SWITCH Training Kit
INTEGRATED URBAN WATER MANAGEMENT IN THE CITY OF THE FUTURE

Module 5
WASTEWATER
Exploring the options
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Module 5
WASTEWATER
Exploring the options
The SWITCH Training Kit

Integrated Urban Water Management in the City of the Future

The SWITCH Training Kit is a series of modules on Integrated Urban Water Management (IUWM) developed in the frame of the project ‘SWITCH – Managing Water for the City of the Future’. The Kit is primarily designed for training activities with the following target groups in mind:

- Political decision makers from local governments;
- Senior staff of local government departments that:
  - are directly in charge of water management,
  - are major water users themselves, such as parks and recreation,
  - have major impacts on water resources, such as land-use planning,
  - have an interest in water use in general, such as environmental departments;
- Water managers and practitioners from water, wastewater and drainage utilities.

All modules are closely linked to one another and these links are clearly indicated throughout. In addition, information contained in the modules is backed up by a library of online resources, case studies and weblinks to external material, all of which are highlighted where applicable in the text. The following symbols are used to indicate when further information is available:

- Refers to another SWITCH Training Kit module where more information can be found
- Refers to additional SWITCH resources available on the SWITCH Training Desk website (www.switchtraining.eu/switch-resources)
- Refers to a case study available on the SWITCH Training Desk website
- Refers to information outside the SWITCH Training Desk
SWITCH Training Kit: All modules

The overall SWITCH approach to IUWM

Module 1
STRATEGIC PLANNING
Preparing for the future

Contains an introduction to key challenges of managing water in urban areas now and in the future and a step-by-step explanation on how to develop and implement a strategic planning process.

Module 2
STAKEHOLDERS
Involving all the players

Contains an overview of different approaches to multi-stakeholder involvement – including Learning Alliances – and ways and means by which such an engagement can be effectively realised for the purposes of IUWM.

Module 3
WATER SUPPLY
Exploring the options

Module 4
STORMWATER
Exploring the options

Module 5
WASTEWATER
Exploring the options

Sustainable solutions

Describes how urban water supply / urban stormwater management / urban wastewater management can benefit from increased integration including examples of innovative solutions as researched in SWITCH and the contribution these can make towards a more sustainable city.

Decision making

Module 6
DECISION-SUPPORT TOOLS
Choosing a sustainable path

Introduces the concept of integrated decision making for urban water management, including details of a number of decision-support tools such as the SWITCH developed ‘City Water’.
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Introduction

The management of wastewater in cities throughout the world tends to follow a standard approach. This approach, though complex in technological requirements, is based on the simple concept that wastewater is an unwanted product that needs to be removed from the urban environment as safely and efficiently as possible.

Module 5 challenges this concept by examining alternatives to urban wastewater management in which decentralised technologies and natural systems are used to recycle wastewater and the nutrients and energy it contains. This alternative approach is based on the recognition that wastewater management is inextricably linked with the rest of the urban water cycle as well as many other urban management sectors. The module demonstrates how an integrated approach can be more sustainable than conventional wastewater management and introduces a number of options to implement tangible change in this direction.

The overriding message of the module is that by encouraging more integrated urban wastewater management and promoting the recycling of resources, a city stands to gain a range of benefits. Not only can they increase the efficiency of the day-to-day operation of wastewater, water supply and drainage services, but also improve other aspects of urban management such as economic development, environmental protection, food security and resilience to climate change.

Module 5 is closely related to Modules 3 and 4 which cover a similar practical approach to water cycle management from the perspective of water supply and urban drainage respectively.
Learning targets

Module 5 presents an overview of wastewater management and how this influences and is influenced by the urban water cycle and urban development as a whole. It is intended to give the user knowledge of the limitations associated with a conventional approach to urban sanitation and how an integrated approach, and the selection of alternative solutions, can not only overcome these but also provide additional benefits. The module is therefore relevant for all cities regardless of their current sanitation situation.

More specifically, the module will assist users to gain a better understanding of:

- what constitutes a more sustainable approach to wastewater management and how this differs from a conventional approach;

- the direct and indirect benefits that a city can gain by managing wastewater as a resource rather than as a waste product; and

- the solutions that are available to put a more sustainable approach to wastewater management into practice, including the use of natural systems.

It should be noted that it is not the purpose of the module to provide the user with the necessary technical detail to select, design and construct the wastewater management solutions best suited for their local situation. Users who want to take this next step towards implementation are rather encouraged to consult the many technical manuals and guidelines that are readily available for this purpose. Some of these resources are referred to within the module.

Figure 1: Wastewater within the urban water cycle
The need for sustainable wastewater management

Within the urban water cycle, the management of the wastewater component is often the most complex. When systems are well designed and maintained the water-based waste of a city is safely collected, treated and disposed of without impacting on the quality of urban life. However, when systems are inadequate or non-existent the resulting pollution leads to diseases and environmental degradation.

Despite its importance in our cities, for most urban dwellers wastewater management, particularly the human waste aspect, is an unpleasant subject, a cultural taboo and a topic best ignored. If a system exists that allows users to flush the toilet, take a shower and wash the dishes without having to think about what happens next there are likely to be few complaints. Looking beneath the surface, however, there are considerable requirements concerning the management of the used water flows, to ensure that:

- the threat of contamination and human disease is eliminated; and
- damage to the natural environment is minimised.

The management of urban wastewater involves the collection, conveyance, treatment and reuse or disposal of various flows differing in composition and treatment and disposal requirements. These include:

- Faeces: (Semi-solid) excrement without urine or water.
- Urine: Liquid waste produced by the body to rid itself of urea and other waste products.
- Flushwater: Water that is used to transport excreta from the user interface to the next technology.
- Blackwater: The mixture of urine, faeces and flushwater.
- Greywater: The total volume of water generated from washing food, clothes and dishware as well as from bathing.
- Stormwater: The general term for the rainfall runoff collected from roofs, roads and other surfaces before flowing towards low-lying land.

(Source: Tilley, E. et al, 2008)

Each of these elements is made up of different quantities of water, pollutant loads and nutrient content. The challenge cities are facing is to manage the different elements in an affordable way with minimal impact on human health and the natural environment.

Figure 2 shows what needs to be managed from a typical residential household alone and how the different elements vary in volume and content.
Figure 2: Domestic wastewater streams (source: Wageningen University)

- **Flushwater**: ~3,000-15,000 litres per person per year (l/p/yr)
  - Typically potable quality
  - No nutrients

- **Urine**: ~500 l/p/yr
  - Typically pathogen free but may contain pharmaceuticals
  - Rich in nutrients (2-4 kg of nitrogen per year)

- **Faeces**: 50 l/p/yr
  - Contains high pathogen loads
  - Few nutrients

- **Greywater**: ~35,000-45,000 l/p/yr
  - Contains detergents, chemicals and food waste but few pathogens
  - Few nutrients

- **Stormwater**: Volume dependent on rainfall
  - Can contain chemical pollutants and heavy metals
  - No nutrients

Distribution of main contents among the different elements of wastewater (excluding stormwater)

- **Volume of water**
  - Flushwater
  - Greywater
  - Urine
  - Faeces

- **Pathogen content**
  - Flushwater
  - Greywater
  - Urine
  - Faeces

- **Nutrient content**
  - Flushwater
  - Greywater
  - Urine
  - Faeces

(Approximate proportions only)
3.1 The conventional approach to wastewater management

The conventional approach to urban wastewater management is based on a centralised system that collects and treats a combined flow of most or all of the wastewater elements described in Figure 2.

This approach dates back to Roman times but was developed in its current format during the industrial revolution as cities were growing in size, population and density. The increasing volumes of untreated human waste severely affected the health of inhabitants resulting in outbreaks of diseases such as cholera. To overcome the problem, water-based toilets, piped sewer networks and centralised treatment facilities were constructed; this proved to be an effective solution to prevent the spread of disease through human contact with wastewater in the city.

Over 150 years later this concept remains the most common and most sought after approach to urban wastewater management throughout the world. As shown in Figure 3, the system uses a network of sewerage pipes to collect wastewater from individual households, businesses, industries and, in some cases, rainfall runoff. The pipes convey the mixed flows to central treatment facilities where the combined effluent is treated and discharged to surface water bodies.

