throughout the city. These reservoirs are either elevated or mechanically pressurised and deliver 50 million m$^3$ of fresh water a year to 117,000 households (hh), (CCC 2012). Unlike many cities in the world, Christchurch’s water is of exceptional quality and is delivered to its citizen untreated (ONE News 2011). However the earthquakes of 2010 - 2011, damaged almost 50% of the cities 15,000 km of freshwater delivery pipes and the Council decided to add chlorine to the water supply to protect the citizens from potential health risks from contamination by a leaky sewage system. In December 2011 the water supply network was repaired and the civic water supply was again delivered without treatment or additives (ONE News 2011).

- **Desalinated water** resources come from the artificial (mechanical) process of distillation or reverse osmosis where saline water is converted to freshwater. In cities such as Melbourne, Australia, desalinated water is pumped to manmade reservoirs and stored as surface water. This infrastructure is expensive and energy intensive.

3.3 Water use and price

According to the Australian/New Zealand Standard (AS/NZS 2000) the average person in Australia and New Zealand consumes 180 (.18 m$^3$) litres a day (l/day) of freshwater. Mike Bourke (2012) of Christchurch City Council suggests citizens of Christchurch use between 200 and 250 l/day. This Figure is close to the average daily use of freshwater in America which is 263 l/day (Kloss 2008). This thesis will be using the data provided by the AS/NZS (2000). These Figures only takes into account the water serviced to citizens and does not consider the water embodied in things consumed such as food or materials.
According to Ferguson, Dakers, Gunn (2003), 60% of the water provided to New Zealand citizens is used internally for drinking, flushing, showering, etc. (Fig 3.2), while the remaining 40% is used externally for irrigation, washing etc. A significant amount (almost 70%) of this use requires a lesser quality of water for things like toilet flushing, irrigation and laundry. This presents many opportunities to consider water systems where water “cascades” through uses that require a lesser quality of water than the previous use.

There are several other strategies for reducing the amount of freshwater consumed such as retrofitting buildings with “low flow” appliances, including shower heads, toilets, sinks, dishwashers and laundry machines. Externally, rainwater can be collected off the roof of buildings and used for non-potable uses or treated and used internally for potable uses. All these technologies contribute to an increased efficiency of a site’s water use, thus enhancing its resilience to external events.

3.4 Classification and composition of wastewater

As discussed earlier, wastewater can be referred to as greywater, blackwater and stormwater. Each classification can be collectively referred to as wastewater as they contain varying levels of contaminants, measured by total suspended solids (TSS), total phosphorus (TP) and total nitrogen (TN) in mg/l. Biological oxygen demand (BOD), is also used as an indicator of water quality (Table 3.1). Each type of wastewater are defined as follows:

Greywater is wastewater discharged from sinks, showers, laundry, drinking fountains, etc. but does not include toilets and urinals. Greywater can be broken up into two other sub classifications:

- Light greywater is water from bathroom sinks, showers, bathtub, laundry and drinking fountains.
- Dark greywater is water from kitchen sinks and dishwashers that contains a higher level of contaminants.
### Wastewater Wetlands

#### Chapter 3: Wastewater Systems and Technologies

**Blackwater** is water containing solid and liquid wastes from the toilets and urinals.

**Stormwater** is precipitation that falls on the roof or ground surface of a property.

Traditionally plumbing of residential buildings combines grey and blackwater streams in one conveyance system connected to the municipality’s wastewater network. However, in recent years “eco buildings” and retrofitting of an existing building’s plumbing separates grey and blackwater streams at the source. Greywater contains significantly less contaminants than blackwater and is easier to treat and reuse in a cascading water system. The regional authority of Christchurch, Environment Canterbury (ECan) has set guidelines for application of domestic greywater under the Canterbury Natural Resources Regional Plan (ECan 2011): Rule WQL 10. Using the statistic provided by AS/NZS (2000), if all of the greywater effluent of a residential dwelling was reused on site it could reduce the amount of wastewater being diverted into the conveyance network by 63%.

<table>
<thead>
<tr>
<th>Wastewater Composition</th>
<th>TSS</th>
<th>BOD (5)</th>
<th>TP</th>
<th>TN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blackwater</td>
<td>391</td>
<td>400</td>
<td>121</td>
<td>169</td>
</tr>
<tr>
<td>Greywater</td>
<td>115</td>
<td>160</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>Stormwater</td>
<td>100</td>
<td>9</td>
<td>33</td>
<td>1.22</td>
</tr>
</tbody>
</table>

Table 3.1 Composition of wastewater measured in mg/l.

**Blackwater** is water containing solid and liquid wastes from the toilets and urinals.

**Stormwater** is precipitation that falls on the roof or ground surface of a property.

One of the results of urbanisation is an increase in the area of impermeable surfaces such as streets, footpaths and roofs. Pollutants from cars, cleaning products and other sources can settle on these surfaces and when it rains the pollutants become diffused and are carried away with stormwater. The current Christchurch stormwater infrastructure follows a 19th century model which uses gutters and sewers to convey runoff rapidly to the nearest river network (Alberti et al 2007). This system does not treat diffused pollution before it reaches the receiving environment and the pollutants can contaminate surface waters and severely harm river ecologies (D’Arcy and Frost 2001). In New Zealand, sustainable design principles that support ecological stormwater drainage and treatment technologies is called Low Impact Urban Design Development (LIUDD).

The suite of LIUDD stormwater drainage and treatment techniques include:

- **Greenroofs** reduce the runoff velocities of stormwater and provide temporary storage of rainwater, releasing some of that water through evapotranspiration (Carter and Jackson 2007). Green roofs also contribute to reduction of the urban heat island effect.