Figure 3: Conventional wastewater management
3.2 The issues arising from conventional wastewater management

The assumption that successful wastewater management is dependent on a centralised collection and treatment system is not necessarily true. Although a well designed and maintained system protects public health and has few environmental consequences, not all urban settings are compatible with conventional designs and, even in the ones that are, a range of limitations raise the question of sustainability in the long-term.

Some of the issues with conventional urban wastewater management are as follows:

- **Dilution of flows**: By combining all wastewater streams, treatment techniques are required for large volumes of diluted wastewater. This results in an inefficient treatment process.

- **High water use**: Conventional systems require a reliable supply of water to operate (for the flushing of toilets and conveyance of waste). The water needs for the system typically account for around a third of a household’s water consumption.

- **Pollution risk**: When functioning poorly or combined with stormwater collection, wastewater transportation networks may leak or overflow causing untreated wastewater to be dispersed to the environment.

- **Cost**: The cost of constructing, operating and maintaining centralised wastewater collection and treatment infrastructure is high.

- **High energy demand**: Conventional centralised wastewater treatment is energy intensive and therefore requires a reliable and affordable power supply to operate effectively.

- **Waste of a valuable resource**: Centralised systems fail to exploit the valuable resources in human excreta and greywater such as the nutrients and energy it contains, and the potential for reclaimed water use.

- **Nutrient overload**: Typical discharges from centralised wastewater treatment plants contain high levels of nutrients. These cause an increase in algal blooms and a depletion of oxygen in receiving water bodies.

- **Non-flexible**: Large wastewater treatment plants have a capacity based on forecast volumes of wastewater and, in combined systems, the predicted stormwater runoff rates. These systems are not easily adapted if design specifications prove to be too high or too low due to population growth, migration or change in climate patterns.

- **Inappropriate for local conditions**: Technology and infrastructure are based on ‘one-size-fits-all-solutions’ which may not be suitable for the needs of the location in which they are placed.

Conventional wastewater management is a rigid solution and this lack of flexibility makes it difficult to adapt to unexpected future change. In cities where sanitation systems are either non-existent or badly designed and maintained, the ability to keep up with rising pressures such as rapid urbanisation and population growth is obviously a massive challenge. But even in cities where effective centralised systems have been in place for decades, anticipated future developments, such as a changing climate, are raising doubts over an approach to wastewater management that was previously unquestioned. Figure 4 shows some of the pressures that wastewater management in the city will be increasingly confronted with in the future.
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Figure 4: Examples of future pressures on urban wastewater management

Population growth
More people mean more wastewater to collect and treat. Expanding conventional infrastructure to cope with this increase is a costly process.

Urbanisation
Urban sprawl often occurs faster than centralised wastewater infrastructure can be built. This can result in a lack of adequate sanitation services for large urban populations, especially in informal settlements.

Stricter environmental legislation
Increasing awareness and concern over the impact of wastewater discharges on the environment means that more efficient treatment processes are legally required.

Climate change
Combined sewers that collect and treat both wastewater and stormwater are vulnerable to climate change. Increases in the intensity and duration of rainfall events cause combined sewers to overflow more frequently discharging untreated sewage to the environment.

Deterioration of infrastructure
As wastewater infrastructure ages leakages from the system and sub-standard performance become more likely.

Future energy costs
Wastewater management relies on energy for pumping and treatment. A rapid rise in fuel costs would therefore have serious implications on the cost of wastewater management.
Adopted in 1991, the European Urban Wastewater Treatment Directive (91/271/EEC) addresses the need to protect Europe’s groundwater, rivers, lakes and seas from the impacts of poorly treated wastewater. The Directive requires that all wastewater generated in areas with a population equivalent in excess of 2000 must receive at least secondary treatment. In addition, cities identified as being in vulnerable, or ‘sensitive’, areas face more stringent treatment requirements. The Directive is closely related to the European Water Framework Directive (2000/60/EC) which requires that all waters in the European Union achieve good ecological status by 2015.

Despite being introduced almost 20 years ago, the Directive continues to pose a significant challenge for cities throughout Europe. In particular the more stringent treatment requirements for big cities located in ‘sensitive’ areas are still a major issue and 50% of the load from these cities is still being discharged without adequate treatment.


Further information on the Urban Wastewater Treatment Directive can be found at:
### 3.3 A more sustainable approach to wastewater management

An alternative approach to wastewater management views wastewater not as a problem that needs to be disposed of but rather as a variety of resources that, when managed correctly, can be reused.

As shown in Figure 5, conventional wastewater management can be considered a linear process with inputs (combined wastewater flows) at one end and outputs (downstream discharges of treated effluent and disposal of sludge) at the other. An integrated approach that is based on the cyclical processes observed in nature in contrast encourages the separate collection, treatment and reuse of urine, faeces, greywater and stormwater. This approach is considered more sustainable as solutions can be applied that improve treatment performance at less cost and enable resources to be recycled more efficiently.

**Figure 5: Linear versus cyclical wastewater management**

The key differences between the conventional approach and an integrated one are:

- Combination versus separation;
- Centralised versus decentralised collection and treatment;
- Disposal versus reuse.

These differences are described in more detail in Table 1.
In The City of the Future
Aspect of wastewater management

<table>
<thead>
<tr>
<th>Conventional approach (wastewater management as a linear process)</th>
<th>Integrated approach (wastewater management as a cyclical process)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Collection</strong></td>
<td>Faeces, urine, greywater and stormwater are combined and conveyed through an expensive sewer network to a centralised treatment facility.</td>
</tr>
<tr>
<td><strong>Treatment</strong></td>
<td>Centralised treatment of combined wastewater elements based on energy- and chemical-intensive infrastructure and technology.</td>
</tr>
<tr>
<td><strong>Treated effluent</strong></td>
<td>Treated effluent is discharged downstream to receiving water bodies such as rivers, lakes and estuaries.</td>
</tr>
<tr>
<td><strong>Nutrients</strong></td>
<td>Nutrients are disposed of in the environment through discharged effluent and sludge.</td>
</tr>
<tr>
<td><strong>Sludge by-product</strong></td>
<td>The sludge by-product is disposed of in landfill or through incineration.</td>
</tr>
<tr>
<td><strong>Energy consumption</strong></td>
<td>Large amounts of energy are used for treatment and pumping.</td>
</tr>
</tbody>
</table>

Table 1: Key differences between a conventional and an integrated approach to wastewater management

When operating as intended, the conventional approach to wastewater management prevents disease and environmental pollution – the most important objectives for any system. But as highlighted above this approach also fails to take advantage of the many opportunities that exist when wastewater is recognised as more than just a waste product to be disposed of as efficiently as possible.

By adopting an approach to wastewater management that is based on decentralised solutions for separation and reuse, the key health and pollution control objectives are achieved as well as the following additional benefits:

- **Increased access to sanitation**: Decentralised systems can provide low-cost sanitation at the household and community level in areas where lack of funds and logistics prevent the provision of centralised infrastructure.

- **Water savings**: Recycling greywater, stormwater and treated blackwater (water containing urine and faeces) for irrigation and other non-potable uses reduces demands on the water supply network. In addition, recycled wastewater can be used to recharge aquifers during dry periods.

- **Flexibility to population growth**: Urban population growth challenges the design capacity of centralised sewers and treatment facilities. Decentralised systems prevent infrastructure overload by separating greywater and stormwater and managing human waste at the household and community level.
• **Recycling of plant nutrients**: Urine and biosolids from faeces provide a cheap and environmentally friendly source of fertiliser and soil conditioner for agriculture and urban greening. The extraction and reuse of nitrogen and phosphorus also prevents nutrient overload in local water bodies.

• **Financial savings**: The construction and operation costs of many decentralised wastewater management options are low compared to centralised systems. Savings are made through reduced energy and chemical costs, and additional revenue can be gained through the reuse of wastewater and the nutrients and energy it contains.

• **Employment generation**: Resource recovery and productive reuse creates additional employment and may stimulate private (micro-) enterprises.

• **Energy recovery**: Blackwater can be digested to create biogas. This can be used as a cheap, renewable source of energy for cooking, electricity generation and vehicle fuel.