- **Porous Pavement** can be used in place of traditional impermeable surfaces including streets. They are typically made of a matrix of materials with voids that allow stormwater to infiltrate through to the underlying soils. Porous paving does not allow all stormwater...
to infiltrate, especially in extreme rain events, but it has been shown to reduce the amounts of diffused pollutants being carried to the receiving environment (Brattebo & Booth, 2003).

**Constructed Wetlands**, similar to those used in the treatment of grey and black water can also receive and treat stormwater. Constructed wetlands for stormwater applications often have permanent surface water and provide flood attenuation and water treatment through ecological processes. They can provide multiple uses and benefits for communities and ecosystems (Auckland Regional Council, 2003) which will be explored in the context of wastewater wetlands later in this chapter and in Chapter 4.

**Wet-ponds** are permanent water bodies that enhance storage capacity and reduce the peak flow discharge during rain events. Wet ponds trap suspended solids and other decayed plant material, animal debris, etc, (Yousef, Hvitved-Jacobsen, Sloat, & Lindeman, 1994).

**Dry Detention Basins** are artificially constructed depressions that store and treat stormwater. They provide a level of treatment by allowing the sedimentation of coarse particles and retain stormwater to reduce the peak flows into the receiving environment. In dry periods grassed dry basins can facilitate recreation opportunities such as playing fields (CCC 2003).

**Rain Gardens** are a type of biofiltration system that captures and vertically filters stormwater through soil media and dense vegetation. Rain gardens are very efficient in ecologically treating stormwater and they are highly flexible in terms of size, location and configuration (Hatt et al 2009).

**Infiltration basins** (bio-retention basins) are similar to dry detention basins, however infiltration basins do not release stormwater. Instead infiltration basins allow stormwater to infiltrate through to groundwater. Care needs to be taken with infiltration basins as they can eventually lead to the contamination of underlying soils and groundwater (Dechesne, Barraud, & Bardin, 2004).

**Swales** are used as conveyance alternatives to traditional concrete kerb and channel systems. There are two types of swales; grassed swales and wetland swales, the latter of which require more land area but provides a higher level of treatment. Swales provide pretreatment through filtration and sedimentation while conveying stormwater. They are best used in conjunction with other stormwater treatment and storage systems (Mazer, Booth, & Ewing, 2001).

Stormwater drainage and treatment technologies are leading the way towards integration of urban landscape performance and essential city infrastructure. The multiple benefits of ecologies and place making generated by existing LIUDD projects, especially projects that utilise constructed wetlands, have opened the eyes of policy makers and the public to the potential to integrate natural systems into urban landscape functions. These existing projects can provide insight and inspiration into the design and integration of wastewater wetlands that treat black and grey water.
3.6 Conveyance

Varying combinations of wastewater (grey, black and stormwater) is called sewage and the reticulation of it demands a large capital investment for municipalities as it require the design, construction and maintenance of a complex web of roads, pipes, pumps etc. (Spataro & Sisolak 2011). Sewage conveyance is one of the greatest drivers of urban form and the CCC and Ecan steer the way developments occur according to the capacity of the existing conveyance systems (Meeks 2011). The function of conveyance systems is to transport wastewater from its source to treatment. Some cities have combined sewage systems that mix storm, grey and black water and convey them as combined wastewater to a treatment facility. One of the benefits of the existing conveyance system in Christchurch is that wastewater and stormwater are conveyed separately resulting in reduced volumes being conveyed to the treatment facility.

The earthquakes of 2010 and 2011 caused significant damage to the underground conveyance network and at time of print approximately $25M has been spent repairing the infrastructure. Direct discharge of untreated sewage to rivers during normal flow has been eliminated, however, many wastewater pipes are still damaged and flows to the CWTP have increased by 48%. This increase is attributed to the high water table of Christchurch resulting in groundwater infiltration to fractured pipes. Although stormwater and wastewater conveyances are intended to be kept separate, the countless leaks into the wastewater pipes allow the volumes and pressures of storm events to increase the infiltration into sewage pipes. The conveyance network was not designed with enough capacity to carry the increased inflows and during storm periods untreated sewage overflows directly to surface waters.

It has been estimated that it will take 12-years for a complete repair of the network (Beca 2012) and would cost $1,225 million (CCC 2012). The Stronger Christchurch Infrastructure Rebuild Team (SCIRT 2012) is currently replacing the most severely damaged main pipes to return the conveyance network to pre-earthquake capacity but none of the private laterals will be repaired. CCC is working with several engineering firms to pursue alternatives to the city's wastewater network that's more environmentally and economically sustainable and resilient to earthquakes (Beca 2012).

Sewage conveyance systems are generally built to last up to 100 years and many throughout the world are at the end of their useful life-span (Glennon 2009). There are essentially three types of conveyance services; centralised, clustered (distributed) and on site. Several plumbing technologies have evolved to facilitate a city's

Figure 3.5 Street sewer repairs in Christchurch.

Figure 3.6 A diagram representing sewage conveyance configurations.
desired conveyance configuration. The following is a synopsis of the most available conveyance systems with reference to how they fit in the context of Christchurch and possible wastewater scenarios:

A **conventional** sewage conveyance system is the network currently used in Christchurch. This system starts at private laterals which are 100 mm to 150 mm diameter clay or concrete sewer pipes. The council has limited control over these pipes as they are generally on private property (Bourke, 2012). Private laterals connect to a street lateral which then links to the street sewer. The street sewer pipes can be buried up to two meters under the surface and can reach a diameter of up to 1.8 m. Christchurch has 1,858 km of street sewer pipes of which 300 km need complete replacement due to earthquake damage.

Conveyance systems are designed to use gravity to aid in the reticulation of sewage to pumping stations, which push wastewater through the system to its treatment destination. Manholes provide access to street sewers in all changes of direction and connections. The maximum distance between manholes is 90-100m to accommodate for manual cleaning rods. In normal conditions, manholes contribute significantly to sewage costs (15%-20%) and are a point of weakness where infiltrations can occur.

**Modified conventional** sewage systems offer smooth-bore, long length plastic pipes as a replacement for clay or concrete pipes. SCIRT is using modified conventional sewage materials to repair Christchurch’s existing conveyance system. Manholes are replaced with smaller “eyes” for access and gradients can be varied by using grinder pumps.

In a **pressure** sewage system, wastewater is injected from virtually every private lateral by a grinder pump into a pressurised reticulation network. This network consists of small-bore plastic pipes that can be buried at shallow depths. The pressurised system allows wastewater to flow over topographic obstacles. This system is high maintenance due to the number of grinder pumps required but the pressurised system eliminates infiltration.

![Figure 3.7: The different components and layouts of conveyance systems.](image-url)
Vacuum sewage systems use a vacuum unit to convey sewage through small-bore plastic pipes. Vacuum conveyance systems are ideally used in areas with flat topography and with high water tables (Ferguson, Dakers, Gunn 2003).

Another style of sewage conveyance system is the Septic Tank Effluent Gravity (STEG) and Septic Tank Effluent Pumping Systems (STEPS). With these systems each site has its own septic or vermicomposting system with an outlet filter connecting to street laterals. This system can be wholly gravity fed (STEG) or wholly pumped (STEPS). It is best suited to retrofitting existing infrastructure or implementing new septic systems with low diameter sewage lines, modified central or cluster facility and centralised management system (Ferguson, Dakers, Gunn 2003).

The existing conventional sewage system in Christchurch has proven to not be effective as the earthquakes have caused significant volumes of groundwater infiltration, resulting in overflows to surface waters and increased flows to the CWTP. The resulting pollution of surface waters has caused environmental problems and public health hazards and increased flows of groundwater to the CWTP has resulted in volumes of water that otherwise would not require treatment. The CCC has recognised the need to eliminate infiltration and is looking to the alternatives of vacuum and pressure systems utilising shallower pipelines and smaller catchments (Beca 2012). This type of conveyance system is compatible with wastewater treatment wetlands.

<table>
<thead>
<tr>
<th>Conveyance Systems</th>
<th>On-site</th>
<th>Clustered</th>
<th>Centralised</th>
<th>Sustainability Criteria</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Ideal Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modified Conventional</td>
<td>●</td>
<td></td>
<td></td>
<td>More resilient and reliable than conventional.</td>
<td>Reduces infiltration and maintenance costs of conventional systems.</td>
<td>Large diameter pipes buried Deep. High replacement cost.</td>
<td>Cities with existing conventional systems in need of minor repairs.</td>
</tr>
<tr>
<td>Pressure</td>
<td>●●</td>
<td></td>
<td></td>
<td>Resilient to ground movement. Reliable, environmental (less infiltration or leaks) and economic.</td>
<td>Infiltration avoided. Can travel over topography. Shallow trenches. Low construction cost.</td>
<td>Grinder pumps needed at all street laterals. Odour potential. High maintenance and initial investment.</td>
<td>Decentralised reticulations systems with high water table.</td>
</tr>
<tr>
<td>Vacuum</td>
<td>●●</td>
<td></td>
<td></td>
<td>Resilient, reliable, economic, and environmental (less infiltration or leaks).</td>
<td>Eliminates infiltration. Shallow trenches and low construction costs. No odour.</td>
<td>Vacuum sewers have a limited volume capacity. High initial investment.</td>
<td>Small, decentralised reticulation systems with a high water table.</td>
</tr>
<tr>
<td>STEPS and STEG</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Environmental, economic, reliable, resilient and low vulnerability measures.</td>
<td>Simple and well understood. Shallow trenches and low constructions costs.</td>
<td>Initial installation of septic tanks on sites. Potential for odour.</td>
<td>Retrofitting systems or new communities.</td>
</tr>
</tbody>
</table>

Table 3.2 Comparison of conveyance systems.
3.7 Treatment stages

Wastewater treatment facilities are generally at the end of a conveyance network whether that system is on site, clustered or centralised and provide a level of treatment suitable for effluent reintroduction to the natural water cycle and ecosystem. Treating wastewater involves the elimination of pathogens, reducing the biological oxygen demand (BOD) and the removal of nitrogen, phosphorus and stabilising toxins. There are several stages of wastewater treatment including primary, secondary, tertiary and advanced tertiary.

**Primary** treatment is where most solids and fats are separated. Conventional septic tanks provide primary treatment for many onsite systems in New Zealand but are not common in urban environments. Vermicomposting systems such as the Biolytix eco-septic system are another option for onsite primary treatment that is a medium position between composting toilets and conventional flush-away systems (Dakers 2011). With most centralised systems, including the one in Christchurch, primary treatment occurs mechanically at a central facility through a primary clarifier or primary sedimentation tank. Primary treatment stages have the capability of producing biogas through microbial digestion of organic solids. Wastewater wetlands are generally not suitable for primary treatment as coarse particles and solids can clog the system. Primary treated wastewater is rarely suitable for ecosystem introduction or reuse.

**Secondary** treatment usually deals with the dissolved and suspended organic waste after primary treatment as well as providing an initial stage of nutrient removal. There are many methods of secondary treatment. In certain conditions after secondary treatment water quality can often be to a standard for ecosystem reintroduction. Wastewater wetlands are ideally suited to provide secondary treatment.

**Tertiary** treatment provides a final polishing component. Tertiary treatment removes the stubborn contaminants, usually nitrogen and phosphorous that remains after primary and secondary treatments. Different configurations of wastewater wetlands can be used for tertiary treatment. Tertiary treated wastewater is suitable for ecosystem reintroduction and in most cases food production, but it is not potable.