• **More efficient treatment**: The separation of wastewater flows and confinement of specific pollutants allows the most effective and cost-efficient treatment techniques to be employed. Pathogens, heavy metals and micropollutants such as pharmaceuticals can therefore be isolated and removed more easily than is possible in diluted flows.

• **Urban biodiversity and amenity**: The construction of wetlands and other natural systems for wastewater treatment provides habitats that support biodiversity and increases the area of green space in a city.

The benefits listed above clearly show that the management of wastewater is closely linked with other areas of the urban water cycle as well as urban planning as a whole. Rather than selecting options based on narrowly-defined problems and objectives, a more sustainable approach can identify multi-purpose solutions that provide urban benefits within and beyond the sanitation sector. Section 4 explores these linkages in more detail.
Wastewater in the city

4.1 Linkages within the urban water cycle

Wastewater management has traditionally been managed independently from other areas of water management such as stormwater and water supply. This approach neglects the many linkages between wastewater and the urban water cycle as a whole leading to:

- missed opportunities (for example failing to reuse wastewater for water supply purposes in water scarce environments);
- unexpected impacts (for example the discharge of treated effluent with a high nutrient load contaminating a water supply source downstream).

Looking at the urban water cycle holistically helps identify the linkages between wastewater and other areas of water management. The recognition of these linkages avoids interventions that provide perceived benefits to one area of urban water management but which cause damage elsewhere. Greater integration of the urban water cycle therefore leads to decisions being taken that are more likely to result in more sustainable urban water management as a whole.

Some of the links that may need to be recognised between wastewater and other areas of the urban water cycle are shown in Figure 6.

Figure 6: Examples of how wastewater management is linked to the urban water cycle

**Wastewater and stormwater management**

In many cities stormwater collection is linked to wastewater management through combined sewer systems. Heavy rainfall increases the volume of water needing to be treated and can result in overflows from the system. This causes untreated sewage to be released to the environment.

**Wastewater and domestic water consumption**

Household water use is directly related to the volume of wastewater to be treated. Rising consumption through the installation of high water use appliances increases the volume of wastewater to be treated while reducing the concentrations of human waste within it.

**Wastewater and water quality**

Treated effluent discharged from centralised wastewater treatment works typically contains high levels of nutrients causing an increase in algal blooms in receiving water bodies. Poorly treated discharges and overflows of untreated effluent can also cause severe pollution to ground and surface water resources. In many occasions this same water is re-abstracted downstream for potable uses.

**Wastewater and non-potable water supply**

Wastewater (treated and untreated) is a cheap source of non-potable water that may be used for supply purposes. Greywater and treated effluent can be reused for irrigation, industrial uses, toilet flushing and to recharge aquifers. Wastewater reuse is particularly valuable in cities that suffer from water scarcity and drought.
4.2 Linkages between wastewater management and other urban management sectors

Wastewater is also closely related to other areas of urban planning. Energy, urban agriculture, housing, education and health are just some of the sectors that are influenced by, or have an influence on, wastewater management. As with the urban water cycle, decision makers must also be aware of the linkages between wastewater and other areas of urban management. This can prevent actions being implemented that lead to unexpected negative impacts and allows planners to make the most of existing opportunities and multi-purpose solutions.

Some of the most significant linkages between wastewater management and urban planning and development, including the positive and negative impacts that these can cause, are shown in Figure 7.

**Figure 7: Examples of how wastewater management is related to other urban management sectors**

- **Urban agriculture:** Nutrients such as nitrogen and phosphorus contained in wastewater can be recycled as fertiliser for farming purposes. If safely managed, treated effluent can also be used as a source of irrigation for crops. The application of sewage sludge to agriculture also improves the quality and soil moisture retention of soils (see also Section 4.3).

- **Health and poverty alleviation:** Inadequate sanitation is one of the main causes of disease in developing countries. The relationship between urban poverty and sanitation-related disease is strong and improved wastewater management can go a long way to increase standards of living.

- **Education:** Wastewater management is closely related to human behaviour. Education has a large role to play in promoting more hygienic sanitation practices and encouraging the use of safer technologies.

- **Housing:** The construction of new housing developments requires new wastewater collection infrastructure and expanded treatment facilities to manage the increased volumes of wastewater.

- **Parks and recreation:** Recycled greywater and treated effluent can be used as a cheap and reliable source of irrigation for parks, gardens, golf courses and sports fields.

- **Energy:** Wastewater treatment can be either a high energy consuming activity, an energy neutral activity, or an energy producing activity. Conventional wastewater treatment is dependent on a reliable supply of energy. However, the digestion of wastewater sludge can also be used to produce biogas that can be used as a renewable energy source.

- **Environmental management:** Discharges of poorly treated wastewater pollutes the natural environment causing the destruction of ecosystems. Using natural systems such as ponds and wetlands to treat wastewater can however increase biodiversity in a city.
4.3 Wastewater management and urban agriculture

Urban agriculture is the practice of ‘growing plants and raising animals within and around cities and the related input provision, processing and marketing activities and services’. Farming in cities is varied and can consist of individual gardens, formal and informal allotments, and the use of other available urban green space such as parks, river banks, roof tops and public grounds. Products grown are wide-ranging and depend largely on the local environment and market demands.

The role of urban agriculture in sustainable urban development is being increasingly recognised through its contribution to poverty alleviation, food security and nutrition, employment generation, urban environmental management and climate change adaptation. Urban agriculture is an integral part of the urban socio-economic and ecological system due to its relationship with:

- the provision of livelihoods;
- urban resources (land, water and nutrients);
- the urban food system (urban consumers and producers); and
- urban conditions (the influence of policies, regulations, etc.).

Urban agriculture, including urban greening, creates a market for the reuse of wastewater and the nutrients within it. This is particularly the case where decentralised wastewater collection and treatment systems are established. The demand from urban agriculture for cheap fertiliser, irrigation water and soil conditioner creates a market and incentive for wastewater reuse. The value of nutrients encourages the separation of urine from faeces, stormwater becomes a reliable source of crop irrigation and the composting of faeces provides readily available organic soil improver. The economic value of these products helps to redefine wastewater as a resource rather than a problem – a crucial requirement to generate a cyclical process for managing it. In addition, productive use of wastewater for urban agriculture will help to reduce the demand for freshwater supply as well as to reduce the volume of discharged wastewater.

Urban agriculture is therefore closely integrated into the wastewater management cycle and, consequently, urban water management as a whole. However, due to the lack of formal recognition of the practice the use of wastewater for productive purposes is often poorly regulated, particularly in cities in developing countries. Uncontrolled collection, transport and reuse of wastewater products leads to health risks, especially through human contact with pathogens. These risks can however be overcome through a number of simple ‘from farm to fork’ precautions. These include:

- Basic treatment measures such as storage and settling in the case of urine;
- Composting at high temperature, long-term storage and avoidance of moisture from urine in the case of faeces;
- Watering regimes that leave sufficient time between irrigation and consumption of products;
- Use of equipment that protects against human exposure to pathogens;

• Hygienic preparation of product prior to consumption;

• Education and awareness-raising activities; and

• Acceptance of urban agriculture as a formal land use and the creation of policies and regulation that recognise it as such.

The RUAF Foundation (Resources Centre on Urban Agriculture and Food Security) provide a distance learning course on urban agriculture which is available free of charge at http://moodle.ruaf.org

The potential of wastewater reuse for urban agriculture in Accra, Ghana

It is estimated that up to 90 per cent of fresh vegetable consumption in Accra comes from intensive production within and around the city. To maintain soil fertility the farmers often use poultry manure and chemical fertilisers. However, the high cost of these fertilisers is increasingly becoming a constraint to farming activities in the city, creating a market for alternative sources of nutrients.

Around 95% of Accra’s population uses on-site sanitation facilities, creating a potential source of nutrients and organic matter for urban agriculture in the city. For example, many public urinals located in some of the most densely populated residential areas suffer from inadequate maintenance and management. Consequently, urine is discharged directly into stormwater drains, causing pollution in receiving water bodies. The option to collect and reuse urine for urban agriculture therefore provides the dual benefit of improving wastewater management and reducing the cost of crop production in the city.