**Advanced tertiary** treatment is often required by municipalities to safeguard against the presence of any potentially remaining pathogens. Advanced tertiary treatments such as ultraviolet light (UV) in most cases returns wastewater to a potable standard.

3.8 Treatment technologies

The CWTP at Bromley suffered tremendous damage after the earthquakes of 2011 and at time of writing could only provide primary and secondary treatment to process 30% of its intake (Gorman 2011). This means sewage was not receiving proper primary and secondary treatment before being discharged to 230 ha of oxidation ponds which provide tertiary treatment (Fig 3.8). There is still a chance that the oxygen levels in the ponds could drop below functioning levels and the oxidation ponds could turn into an odorous cesspit (Swiggs 2011).

**Figure 3.8** The Christchurch oxidation ponds and the Avon - Heathcote Estuary.
The existing CWTP begins treating wastewater at a preliminary stage where sewage passes through four filters removing debris. Then wastewater is taken to a grit removal tank that removes grit, fat and grease. After pre-treatment the wastewater enters a primary sedimentation tank where suspended solids settle to the bottom of the tank and are scraped away. These solids are then transported to a digester where they are biologically broken down, releasing methane. The methane gas released is captured and used to help power the plant. Solids are pressed and sold as a fertilizer or removed to landfill. After the sedimentation tanks wastewater passes through one of two trickle filters, a bubbling tank and final clarifiers for secondary treatment. The effluent is then sent through a series of seven oxidation ponds covering 230 ha where oxygen is pumped from the floor of the ponds and the sun’s ultraviolet rays combined with the ecology of zooplankton reduce the pathogens in the wastewater by 99.99%. The treated wastewater was once discharged directly to the Avon/Heathcote estuary, but in 2010 the $87.2 m Ocean Outfall project was completed, sending treated wastewater 3 km out to sea (CCC3 2012).

The CWTP does offer some sustainability initiatives such as the generation and use of methane to help power the plant, the use of organic solids in land remediation and the bird habitat of the oxidation ponds. The level of sustainability is relatively low however as the methane generation is not enough to meet the enormous energy requirements of the plant. Also the treated water is essentially wasted out to sea. The treatments systems of the CWTP do not meet Māori cultural values.

There are many wastewater treatment alternatives meeting variable levels of sustainability. Each treatment technology falls under one of six categories: non-water discharging containment, attached growth, suspended growth, hybrid, natural or chemical.

1. **Non-water discharging containment** systems collect and process human wastes without the use of water. These systems include composting toilets, incinerating toilets and evaporation systems. Composting toilets and similar technologies are subject to ECan’s Rule WQL13 and the Building Act (1991). These systems offer excellent alternatives to using water as a means of waste conveyance. However no composting toilets have been approved to date in Christchurch City. Although these systems meet Māori cultural values, have proven to be safe and effective and are approved for use in many urban environments internationally, they have not been approved in urban areas anywhere in New Zealand.

This thesis recognises the potential non-water discharging containment systems have to reduce the need to process blackwater at all, and that the use of non-water discharging containments could reduce the inputs of wastewater by 30%, reducing the wetland area required to process wastewater. However since NZ policy thus far prohibits their use in urban environments, their potential will not be widely considered in the context of this research.

2. **Attached Growth** or **Fixed Film** systems treat water through active microorganisms attached to granule, organic or synthetic media.

A *biofilter* (trickle filter) is an example of a fixed film treatment system. This system is used at the CWTP and is a popular conventional system for secondary treatment. It is good for a constant population and uniform loading. (Ferguson, Dakers, Gunn 2003) Biofilters require a secondary settlement tank to capture more biological substances. The biofilter utilises uniform gravel size, crushed rock, or a plastic medium to grow aerobic bacterial slimes that cleanse settled wastewater. This oxygen rich biological sludge is periodically removed from the system and in the case of the CWTP is processed by digesters. Biofilters often use rotating biological contactors (RBC) which are 2-3 m diameter thin plastic discs that turn through a trough of settling water. Simply put, suspended solids become slime as the water flows through a medium to which this slime can adhere.

*Sand filter* systems are fixed film treatment systems that can be passive or mechanical. They require prior primary treatment. Sand filters are a packed bed biological reactor that utilises a uniform
### Table 3.3 Comparison of wastewater treatment technologies.

<table>
<thead>
<tr>
<th>Treatment Systems</th>
<th>Primary Sustainability Criteria</th>
<th>Secondary Sustainability Criteria</th>
<th>Tertiary Sustainability Criteria</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Ideal Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constructed Wetlands</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Well known and understood in NZ. Low energy requirements. Provides habitat.</td>
<td>Large footprints (6 m²/person)</td>
<td>Centralised, clustered or on site configurations with sufficient land area.</td>
</tr>
<tr>
<td>Staged Planning Wetlands</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Reduced footprint (2 m²/person. Low energy requirements. Provides habitat.</td>
<td>Complex systems not widely understood in NZ.</td>
<td>Centralised, clustered or on site configurations with limited land areas.</td>
</tr>
<tr>
<td>Controlled Environment Aquatics</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Compact and interesting interior ecologies. Low energy requirements.</td>
<td>Ecologically complex systems not widely understood in NZ. Proprietary technology.</td>
<td>Clustered and on site configurations.</td>
</tr>
<tr>
<td>Planted Evapotranspiration</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Can completely eliminate wastewater. Low energy requirements. Provides habitat</td>
<td>Effluent not available for reuse. Large footprint. Not widely understood in NZ.</td>
<td>Clustered and on site configurations where climates are suitable to year-round evapotranspiration.</td>
</tr>
<tr>
<td>Vermicomposting</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Low maintenance. Zero energy requirements and high quality effluent.</td>
<td>Not widely accepted or understood</td>
<td>On site, STEP or STEG configuration.</td>
</tr>
<tr>
<td>Anaerobic Digesters</td>
<td>●</td>
<td></td>
<td>●</td>
<td>Efficient producers of biogas. Understood and accepted</td>
<td>Requires a large structure.</td>
<td>Centralised and clustered configurations.</td>
</tr>
<tr>
<td>Biofilter</td>
<td>●</td>
<td></td>
<td>●</td>
<td>Reliable</td>
<td>High energy requirements and maintenance.</td>
<td>Centralised and clustered configurations.</td>
</tr>
<tr>
<td>Sand Filter</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Well known and widely available. Copes well with input variants</td>
<td>High maintenance requirements.</td>
<td>Centralised, clustered and on site configurations.</td>
</tr>
</tbody>
</table>