For further information on wastewater management in Accra see the paper ‘Inventory of agricultural demand and value of the application of ecosan fertilizers in SWITCH demonstration cities’ (Tettenborn et al 2009) www.switchtraining.eu/switch-resources
4.4 Wastewater management and the natural environment

The use of the natural environment in wastewater management is typically to the detriment of the health of ecosystems. There are many examples throughout the world where rivers and lakes have been used as conveyors and diluters of wastewater resulting in the complete destruction of aquatic life within them. Even highly sophisticated treatment technologies rarely remove all nutrients from mixed wastewater flows causing an increase of algal blooms and eutrophication in receiving water bodies. Other micropollutants such as endocrine disruptors and medicine traces have only recently begun to be researched and are yet to be fully considered in recommended wastewater treatment standards.

However, natural systems can also be used for wastewater management in a more sustainable way. This requires a redefinition of the role of nature in the management process. In conventional systems this role is the removal and dilution of effluent as described above. But a more sustainable approach makes use of natural systems for treatment purposes, taking advantage of their ability to remove certain pollutants both cheaply and effectively.

Natural treatment is based on the ability of soils, vegetation and sunlight to treat water through physical, chemical and biological processes. These techniques are particularly effective for removing pollutants from greywater and stormwater as well as nutrients, pathogens and certain micropollutants that standard blackwater treatment techniques are unable to capture.

An investigation into the use of natural systems for wastewater management in an urban setting can be found in the paper ‘Application of natural treatment systems in the future expansion area of Cali, Colombia’. (Gaviano et al 2009).

www.switchtraining.eu/switch-resources
The benefits of natural systems for managing wastewater are more than a cheap and low energy treatment method. Systems such as wetlands, ponds and reed beds, which can be incorporated into parks or garden landscapes, provide additional benefits to the urban environment such as:

- **Biodiversity**: The construction of natural treatment systems provide urban habitats for flora and fauna.
- **Enhanced amenity value**: An increase of green space and aquatic environments in the city improves the quality of life for inhabitants.
- **Urban cooling**: An increase in water and vegetation in the city reduces the heat island effect suffered by many cities during hot weather.
- **Improved stormwater management**: Natural systems such as wetlands and ponds attenuate stormwater runoff during heavy rainfall, reducing the risk of local and downstream flooding.
- **Additional resource**: Plants, such as reeds, that are used to absorb nutrients from wastewater can be harvested and reused as a source of fertiliser.

More information about some of the different natural solutions available can be found in Section 7 as well as in the equivalent sections in Modules 3 and 4.
5 The overall direction: Wastewater management and sustainability

5.1 Sustainable wastewater management

Integrated Urban Water Management (IUWM) acknowledges and exploits the linkages both within the urban water cycle and between water and urban development as a whole. Decisions taken based on the evaluation of the bigger picture rather than an artificially isolated part of it, will therefore lead to greater integration and, consequently, increased sustainability.

Section 4 has demonstrated the many linkages between wastewater, the urban water cycle and urban development as a whole. By considering these linkages, the evaluation of planned interventions and actions is more comprehensive enabling more sustainable choices to be made. However, taking a decision that will be the optimal one for the city as a whole requires an agreed understanding of what sustainable urban development means and how it is specifically related to wastewater management.

In brief, sustainable water management may be defined as meeting current social, economic and environmental needs while creating conditions that allow these needs to also be met in the future\(^2\). Figure 8 shows how these criteria can be applied to wastewater.

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\(^2\) The World Commission on the Environment and Development defines sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (1983)
To increase sustainability to the maximum, wastewater management decisions need to be taken with due consideration for each of the above aspects. Adopting a solution that improves sanitation coverage and protects urban populations from wastewater contamination will not be sustainable if the operation and maintenance costs are unaffordable in the long term. Likewise a solution which is cheap to implement and has environmental benefits will only work if it is preferable to alternatives for the intended users. In short, if one of the sustainability criteria is not met, the chances of a solution contributing to sustainable development in the long term are greatly reduced.

Agreeing on and applying the sustainability dimensions to wastewater management can help a city reflect on the overall direction that wastewater planning should be aiming for.

Finally any sustainability assessment needs to be backed up by multi-stakeholder engagement. This ensures that the actions, opinions and needs of all who have an influence on and are influenced by wastewater management are taken into consideration. The involvement of utilities, user groups, agriculture, the private sector, relevant authorities, NGOs, etc. is therefore essential for designing solutions with which stakeholders can identify and for the direct and indirect impacts of management decisions to be truly understood.

More information on stakeholder engagement can be found in Module 2
5.2 Objectives, indicators and targets for urban wastewater management

In line with an integrated approach to urban water management, the selection of objectives and associated indicators for wastewater should ideally not be done separately but rather as part of a larger IUWM strategic planning process in which an overall vision for the city has been agreed upon and priority issues, such as improved sanitation, have been identified.

Bearing in mind the linkages between wastewater, the urban water cycle and other urban management sectors, an integrated approach is more likely to select multi-purpose objectives. Whereas a conventional approach to wastewater management tends to have a narrow range of objectives based on human health and environmental protection, an integrated approach is likely to look not only at securing hygienic living conditions and preserving ecosystems but also at reusing wastewater, recycling nutrients, generating biogas, enhancing biodiversity, reducing energy consumption, etc.

Table 2 gives some generic examples of wastewater objectives that have been formulated with consideration for urban development beyond the wastewater service sector. Examples of associated indicators, through which progress is measured, and targets, which act as the mark to be reached in order to achieve the objective. The final column in the table lists the different urban management sectors that the objective is designed to influence.

The selection and use of objectives, indicators and targets are discussed in much greater detail in Module 1.
### Table 2: Examples of objectives, indicators and targets for urban wastewater management

<table>
<thead>
<tr>
<th>Examples of integrated wastewater management objectives</th>
<th>Examples of associated indicators</th>
<th>Examples of associated targets</th>
<th>Relevant urban management sectors</th>
</tr>
</thead>
</table>
| Eliminate the threat of human contamination and disease | • Number of reported cases of diseases caused by contact with human waste  
• Faecal coliform content of effluent discharges | • Zero cases of disease caused by inadequate wastewater management by year X  
• Zero releases of effluent with a faecal coliform count of X per X | • Wastewater services  
• Health |
| Minimise non-renewable energy consumption in the management of wastewater while maintaining levels of service | • Measured non-renewable energy consumption for pumping and treatment  
• Energy expenditure by wastewater utility | • X% reduction of carbon emissions for pumping and treatment by year X  
• X% of financial savings in non-renewable energy bills by year X | • Wastewater services  
• Energy  
• Climate change mitigation |
| Recycle nutrients from wastewater for use as fertiliser for municipal purposes | • Municipal expenditure on chemical fertiliser  
• Quantity of phosphorus produced from wastewater | • X% reduction in municipal expenditure on chemical fertiliser by year X  
• X kg of phosphorus produced per year | • Wastewater services  
• Parks and recreation  
• Environmental management |
| Disconnect stormwater flows from the wastewater sewage system | • Area of roof space disconnected from combined sewer systems  
• Actual volumes of wastewater treated in relation to measured rainfall rates | • X% of roof area disconnected from the sewer system by year X  
• X% reduction in volumes of wastewater treated during heavy rainfall compared with past events of equal magnitude by year X | • Wastewater services  
• Drainage services  
• Housing  
• Environmental management |
| Increase removal of environmentally damaging pollutants through the wastewater treatment process prior to discharge to the environment | • Quantities of target pollutants present in discharged effluent  
• Change in population numbers of key species in a specified area affected by target pollutants | • Reduction of target pollutants to X amount per unit of treated effluent by year X  
• X number of specie X counted by year X in specified area | • Wastewater services  
• Environmental management |
| Save water supplies through the reuse of wastewater for the irrigation of municipal gardens and playing fields | • Quantity of potable water used for municipal irrigation  
• Quantity of treated wastewater discharged with no reuse purpose | • X% reduction of potable water used for municipal irrigation  
• X% decrease in the volume of treated effluent discharged with no reuse purpose | • Wastewater services  
• Water supply  
• Parks and recreation |
Putting more integrated wastewater management into practice

6.1 Implementation of more integrated wastewater management

The practical management of wastewater can be divided into four simplified components:

- User interface (water-based toilets, dry toilets, urinals, etc);
- Collection, storage, and, if necessary, transport (for example septic tanks, pit latrines, pipe networks, etc);
- Treatment (for example filtration, aeration, digestion, etc.); and
- Reuse / disposal (for example nutrient extraction, effluent recycling, discharge to environment, etc).

Each of these components links to the overall wastewater management cycle and intervening in one is likely to have a direct impact on the others. The conventional approach to wastewater management promotes standard measures to cope with issues that arise in each individual component, for example the investment in treatment technology to remove increased concentrations of pollutants in wastewater flows. This approach is likely to be less sustainable than one that looks across the water cycle (and beyond) to identify solutions that solve the problem whilst providing the most favourable overall cost-benefit ratio for urban development as a whole, for example targeting pollutants at the source.

In practical terms, to make a complete shift from a conventional wastewater management approach to an entirely new one based on decentralised treatment and reuse is complicated. Most cities have wastewater infrastructure in place and it is not easy (or necessarily desirable) to convert a centralised mixed flow system to one in which the wastewater components are managed separately. Nevertheless plenty of opportunities exist in urban areas to start implementing more sustainable wastewater management practices without starting from scratch. These include, but are not limited to:

- **New developments**: The construction of new housing projects, business complexes and industrial estates provide the opportunity to cost-effectively install separated sewer systems and decentralised treatment and reuse facilities.

- **Sludge management**: The installation of facilities to enable the reuse of the sludge by-product from wastewater treatment plants – possibly in combination with other organic wastes – as a replacement for chemical fertilisers and as a source of biogas.

- **Incremental improvements**: The encouragement of small improvements on a city-wide scale such as the retrofitting of greywater recycling systems into housing estates and the construction of sustainable urban drainage systems to disconnect roof surfaces and roads from the sewer system.
• **Alternative solutions**: The exploration of alternative, multi-beneficial and flexible solutions to cope with increasing volumes of wastewater and stricter discharge regulations rather than investing in the expansion of existing infrastructure.

• **Market creation**: The stimulation of opportunities for small businesses and micro-enterprises to benefit from wastewater source separation, collection and re-use.

Taking advantage of a combination of practical entry points such as those listed above helps create a wastewater management system that is better integrated with urban management as a whole. It also furnishes it with greater flexibility to take advantage of opportunities and cope with future uncertainties.

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The book ‘Sustainable sanitation in cities: A framework for action’ published by the Sustainable Sanitation Alliance (SuSanA) provides a detailed outline of how more sustainable urban sanitation can be achieved in practice. This book can be downloaded free of charge from: http://www.eawag.ch/forschung/sandec/publikationen/sesp/dl/sustainable_san.pdf
6.2 Barriers to sustainable sanitation

The practical solutions associated with a more sustainable approach to wastewater management are often non-standard. Infrastructure, legislation, regulation and social attitudes related to sanitation are established in most cities based on a long-held conception of wastewater as a single waste product rather than a multi-faceted resource. Due to these factors and restrictions they cause, it may be difficult to implement non-standard and innovative solutions.

Such restrictions are varied and highly dependent on local circumstances. However a number of commonly encountered barriers, relevant in most cities that are looking to implement innovative wastewater management solutions, can be identified. Some of these are listed in Table 3.

Table 3: Examples of barriers to alternative urban wastewater management

<table>
<thead>
<tr>
<th>Barrier</th>
<th>Description</th>
<th>Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public acceptance</td>
<td>In many cultures the reuse of human waste, even when safely treated, is taboo.</td>
<td>No market for recycled products.</td>
</tr>
<tr>
<td>Legal restrictions</td>
<td>The assumption that the reuse of wastewater causes a risk to human health prevents the development of accommodating legislation and the necessary regulation.</td>
<td>Limitations on the use of wastewater as a resource preventing reuse.</td>
</tr>
<tr>
<td>Institutional aspects</td>
<td>Conflicting objectives and poor coordination between authorities whose responsibilities are relevant for wastewater management including its re-use.</td>
<td>Lack of integrated framework through which more sustainable options can be identified and implemented.</td>
</tr>
<tr>
<td>Political motivation</td>
<td>The benefits (and health risk reduction) of good wastewater management are not widely known so there is little political mileage to be gained from an improved service.</td>
<td>Lack of political support for more sustainable wastewater management options.</td>
</tr>
<tr>
<td>Technical norms</td>
<td>Local engineers and planners have preconceived ideas concerning wastewater solutions based solely on conventional infrastructure.</td>
<td>Alternative, more sustainable solutions are not considered during the planning stage.</td>
</tr>
<tr>
<td>Land rights</td>
<td>Unclear land rights in certain urban areas such as informal settlements restrict investments in sanitation facilities.</td>
<td>Inability to construct sustainable wastewater infrastructure in urban areas that may be in need of it most.</td>
</tr>
<tr>
<td>Perceived risk</td>
<td>New approaches and technologies are perceived as having a high risk of failure as they have yet to be widely tested on a large scale.</td>
<td>Decision makers, politicians and funders are unwilling to invest in non-conventional solutions.</td>
</tr>
</tbody>
</table>
Just as barriers to more sustainable wastewater management are location-specific, so too are the measures through which these can be overcome. However, there are some standard measures that are mostly applicable on a global scale. These include the following:

- **Stakeholder engagement**: A more sustainable, cyclical approach to wastewater management requires the buy-in of many more stakeholders than a conventional, linear approach. The needs and concerns of utility managers, health officers, urban planners, environmentalists, farmers and the local population as a whole must all be considered to overcome misunderstandings and highlight the benefits at stake.

- **Institutional coordination**: Wastewater management cuts across a wide range of local government mandates and responsibilities, especially when managed as a cycle. Increased coordination and the establishment of common objectives between wastewater management and other local government departments such as water supply, health, education, parks and town planning is needed to ensure that conflicts of interest do not arise and synergies are exploited.

- **Demonstration projects**: Practitioners, decision-makers and politicians may doubt the feasibility and effectiveness of non-conventional solutions for wastewater management. The construction of pilot projects to demonstrate the benefits and provide scientific evidence of safety helps to reassure those who believe the level of risk is too high.

- **Awareness raising**: One of the biggest barriers to more sustainable wastewater management is the public perception of wastewater as a waste product rather than a resource. Public education can change this mindset allowing solutions such as wastewater reuse and nutrient recovery to become more widely practiced and politically acceptable.

- **Creating incentives**: Recycling of wastewater and the nutrients and the energy it contains is a key aspect of increased sustainability. However, to do so there must be a market for the products generated. If the use of these resources is financially competitive with alternatives then a market will be created that sustains the economic sustainability of the wastewater management system.

- **Political support**: A large-scale shift from conventional wastewater management to a more sustainable approach requires a concrete commitment from the city council or political body with equivalent power. The top-down creation of policy and legislation that promotes and enables alternative approaches to wastewater management will encourage decision makers, developers, consultants and users to focus on and invest in non-conventional solutions.

See Module 2 for more information on stakeholder engagement, institutional coordination and political support.
Overcoming institutional barriers to wastewater reuse in Lima, Peru

The city of Lima in Peru is increasingly suffering from water scarcity due to its desert climate and rapid population growth. The reuse of treated wastewater, particularly for urban agriculture, is viewed as a viable option to reduce the pressure on the city's scarce water resources. However, existing national legal and institutional frameworks are concerned solely with the treatment and disposal of effluent resulting in an absence of regulation and guidance for safe reuse.

As part of the SWITCH project, Lima has drafted political guidelines to promote the treatment and reuse of wastewater for urban and peri-urban agriculture and green spaces. Based on research and consultation with a wide range of stakeholders, the guidelines seek to influence national policy to the extent that wastewater reuse is recognised and promoted as a resource. In November 2010 the guidelines were formally approved by the Peruvian Minister for Construction, Housing and Sanitation paving the way for more sustainable treatment and reuse of wastewater at the local level.

For further information see the Lima case study. In addition, the following website provides a comprehensive account of the SWITCH activities in Lima http://www.ipes.org/au/switch/index.html (in Spanish)
7 Options for sustainable wastewater management

As described in Section 3, a conventional, centralised wastewater management system is based on the overall aims of combining wastewater streams, transportation through a piped network, treatment at a centralised treatment works and disposal downstream. The options that are typically implemented are therefore selected to achieve these particular aims. Figure 9 gives some examples.