Table 3.3 Comparison of wastewater treatment technologies.
Table 3.3: Continued from previous page.

<table>
<thead>
<tr>
<th>Treatment Systems</th>
<th>Primary</th>
<th>Secondary</th>
<th>Tertiary</th>
<th>Sustainability Criteria</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Ideal Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Septic and Imhof Tank</td>
<td>●</td>
<td></td>
<td></td>
<td>Resilient with few moving parts or need for exterior inputs. Reliable.</td>
<td>Well known and widely available.</td>
<td>Sludge needs to be removed manually. Can produce odour.</td>
<td>On-site or STEP/STEG configuration</td>
</tr>
<tr>
<td>Overland Flow</td>
<td>●</td>
<td>●</td>
<td></td>
<td>Resilient with few moving parts or need for exterior inputs. Reliable. Provides environmental and ecological benefits.</td>
<td>Simple, low maintenance, creates habitat and can be used as open space</td>
<td>Needs large area and can restrict human access due to health concerns.</td>
<td>Places with large areas of suitable land.</td>
</tr>
<tr>
<td>Activated Sludge</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>Reliable. Provides environmental benefits.</td>
<td>Well known and widely available. Lagoons and oxidation ponds provide habitat.</td>
<td>High energy and maintenance requirements. Needs deep shafts or large area.</td>
<td>Centralised or clustered configuration with high volume inputs.</td>
</tr>
<tr>
<td>UV</td>
<td>●</td>
<td></td>
<td></td>
<td>Reliable. Provides environmental, social and ecological benefits.</td>
<td>Kills all remaining pathogens. Has a small footprint.</td>
<td>Expensive.</td>
<td>Centralised or clustered on site configuration where high quality effluent is required.</td>
</tr>
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</table>

medium (crushed glass, sand) to provide surfaces for bacteria to grow and voids for air circulation. Bacteria stored in the voids between the media physically strain wastewater. Mechanical recirculating sand filters use a geo-textile fabric as a medium. This treatment is compact and effective and the systems cope well with input variants (Ferguson, Dakers, Gunn 2003).

**Overland flow** systems provide secondary and tertiary treatment by discharging effluent over a sloped, grassed sheet. Nutrients are absorbed and settle into the soil while excess effluent is recaptured.

3. **Suspended-growth** systems treat water through active microorganisms suspended in aerated environments.

**Activated sludge** systems are suspended-growth treatment systems that take many forms including package plants, oxidation ditches, deep shafts and lagoons. Essentially, wastewater is mechanically aerated to activate aerobic slime. Wastewater passes through a series of sequential batch reactors similar to the oxidation ponds at CWTP. Extended aeration can provide primary, secondary and tertiary treatment and eventually fully treated wastewater.

**Anaerobic digesters** use microorganisms to break down biodegradable material in the absence of oxygen. These systems generally provide primary treatment to wastewater. The main advantages of anaerobic digesters are that they are less capital intensive to install and can produce biogas as a renewable energy. Anaerobic digesters can produce up to 40kw of usable biogas energy if fed the wastewaters of 10,000 people (Bourke 2012). That is the equal to the energy outputs of one normal wind turbine.

4. **Hybrid** systems use both suspended growth and attached growth to treat water.

**Septic and Imhof tanks** provide onsite primary treatment. These systems essentially separate solids from liquids in a contained
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environment, trapping and anaerobically digesting sludge and scum. These systems are common in locations without connections to sewage mains and can be used in a STEG or STEPS configuration. Traditional septic tanks and Imhof tanks only partially digest sludge and the remaining sludge is periodically removed from the tank.

5. **Natural** systems treat water by mimicking the biological, chemical and physical processes occurring in natural wetlands.

A **vermicomposting** tank is similar to a septic tank but instead of using anaerobic bacteria, these systems use a mixed ecology, mainly worms, to process sludge. The worms process the sludge and convert it to humus which in turn helps to process the sludge. Vermicomposting systems are low maintenance and do not require periodic removal of sludge. They are best suited for sites without connection to sewage mains and can be used in a STEG or STEPS configuration.

**Planted evapotranspiration** systems are a type of fixed-film system that "uses up" wastewater by utilizing phreatophytes (thirsty plants) planted in gravel medium. Effluent is passed through the medium and plants absorb and evapotranspirate the water. What is not evapotranspired is returned to tanks or distributed to another system. This system is best suited to areas with high year-round evapotranspiration rates (Del Porto 2008).

**Constructed wetlands** are fixed-film treatment systems used for secondary and tertiary treatment. There are essentially two types of constructed wetlands, surface flow (vertical) where water flows over the top before percolating vertically through the medium, and subsurface (horizontal) flow where water is filtered horizontally, sub-surface through a wetland bed. These wetlands use a gravel medium to permit the growth of treatment bacteria. The rhizomes of emergent wetland plants are used to provide additional habitat for bacteria, aeration, and to absorb nitrates and phosphates. Wastewater generally has a 4 to 10 day retention rate in constructed wetlands (Tanner, Headley, Dakers 2011).