Figure 9: Examples of options for conventional urban wastewater management

A more sustainable approach on the other hand looks to create a closed loop wastewater cycle to keep the valuable resources within the local area and avoid the dilution of pollutants. Alternative treatment options enable this to happen.

Figure 10: Examples of options that complement a closed loop wastewater cycle

Examples of alternative wastewater management options in practice can be found in Part 1 of the SWITCH report ‘Cross-country assessment of the adoption, operational functioning and performance of urban ecosan systems inside and outside the EU’ (Mels et al 2009). www.switchtraining.eu/switch-resources
In some urban settings the design of a wastewater management system and the options selected will be most efficient when serving large numbers of people. This allows for economies of scale, integration with existing infrastructure and the production of large quantities of resources such as fertiliser and biogas. In others, decentralised options are preferable particularly where piped collection networks are not feasible or cost effective and where a local demand exists for resources such as urine, biosolids and greywater. Regardless of the scale, options should be selected that achieve the overall goal of retaining the resource locally.

**Pharmaceuticals and wastewater management**

As healthcare products continue to develop and life expectancy increases, the consumption of pharmaceuticals is on the rise, resulting in large quantities of micropollutants entering wastewater systems. The technologies used in most municipal wastewater treatment plants do not have the capacity to remove many of these compounds which vary in their physical and chemical characteristics. Consequently they remain present in treated effluent released to the environment and within the sludge by-product that may be applied to agricultural land. Such increases in the concentrations of pharmaceutical compounds can have a range of negative ecological impacts and pose a potential threat to human health, particularly through contaminated drinking water supplies.

Upgrading centralised wastewater treatment plants with advanced post-treatment processes such as oxidation techniques, tight membrane filtration and activated carbon sorption, can be effective in lowering the concentrations of pharmaceuticals in treated effluents (Kujawa-Roeleveld 2011). However this is expensive technology that is inefficient to operate due to the large wastewater volumes that need to be treated.

The separation of wastewater flows and use of decentralised treatment techniques can be a preferable option for managing micropollutants. Most pharmaceuticals enter the wastewater system through the urine and faeces of patients. By separating urine and blackwater from other wastewater flows, the dilution of micropollutants is prevented enabling them to be removed more efficiently through biological treatment processes combined with advanced physical-chemical techniques such as oxidation, sorption on activated carbon and tight filtrations (Kujawa-Roeleveld 2011).

For more information on the removal of pharmaceuticals from separated wastewater flows, see the conclusions from the SWITCH research on the subject in the paper ‘Pharmaceutical compounds in environment: Removal of pharmaceuticals from concentrated wastewater streams in source oriented sanitation’ (Kujawa-Roeleveld 2011).

www.switchtraining.eu/switch-resources
7.1 Examples of more sustainable wastewater management options

An enormous variety of options are available to assist with the implementation of more sustainable wastewater management. The few options that are briefly described in this section have been included with the aim of providing summary information on some of the more universally-applicable solutions and how these contribute to more sustainable water management and urban development.

Examples are given of options from the collection, treatment and disposal/reuse sectors of wastewater management. These are alternatives to conventional wastewater management solutions, although each of them has the potential to be integrated into existing infrastructure. The options discussed are as follows:

- **Collection:** Urine Diversion Toilets
- **Treatment:** Soil Aquifer Treatment
- **Treatment:** Constructed wetlands
- **Treatment:** Waste Stabilisation Ponds
- **Treatment:** Biogas production
- **Reuse:** Sludge reuse
- **Reuse:** Greywater reuse

In each case a short description of the option is provided followed by its positive contributions to urban water management and urban development as a whole. Graphs showing a simple ranking of these contributions can also be found. The aim of this ranking is to give a general indication of the extent of benefits that an option can deliver to a city. This is of course highly subjective and in reality the benefits (and costs) that an option delivers are entirely dependent on the local circumstance. An option that ticks all sustainability boxes in one city may do the complete opposite in another.

Local considerations are also listed for each option highlighting some of the common issues associated with implementation. Once again the type and extent of limitations are entirely dependent on local circumstances and the list is for general guidance only.

On the whole, the information in this section is intended as a basis for discussion rather than a detailed analysis of the local suitability of an option. In most cases a thorough investigation including stakeholder involvement and a comprehensive study of local conditions would be necessary to determine whether an option is both feasible and desirable. Specialist knowledge is also likely to be required for the design and construction of the relevant technology.

The Eawag ‘Compendium of sanitation systems and technologies’ provides detailed information and analysis of a wide range of different wastewater management options for developing countries. The compendium can be downloaded free of charge at:
http://www.eawag.ch/forschung/sandec/publikationen/compendium_e/index_EN
Urine diversion toilets

Urine is a pathogen-free substance rich in nutrients. In its pure form or mixed with water, urine can be applied safely as a fertiliser with no prior treatment and is therefore a cheap and highly effective replacement for its chemical equivalents. However, in most systems urine is mixed with faeces, flushwater and other wastewater streams during collection causing dilution and contamination with pathogens and other pollutants. The nitrogen and phosphorus contained in the urine can still be extracted and safely recycled but only after what can be a costly treatment process.

Urine diversion toilets make it possible to separate urine from faecal matter and flushwater at the user interface allowing for easy collection and reuse. The technology can be applied in both dry and flush toilets through the installation of a separate collection drain at the front of the toilet bowl. The urine is collected without water in the front while the faecal matter is removed, either with or without water, through the standard procedure at the back. Waterless urinals for men achieve the same purpose without the need to separate faeces.

Figure 11: Positive influences of urine diversion toilets on the urban water cycle and urban development. The number of segments filled indicates roughly the extent to which the sector is influenced by the option (Note: for the sake of simplicity the graphs consider only direct influences)

\[37\]

3 Storage of 2-6 months is recommended depending on temperature and risk of faecal contamination
Issues to consider

- The collection and recycling of urine may meet with public opposition resulting in reluctance to install and use the systems correctly. To achieve user acceptance and proper use of the facilities, participatory project design along with education and awareness raising campaigns are necessary.

- Along with the installation of a new toilet, a collection and storage system for the urine is necessary. Depending on scale, a dual plumbing system might be needed to collect and store the separated urine. To retrofit the systems on a large scale is a costly process and the technology is therefore best suited to new developments and the installation of toilets in areas where they did not previously exist.

- A market for the separated urine must be in place to ensure there is a product driver for the separation of flows. Urban gardens and allotments are ideal for local use. However, if it is the intention to collect large quantities of urine other options for reducing its volume and allowing transport might be required.
Decentralised Sanitation and Reuse (DeSAR)

As opposed to centralised treatment of combined wastewater streams from toilets, showers, sinks, washing machines and rooftops, a Decentralised Sanitation and Reuse (DeSAR) system is based on the separate collection of blackwater, greywater, stormwater and kitchen waste at the household level. The decentralised system allows the waste to be treated on-site and maximises the possibilities of reusing the resources contained within it locally.

The DeSAR system makes use of low flush vacuum toilets to maintain a concentrated flow of faecal matter and urine. Together with separated organic kitchen waste the excreta is digested to produce biogas which is recycled as an energy source within the household. The digested material that remains from the biogas generation process is pathogen-free, rich in nutrients and can be used as agricultural fertiliser. Greywater and stormwater are also collected separately in order to apply appropriate decentralised treatment on-site. A number of different systems are available to treat greywater (see, for example, constructed wetlands below) whereas stormwater is typically retained and infiltrated into the soil using stormwater Best Management Practices (see Module 4 for details). Both treated greywater and stormwater can be reused for non-potable purposes such as garden watering and cleaning.

A range of DESAR options are available for most urban environments and although the initial cost of implementing the full system can be substantial the investment is likely to be recovered in the long run through reduced energy costs and water bills.

For further information see: [http://www.ete.wur.nl/UK/Projects/DESAR/](http://www.ete.wur.nl/UK/Projects/DESAR/)
Soil Aquifer Treatment (SAT)

Treated wastewater effluent is potentially a valuable resource for the augmentation of urban water supply. This is particularly the case in water scarce cities where increasing water demand is causing overexploitation of available supplies. However, in many cases treated effluent is discharged downstream of a city as well as directly to estuaries or coastal waters where its value is lost.