**Staged planning wetlands** or **tidal wetlands** are a relatively new technology that maximises the efficiency of constructed wetlands by flooding and draining up to 5 deep wetland cells in sequence. The ebb and flow (tidal) of wastewater permits more oxygen to enter the medium and increases the treatment capacity of the wetland area. The wetlands used in the design experiment in Chapter 2 are a staged planning wetland and the data used was provided by Worrell Water, an American company with a patent on the term Living Machine® (Worrell Water 2007). These systems are not presently well understood in New Zealand.

**Controlled environment aquatics** are another relatively new natural technology. In this system a greenhouse type structure houses a series of wastewater tanks which provide primary, secondary and tertiary treatment by mimicking and optimising the natural water filtration of a wetland. Tropical plants are rafted atop the tanks which distribute wastewater in sequence. Sunlight, oxygen, bacteria, algal plants, snails and fish work together to treat wastewater. There are several proprietary systems including Worrell Water's Living Machine® (Fig 3.9), John Todd Ecological Design's Eco Machine and the Ecological Engineering Group's Solar Aquatics System.

*Figure 3.9* Controlled Environment Aquatics systems in the Netherlands. *Image courtesy of Living Machine®*
6. Chemical systems generally provide an advanced tertiary level of treatment to ensure all harmful bacteria are destroyed. Chlorine is often used as a chemical advanced tertiary treatment.

**Ultra Violet (UV)** light treatment systems are generally used for tertiary or advanced tertiary disinfection that destroys or inactivates pathogenic organisms in wastewater. Wastewater must be adequately treated prior to UV treatment. UV systems transfer electromagnetic energy from a mercury arc lamp to an organism’s genetic material, penetrating the cell wall and destroying the organism’s ability to reproduce (EPA 2002).

This thesis is focused on the application of wastewater wetlands in the urban landscape. It seeks a more environmentally and economically sustainable wastewater system that offers increased resilience to the earthquake-prone city of Christchurch. The design experiment of Chapter 2 utilised a controlled environment aquatic model combined with a staged planning wetland for primary, secondary and tertiary treatment. While these technologies are real and meet many of the criteria sought in this research, they are relatively new technologies and not readily available in New Zealand. Constructed wetlands however have been in use in New Zealand for years providing secondary and tertiary treatment to wastewater at the site and community scale. They meet Māori cultural values by passing water through vegetation and the earth, restoring mauri (life force) to water. The loading and engineering requirements are well understood, they are considered by New Zealand policy makers to be safe in the public domain (subsurface) and they produce a quality effluent for reuse. For these reasons this thesis will generally use the horizontal subsurface flow constructed wetland (HSFCW) model as a tool for the spatial and design requirement of Chapter 6 and 7.

3.9 **Horizontal subsurface flow constructed wetlands (HSFCW)**

This wetland treatment typology for wastewater has been used widely around the world for over 50 years to treat wastewater and stormwater. The wetlands are capable under New Zealand conditions of providing reliable, long-term secondary or tertiary treatment of wastewater. They are simple to construct, can function passively without significant energy inputs and with minimal maintenance and can cope with fluctuating loads (Tanner, Headley, Dakers 2011). The following data regarding the performance of, loading, depth, area and other requirements for these treatment wetlands were provided to the Gisborne District Council by the National Institute of Water and Atmospheric Research (NIWA) of New Zealand (2011).

HSFCW wetlands are proven to provide reliable TSS removal, operate without insect or odour problems and minimise the risk of human exposure to potentially harmful wastewater as liquid resides 100 mm below a gravel surface. HSFCW wetlands mimic the water-purifying process that occurs in natural wetlands. Wastewater is treated by a combination of biological and chemical processes in a gravel medium that supports emergent wetland plants. TSS settles in the gravel medium and are broken down by microbes that attach themselves to the gravel and plant rhizomes and roots. This plant material also transports small amounts of oxygen down to the predominantly anaerobic media, providing micro-zones to assist microbes as they process nitrogenous compounds to nitrogen gases. The plants extract a portion of the wastewater nutrients and recycle them as degradable organic matter such as plant litter and root exudates which in turn stimulate microbial activity. Prolonged retention (<4.7 days) of wastewater in the wetland disinfects the wastewater by exposing pathogens to unfavourable environmental conditions and grazing protozoa. The end result is an effluent with a 99% reduction of faecal bacteria, TSS levels <30 and BOD levels <20 g m⁻³. This level of treatment is suitable for land application (sub surface drip irrigation) but not suitable for discharge to surface waters. (Tanner, Headley, Dakers 2011).
The main components of HSFCW wetlands are:

- A basin
- Impermeable barrier to prevent leakage and infiltration
- Gravel medium
- Wetland plants
- Inlet and outlet pipes
- Adjustable water level control device at the outlet.

Figure 3.10 Typical dimensions for a wastewater treatment wetland for a single family home. Image courtesy of Chris Tanner and NIWA (2011).
The depth and area of a HSFCW wetland, combined with a gravel porosity of 40% equates to a normal retention rate of 4.7 days. The area required increases proportionately with the Population Equivalent (PE) loading but as a general rule of thumb, 6 m² is required per person equivalent per day (pp/pd). A length to width ration of 2:1 needs to be maintained with a minimum length of 6 m to insure that wastewater moves freely through the gravel and that surface exposure is avoided.

The depth of a HSFCW wetland is recommended to be 40 cm as this depth promotes flow through the plant root zones and has proven to outperform deeper beds. The water level should be maintained at least 5cm below the surface of the gravel at the outlet. An ideal gravel medium is screened and washed greywacke which is widely available in Canterbury. Two sizes of gravel are used; a coarser (40 - 60 mm, 45% porosity) gravel at the inlet and outlet and a finer size (10 – 20 mm, 40% porosity) though the bed. The base of the bed should be level.

The emergent plants enhance the performance of HSFCW wetlands as well as add habitat and aesthetic values (Chapter 4). These plants can be native New Zealand plants or introduced species (Fig 3.11). They fall into one of two categories: low stature and high stature. It is recommended to plant at least 2 – 3 different species from any category should one species be affected by disease or pests.

HSFCW wetlands are very low maintenance once established, although they are not completely maintenance free. Those working on the wetlands should take appropriate measures to avoid any contact with wastewater. The water level can be lowered when working near the surface. If biosolids do accumulate near the inlet

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Figure 3.11 Wetland plants suggested in New Zealand by Tanner (2011).
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this could be a fault with the pump or primary treatment system. By lowering the water level of the wetland for a few weeks the beds will become aerated and promote the breakdown of biosolids. The surface of the gravel medium should be kept free of weeds as they will compete with the emergent wetland species.

HSFCW wetlands can also be designed as hybrid models that employ pulsed-loading, staged-planning, tidal-flow, and/or recirculating stages. These hybrids significantly reduce the amount of land area required by maximising the performance of HSFCW wetlands by flooding and draining the medium, allowing the gravel to be evenly and fully aerated. These models are significantly more complex and require more sophisticated plumbing, management and capital and to reiterate, the technology and general comprehension of the design for these systems is not widely available in New Zealand. However, should municipalities and investors provide the incentive for the research and development of these systems they have the potential to improve the scope of HSFCW wetlands in New Zealand. However the performance and design of these HSFCW wetlands is well known and celebrated by New Zealand ecological engineers and wastewater planners making them the wastewater wetland of choice.

It is important to note that HSFCW wetlands can be considered part of an open space amenity. They are safe enough to be sited next to a playground or playing field. People can walk across HSFCW’s. A rugby ball could be kicked on and safely retrieved from them. Food can be cooked next to them. They could be considered as ornamental gardens of wetlands plants where the actual performance of wastewater treatment is occurring 10cm below the surface. In most cases the actual performance would not need to be made aware to the viewer. The revelatory function of ecology in service will be explored further in Chapter 4.

HSFCW also increase the biodiversity of an area by providing habitat for invertebrates and birds. Studies have shown that an increased density of plants correlates with higher species diversity thus enhancing the ecosystems of the area. In urban areas this increases the environmental sustainability by providing an ecosystem service (Kazemi, et al 2009). Also the increase in visability of nature in the city provides many social benefits which will be explored in Chapter 4.

3.10 Outflow

What to do with treated wastewater can be one of the biggest challenges of an IWRM system (Bourke 2012). There are varying degrees of treatment needed for a myriad of outflow options. In many areas of the world including Singapore, and American cities prone to drought, wastewater is treated to a potable quality and reintroduced into the drinking water supply (Barringer 2012). Some progressive residential developments in Australia and Europe have employed the cascading water system where water is treated only enough for its next use. The research in this thesis examines the potential to close the loop of urban water cycles by providing landscape solutions to future uncertainties, especially those associated with water shortages. The end-use of treated wastewater is a critical component in not only locating treatment facilities but also in achieving a more sustainable wastewater management system.

ECan is the legislative body that sets the rules and regulations regarding the dispersal, discharge or reuse of wastewaters in Canterbury. The World Health Organization (WHO) also provides guidelines on the safe use of wastewater for several applications in a more global context. Both bodies play an important role in this discussion.

Currently, treated wastewater from the CWTP flows 3 km out to sea through a pipe and is discharged to Pegasus Bay off the coast of New Brighton. Before the completion of the ocean outfall in 2010 effluent from the CWTP was discharged directly to the Avon/Heathcote Estuary. It took the CCC almost 15 years to get ECan approval for the ocean outfall project (Bourke, 2012). Large amounts of energy and resources are consumed to treat Christchurch’s wastewater to a high quality just so it can be diluted in the sea. This practice is common in many New Zealand and international cities. However, the demand in New Zealand for
irrigation water and other non-potable uses is bringing more attention to the practice of reusing or recycling wastewater.

Options for wastewater outflow include:

**Land Application** of wastewater can also have the effect of treating wastewater (overland flow) but in Canterbury it is best suited to disposal of pre-treated water and is subject to ECan’s Rule WQL 14 (ECan 2011). Land application of wastewater can have the advantage of recycling nutrients in the wastewater as fertilizer for irrigated crops. Organic matter in the water can also improve soil structure and the moisture holding capacity of the soil (Meinzinger 2003). Land application can serve as irrigation for pastoral lands, providing a potential solution to the water demands of Canterbury’s dairy farmers. However appropriate site selection and effluent quality must be considered in detail to avoid any potential public health concerns. Franziska Meinzinger (2003) carried out a GIS analysis to determine lands in the Canterbury region suitable for land application (Fig 3.12). This analysis considers slope, climate, soil type, soil pH, soil depth, land use, distance to groundwater, distance to surface waters and distance to dwellings to come up with varying level of suitability for land application of Christchurch’s treated wastewater. Wastewater wetlands can treat water to a quality suitable for land application in most situations.

**Discharge to surface waters** is another option for the outflow of treated wastewater. This is again common practice in many New Zealand cities. In Canterbury, ECan’s Rule WQL48 (Ecan 2011) sets the requirements for discharging treated wastewater into a river, lake or artificial water course. This treated water must meet several criteria to ensure that the receiving environment is suitable and that the quality of the outflow remains within the thresholds set by ECan. In general, outflow from wastewater wetlands requires a tertiary treatment such as UV treatment before it can be discharged to surface waters.