Soil Aquifer Treatment (SAT) is a low cost technology for the advanced treatment, storage and reuse of mixed wastewater flows. Secondary treated effluent is infiltrated through a soil percolation zone into an aquifer where it mixes with existing groundwater. Contaminants (chemicals and microbes) are removed through physical, chemical and biological processes that occur in the soil matrix and aquifer itself. The water is then extracted for reuse through boreholes outside of the aquifer treatment zone.

SAT technology serves the purpose of providing natural treatment of wastewater as well as replenishing groundwater sources for future water supply abstractions creating a semi-closed urban water cycle. Depending on wastewater quality, land availability and intended water supply usage, SAT can be complemented by various pre- and post-treatment technologies such as biological reactors and nanofiltration.

**Figure 12**: Positive influences of SAT on the urban water cycle and urban development

(Note: for the sake of simplicity the graphs consider only direct influences)
Issues to consider

- The performance of SAT is closely related to local conditions. The quality of the influent wastewater, soil types and purpose of reuse will all determine the feasibility of the technology and the level of pre- and post-treatment required. Detailed site investigations and pilot studies are therefore required.

- Typical SAT systems require a large surface area to infiltrate the wastewater into the aquifer. In many cities the required land is costly and often unavailable due to high population densities. Alternative SAT technologies that require much less space are however being investigated such as the Short SAT – Nanofiltration system in which less retention time and consequently space is required.

- The suitability of SAT is dependent on the characteristics of the local groundwater. The use of aquifers of good quality can cause the deterioration of the groundwater and environmental damage elsewhere in connected aquatic systems. SAT may also increase the risk of flooding in areas where groundwater levels are high.

For information about the use of SAT in Tel Aviv, Israel, see the Tel Aviv case study www.switchtraining.eu
**Constructed wetlands**

Natural wetlands contain a wide range of treatment mechanisms that can remove contaminants such as organic matter, suspended solids, nitrogen, phosphorus, trace metals and pathogens. Wetlands based on different water flow characteristics and plant species can be constructed in cities to treat wastewater from a variety of sources. They are cheap to build and maintain, and the treated effluent can be reused for non-potable purposes such as irrigation and toilet flushing.

Constructed wetlands consist of a range of designs that vary according to the way the flow is directed (i.e. horizontal or vertical) and the water level within the system (i.e. inundation vs. percolation systems). The appropriateness of the system depends on the type of pollutants to be removed, the volume of water to be treated, the possibility of inconvenience to nearby residents (for example through odour and mosquitoes) and the amount of space available. Wetlands are effective at capturing most pollutants contained in greywater and stormwater runoff as well as at removing pathogens, nutrients and micro-pollutants from septic tank outflows and conventional wastewater treatment discharges. The systems can therefore be used as a decentralised solution to treat separated wastewater flows as well as an addition to existing centralised wastewater infrastructure to improve the quality of effluent discharges.

Although wetlands require regular maintenance, this can be done using locally available skills and through basic training. The simple technology involved and the effectiveness at removing pollutants from wastewater of widely varying quality mean that wetlands are a feasible solution in both the developed and developing world.

**Figure 13:** Positive influences of constructed wetlands on the urban water cycle and urban development

(Note: for the sake of simplicity the graphs consider only direct influences)
Issues to consider

- In climates prone to mosquito transmitted diseases, the construction of wetlands may pose a risk to health. In such settings, wetlands should be designed with subsurface flows resulting in no standing surface water to provide breeding grounds for insects.

- The initial cost of designing and constructing a wetland can be high. However, this is often a sound investment as operation costs are low.

- Wetlands require a large land area which is not always available in densely populated urban areas. Different designs, such as vertical flow wetlands and combinations with other treatment techniques, do exist however and greatly reduce the amount of space required.

- The maintenance requirements of constructed wetlands are quite high, particularly to prevent clogging of the filter media. Although the skills needed to maintain wetlands are likely to be available locally, an efficient regime should be established and adhered to.
Waste Stabilisation Ponds (WSP)

Waste Stabilisation Ponds (WSP) are shallow, man-made basins that make use of algae and bacteria to treat domestic and industrial wastewater. The ponds are often built as a series of anaerobic, facultative and aerobic maturation ponds which provide different stages of treatment to remove organic matter and pathogens. WSPs are reliable and easy to operate, and the treated effluent can be reused in the water cycle for non-potable purposes and resource recharge.

Although expert design is necessary, WSPs can be constructed and operated cheaply using local materials and skills. If a number of aerobic ponds have been constructed at the end of the series, the last of these can also be used for fish farming. Not only does this generate local income but the fish also provide additional treatment by feeding on the remaining nutrients within the effluent. Similar benefits can be achieved through the use of the ponds for the cultivation of floating plants. The sludge that is collected at the bottom of the ponds has to be removed and safely disposed of although this is not required on a regular basis (typically every 10 to 20 years).

Figure 14: Positive influences of WSPs on the urban water cycle and urban development
(Note: for the sake of simplicity the graphs consider only direct influences)
Issues to consider

• As with many natural treatment systems, WSPs require a large land area which is often a restriction in dense, urban areas. The value of this land can therefore add considerably to the capital cost of constructing the ponds.

• Maintenance requirements are basic but must be done on a regular basis to ensure that the ponds remain free of debris and are secured from people and animals. Vegetation must also be removed from the ponds to ensure that they do not become breeding grounds for mosquitoes.

• WSPs are suitable for most locations but the performance of the systems will vary depending on the climate (pathogen removal is most effective in warm climates). Specialist design is therefore required to ensure maximum performance.

For more information on the design and use of waste stabilisation ponds see the paper ‘SWITCH Literature review on the use of natural systems for wastewater treatment’ (UNESCO-IHE 2008). www.switchtraining.eu/switch-resources
**Biogas production**

Wastewater sludge is a potential source of energy which can be digested to create biogas for cooking, electricity, heat and transport fuel. The generation of biogas can be done on a large scale using the sludge by-product derived from primary and secondary wastewater treatment processes or on a neighbourhood or household scale through the digestion of untreated human and kitchen waste derived directly from the buildings (see also DeSAR box example above).

The process involves the biological degradation of wastewater sludge within an anaerobic reactor. As well as generating energy, the reactor also removes some pathogens from the sludge, enabling it to be used as a soil conditioner. The biogas reactor itself can be a simple digestion chamber constructed from bricks, concrete or pre-fabricated material, or a more sophisticated construction using mixing devices and pre-treatment to create a more efficient process.

**Figure 15: Positive influences of biogas production on the urban water cycle and urban development (Note: for the sake of simplicity the graphs consider only direct influences)**

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4 Pathogens are removed to a limited extent only. Depending on the purpose of reuse post-treatment may still be needed to remove hygiene-related risk.
Issues to consider

- Depending on the size of the biogas reactor and the use of the gas generated, the capital costs to construct the reactor itself and accompanying infrastructure can be high. However, the long life span of the infrastructure and the value of the energy generated means that the payback period tends to be short.

- The natural digestion process is most effective in hot climates as higher temperatures speed up the process. In colder climates the systems may need to be heated.

- Unless the reactors are heated to over 50°C pathogens may still be present in the digested sludge. Additional treatment may therefore be required prior to reuse or disposal.

- Maintenance (i.e. removal of settled solids, scum layer) and correct operation (i.e. avoiding overloads and abrupt changes in pH which will damage the bacterial consortia) need to be guaranteed to achieve the optimum efficiency.
Sludge reuse

Most wastewater treatment processes generate a sludge by-product that needs to be either disposed of or reused. The quantity and quality of the sludge varies depending on the treatment process used and the variety of pollutants in the wastewater that was treated. Typically, much of this sludge ends up in landfill or is incinerated despite the fact that if treated to sufficient standards it can be used as biosolids for a range of productive purposes.

Biosolids are made up of the organic matter separated during the wastewater treatment process. The potential to reuse biosolids is largely dependent on the quality of the product and public acceptability. Biosolids are widely used in agriculture due to the nutrients they contain and as a soil conditioner because the organic matter they are made up of helps soils to retain moisture and nutrients. They are also valued for the same reasons for forestry use and the landscaping of parks, gardens, golf courses, etc.

The main concern surrounding the use of biosolids centres on those derived from the treatment of wastewater mixed with industrial and stormwater flows. In such cases there is a risk that traces of heavy metals and chemicals that the wastewater treatment process is unable to remove will be transferred to the food products grown. These health concerns together with potential public opposition to the use of a human waste product for agricultural purposes has resulted in some countries banning the practice altogether. The extent of this threat is dependent on the quality of the wastewater prior to treatment. The risk is therefore considerably reduced if stormwater and industrial waste have not been mixed with human waste during the treatment process. Where this is the case, or their impact is minimal, the use of biosolids for agriculture is on the whole considered a sustainable use of sludge.

In areas where there is less demand for the use of biosolids for land application, alternatives include the incineration of sludge for energy recovery and the conversion to alcohol and other fuels. These options provide a useful source of renewable energy for a city although fail to recycle the nutrients contained within the sludge.
Figure 16: Positive influences of the use of biosolids on the urban water cycle and urban development (Note: for the sake of simplicity the graphs consider only direct influences)

Within the water cycle
- Biosolids can be applied to forests that are lacking in nutrients to enhance tree growth.
- Cost savings can be made through the value of biosolids as well as the savings made through no longer having to dispose of unwanted sludge.
- Biosolids improve the moisture retention of soils making them less vulnerable to erosion and attenuates rainfall.
- Biosolids enable the nutrients contained in the treated sludge to be recycled as fertilizer.
- The treatment of sludge to enable safe reuse removes remaining pollutants that might otherwise be dispersed to the environment.

Within urban development in general
- Due to their nutrient content and soil improvement potential, biosolids can be used for turf growing and landscaping for parks and gardens.
- Safe removal of pathogens from sludge by-product.
- Biosolids produced for public use are a valuable product for home gardening.
- When not recycled as biosolids, sludge can be incinerated for energy recovery or converted into biofuels.
- Biosolids are of value for agricultural use as fertilizer and soil conditioner.

Issues to consider

- Biosolids need to be free of harmful substances prior to reuse. Inadequately treated sludge and sludge derived from wastewater containing high levels of heavy metals poses a potential health risk to users and consumers of the related products.

- Health concerns associated with the use of biosolids have resulted in legislation that bans their use on agricultural land in some countries. In such cases treated biosolids can instead be reused for purposes not involving the production of food for human consumption, such as municipal landscaping projects.

- The use of biosolids for agricultural purposes should take into account the quantity of nutrients that these contain. This allows them to be applied at an efficient rate without causing nutrient pollution.
Greywater reuse

Greywater consists of wastewater from bathing, kitchens, clothes washing, cleaning and other domestic water uses other than that of toilets. In households with flush toilets, greywater can account for over two thirds of the wastewater generated. Common pollutants in greywater include detergents, chemicals, food particles and cooking oils. It usually contains few pathogens and also has a low nutrient content.

Despite the relatively low level of harmful pollutants contained in greywater, in many cities it is nevertheless mixed and treated together with diluted excreta. This greatly increases the volume of wastewater to be treated and also fails to take advantage of opportunities to reuse greywater for non-potable uses such as irrigation, toilet flushing and industrial purposes.

A number of technologies exist for the separate collection, treatment and reuse of greywater. These can be complex, such as the installation of a system that collects, treats and pumps greywater for reuse within the household, to more simple diversion devices in which greywater is treated through natural systems such as constructed wetlands. Systems range from large scale infrastructures that manage greywater from entire housing estates or businesses, to individual household installations that collect and reuse greywater at the source.

Figure 17: Positive influences of the reuse of greywater on the urban water cycle and urban development (Note: for the sake of simplicity the graphs consider only direct influences)
Issues to consider

- Although containing few high risk pollutants, greywater is still unsafe for human consumption. Extra care must be taken to ensure that cross-connections between potable water and greywater plumbing are avoided. Taps that dispense greywater must also be clearly marked as non-potable water.

- Depending on the source and user behaviour, greywater may contain traces of pathogens. Although the impact on human health is likely to be minimal, appropriate treatment of greywater may be necessary prior to reuse in locations where the risk of contamination with faecal coliforms exists.

- Untreated greywater should not be stored for more than 24 hours due to the existence of nutrients and, potentially, pathogens within it.

- The cost of greywater collection and reuse systems are dependent on the system chosen and the purpose of reuse. However, even sophisticated systems with high capital costs can have a short payback period when the reduced potable water consumption and wastewater treatment charges are considered.

7.2 Selection of options

In wastewater management and the urban water cycle as a whole, the selection of options should be based on the agreed objectives, indicators and targets, along with the need to consider all aspects of sustainability as described in Section 5. Potential options must therefore be identified that achieve specific goals without compromising the sustainable development of the city as a whole.

Although an identified technological solution may theoretically help to achieve the targets associated with an objective, this does not necessarily mean that the solution itself is a sustainable one in the context under consideration – cost, social implications, unwanted side effects and a range of other aspects also need to be assessed.

The construction of latrines to serve the inhabitants of an informal settlement is based primarily on social needs. But if the chosen design lacks consideration for economic and environmental criteria, unexpected consequences such as high maintenance costs and contamination of the local water supply may well offset, and ultimately negate, the social benefits initially gained.

In reality, an option will never be entirely sustainable and trade-offs between benefits and costs are always necessary. For example, the social and environmental benefits gained by installing an activated sludge plant where previously wastewater was discharged untreated are likely to outweigh the negative impact of increased carbon emissions caused by the operation of the plant. Such concessions are inevitable but what is important is that all sustainability criteria are considered during the selection process to ensure that trade-offs can be made with the confidence that the chosen option will, on balance, nevertheless move the city towards increased sustainability.

Assessing the social, economic and environmental implications over space and time of a potential option is not easy; particularly when its relationship with planned and existing infrastructure elsewhere also needs to be understood. Integrated modelling software and decision support tools can be used to assist in the management and understanding of this vast amount of information. Using generic and locally specific sustainability criteria, these tools can manage data in a way that enables a range of different implications, scenarios and combinations of options to be assessed.

Sanitation targets

In the developing world, the improvement of urban wastewater management is often associated with sanitation coverage. Objectives and targets tend to reflect this by focusing on the installation of sanitation facilities in communities where previously these did not exist. However, increased coverage does not necessarily equal more sustainable wastewater management and there are many cases where coverage targets have been met with unhygienic and badly maintained facilities that increase the threat of disease within the community and pollute the local environment.

The Millennium Development Goal (MDG) target to halve the proportion of the population without sustainable access to basic sanitation by 2015 is to some extent an example of this. The target is heavily focused on coverage and does not mention the closely related issues of hygiene education, social acceptability and safe management of the resulting waste – essential aspects of sustainable sanitation. The target could therefore arguably be met through actions that fail to address unhygienic behavior, safely remove excreta and protect the local environment.

For more information see:
http://tilz.tearfund.org/Publications/Footsteps+71-80/Footsteps+73/Sanitation+and+the+Millennium+Development+Goals.htm

For further information on the evaluation and selection of urban wastewater management options see the SWITCH paper ‘Best practice and a decision-support system for ecosan systems’ (Agudelo et al 2010).

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See Module 6 for details of the decision-support tools that are available to assist with the selection of urban wastewater management options.
Wrapping up

Wastewater is made up of different streams including urine, faeces, flushwater, greywater and stormwater. These streams are potential sources of nutrients, energy and water supply and can be recycled for productive use.

Conventional wastewater management, although capable of protecting human health and the environment, fails to exploit many of these resources due to its centralised technology and disposal-oriented approach.

In addition the conventional approach is non-flexible and struggles to cope when confronted with unexpected change such as rapid urbanisation and climate variability.

An integrated approach to wastewater management on the other hand recognises the links between wastewater, the urban water cycle and city development as a whole.

Such a perspective reveals the benefits of recycling the different wastewater streams thereby encouraging a cyclical wastewater management process rather than a linear one based on disposal.

To achieve this, alternative options are required. These are typically flexible, decentralised solutions many of which make use of natural systems such as ponds, wetlands and soils.

By selecting wastewater management objectives based on the needs of the urban water cycle and city development as a whole, options are identified that provide multi-purpose benefits and are less likely to result in unexpected impacts.
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Notes
The SWITCH project aimed to achieve more sustainable urban water management in the “City of the Future”. A consortium of 33 partner organisations from 15 countries worked on innovative scientific, technological and socio-economic solutions with the aim of encouraging widespread uptake around the world.