**Non-potable internal use** of treated wastewater is subject to the Building Act of (1991) and would require special consideration. In many countries, including Australia, treated wastewater can be used internally for non-potable uses such as toilet flushing, laundry and fire suppression. As a precautionary measure this water is usually indicated as reclaimed with signs, however it is generally treated to an advanced tertiary level (using UV treatment) to mitigate any risks associated with potential human contact.

**Food production** on large scale agricultural plots or small veggie gardens can receive properly treated wastewater for irrigation. The environmental impacts of a global food economy have propelled a local foods social movement (Viljoen 2005) and the use of treated wastewater for local food production can provide greater food security and resilience. Wastewater recycling can increase opportunities for community gardens and other urban agriculture applications where other sources of irrigation may be limited (Fig 3.13). The use of wastewater in food crops has many benefits including being a reliable, year-round source of water that contains nutrients that are beneficial to plants and fish (WHO 2006). The WHO has undertaken extensive research on the appropriate use of wastewater in agriculture and has developed rules for the various levels of wastewater treatment needed for certain types of uses.
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of agriculture. These rules are set at different levels for a variety of food crops and are intended to protect both the consumer and the agricultural worker by recommending specific log \(^1\) reductions of harmful elements contained in wastewater. For example, drip irrigation of high growing crops such as fruit trees only requires a two-log reduction, which can be achieved via secondary wastewater wetland treatment. The use of wastewater for spray irrigation of leaf crops such as lettuce or for labour intensive agriculture requires a three-log reduction, or tertiary treated water. Irrigation of root crops such as onions requires a four-log reduction, or advanced tertiary treatment.

There are several other outflow options including deep well injection in which treated wastewater is injected into the earth between impermeable layers. Also treated wastewater can be sold back to industry for other internal, non-potable uses. Or water can be treated to a potable standard and sold back to consumers as drinking water as has been done in other parts of the world. This thesis seeks to close the loop of urban wastewater cycles and return valuable nutrients and water to uses such as food production, ecological regeneration, forestry and non-potable uses so the energy and materials used to convey and treat a city’s wastewater can be productive instead of wasteful.

3.11 Other emerging technologies and systems

Wastewater contains valuable resources that can be exploited in many ways. Harnessing the energy embodied in the elements of wastewater and recovering these elements for reuse is an important role in sustainable wastewater management. Perhaps most notable in the field of technological advancement of wastewater technology is the emerging role wastewater can play in producing biofuel. Research conducted by the University of Canterbury reports “microalgal biomass grown on wastewater has the potential for sustainable biofuel production” (Valigore et al p.1). This research was conducted at the CWTP and determined that primary treated wastewater could facilitate the growth of algae in a bioreactor which can then be converted to biofuel and biomass. The generation of biofuel in algae bioreactors reduces the demand on agricultural lands for biofuel crops and converts waste products into energy, a guiding principal of this thesis. It was used in the design investigation in Chapter 2. The technology is still in its infancy but is progressing rapidly and as demands for biofuels continues to grow, the technology of extracting biofuel from algae grown on wastewater could become common place in wastewater treatment facilities.

Another study reports that significant amounts of ethanol can be created through the processing and fermentation of plant starch and proteins (Bloom 2007). This study examines Raupo (Typha sp.) harvested from wastewater wetlands and demonstrates that the use of this plant as a feed stock for ethanol generation can aid in creating resilience to peak oil and generate a commodity from a waste product.

1. A log reduction is an engineering term that in the context of wastewater expresses levels of decreased biological contamination by factors of 10.
3.13 Summary and conclusions

The conventional method of Christchurch’s wastewater conveyance, treatment and outfall has proven to be unsustainable and not suitable to the city’s natural environmental, which has a high water table and is prone to liquefaction from seismic activity. Therefore a new sewage configuration must be implemented that utilises more resilient and multi-beneficial conveyance, treatment and outfall technologies. This new system must be considered as a part of an IWRM system which also considers freshwater quality, freshwater delivery, stormwater catchment, treatment and drainage and other opportunities to close the loop of the urban water cycle.

More sustainable and resilient systems have been identified in this chapter and these paths will be used in Chapters 6 and 7 as a tool for examining the urban landscape spatial implication and design opportunities. They include the use of a clustered configuration which would permit the use of a small bore conveyance network such as a pressure or vacuum system. A cascading wastewater treatments system would begin with primary treatment in anaerobic digesters capturing methane gas for energy. Then wastewater wetlands would provide secondary treatment at which point wastewater is to a quality acceptable for many uses including land applications for several agricultural purposes. Finally UV tertiary treatment is required to return wastewater to surface waters, for internal non-potable uses or spray irrigation (Fig 3.11).

These paths represent a dramatic shift from a “flush and forget” culture to integrative wastewater recycling systems that use landscape as key component for the recovery and reuse of wastewater. Public aversion to such systems exists, and the barriers to widespread acceptance of landscapes that treat and reuse wastewater will be addressed in a cultural and social context in Chapter 4, which examines theoretical approaches to the aesthetic design of performance landscapes. The case studies in Chapter 5 will demonstrate the real application of the technologies and systems explored in this chapter and how landscape theory has aided in the public acceptance and appreciation of the new wastewater landscape systems.
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**Figure 3.11**

**Sustainable Wastewater Pathways**

- **Source**
  - New Residential Developments
  - Existing Residential Developments

- **Conveyance**
  - Wastewater
  - STEP / STEG
  - Pressure or Vacuum
  - 10,000+ population

- **Treatment**
  - Primary
    - Vermicomposter
    - Anaerobic Digester
      - Gas
      - Solids
      - Biogas
      - Compost

**Outputs**

- D1 = Low density 10 hh/ha
- D2 = Medium density 17 hh/ha
- D3 = High density 25 hh/ha