GUIDELINES FOR LAND-FILTER AND CATCHMENT-FILTER TECHNIQUES TO REUSE WASTEWATER IN CHINA

Nihal Jayawardane, John Blackwell, Evan Christen, Shahbaz Khan, Freeman Cook, Gao Zhanyi, Cheng Xianjun, Meng Guoxia and Zhang Jinkai

Australian Government
Australian Centre for International Agricultural Research

CSIRO Land and Water Report 79/07

Report to ACIAR June 2007

www.csiro.au

Copyright and Disclaimer

© 2006 CSIRO To the extent permitted by law, all rights are reserved and no part of this publication covered by copyright may be reproduced or copied in any form or by any means except with the written permission of CSIRO Land and Water.

Important Disclaimer:

CSIRO advises that the information contained in this publication comprises general statements based on scientific research. The reader is advised and needs to be aware that such information may be incomplete or unable to be used in any specific situation. No reliance or actions must therefore be made on that information without seeking prior expert professional, scientific and technical advice. To the extent permitted by law, CSIRO (including its employees and consultants) excludes all liability to any person for any consequences, including but not limited to all losses, damages, costs, expenses and any other compensation, arising directly or indirectly from using this publication (in part or in whole) and any information or material contained in it.

ISSN: 1883-4563

Report Title: Guidelines for Land-FILTER and Catchment-FILTER technique to reuse wastewater in China

Authors: Nihal Jayawardane[a], John Blackwell[a], Evan Christen[a], Shahbaz Khan[a], Freeman Cook[a], Gao Zhanyi [b], Cheng Xianjun [b], Meng Guoxia [c] and Zhang Jinkai [c]

Affiliations:

[a] CSIRO, Land and Water, GPO Box 1666, Canberra laboratories, ACT 2601, Australia

[b] China Institute of Water Resources and Hydropower Research, Department of Irrigation and Drainage, 20 West Chegongzhuang Road, Beijing 100044, China

[c] Shanxi Institute of Water Resources and Hydropower Research, Department of Water Resource, No.113 Xinjian Road , Taiyuan, Shanxi Province, China 030002

CSIRO Land and Water Report 79/07

Report to ACIAR June 2007

Acknowledgements

This publication was prepared by research scientists from CSIRO Land and Water, Australia, the Institute of Water Resources and Hydropower Research (IWHR) in Beijing, and Shanxi Institute of Water Resources and Hydropower Research (SIWHR), with partial funding for this work being supplied by the Australian Centre for International Agricultural Research (ACIAR).

FOREWORD

Communities and governments in many countries are concerned about preventing the pollution of natural water bodies such as streams, rivers, lakes and seas by release of untreated or inadequately treated wastewaters. Such pollution of natural water bodies can reduce the potential downstream reuse of the water and poses risks to agriculture, fisheries and public health.

Furthermore, in many countries urban expansion and industrialisation has led to more water being diverted for domestic and industrial uses, thereby decreasing the future water supplies for agriculture and other uses. In China, irrigated lands produce two thirds of the total crop production. However, irrigation water supplies are rapidly diminishing by diversion to meet the needs of increased urbanisation and industrialisation. This in turn causes production of more wastewater, which has led to increased environmental pollution. Therefore, wastewater treatment and reuse options need to be developed to offset these increasing demands on scarce fresh water supplies and to address the increasing water pollution problems. Predictions of future climatic changes due to global warming which could lead to increased water demands and associated supply scarcities emphasise the need to consider appropriate wastewater treatment and reuse strategies, including new cost-effective techniques.

The specific combination of wastewater treatment, reuse and release techniques suited for adoption in a rural, urbanised or industrialised area of any river catchment will vary according to local factors in different regions of China. These factors which need to be considered holistically include the local demand for renovated water, the need to maintain adequate downstream environmental flows in rivers and streams, suitability and availability of land for irrigated cropping with wastewater and factors which influence the suitability and the cost effectiveness of other potential reuses for wastewater.

Chemical and engineering wastewater treatment plants are commonly used in Europe, North America and Australia, and in some Chinese cities. The capital and operating cost of these plants makes them unattractive options for developing countries and rural areas of developed countries, and therefore cheaper land based treatment and reuse techniques adapted to local conditions are more attractive. The development of alternative land based treatment and reuse techniques needs to address any deficiencies and disadvantages of the existing techniques under different local site conditions, to encourage adoption of these alternative techniques.

Current water pollution problems and wastewater reuse in China

Surveys in China indicate severe pollution in many rivers, lakes, bays, groundwater and coastal areas. For instance, the proportions of sewage and industrial effluent treated before discharge in 1985 were less than 3 % and 22 %, respectively. Some lakes, bays and rivers close to cities receive large quantities of untreated wastewater, thereby diminishing their potential function of providing drinking water supplies, recreation, tourism and commercial use for fisheries. In a survey of 878 rivers in the early 1980s, it was found that 82 % were polluted to some degree and more than 5 % of total river length had become devoid of fish. These surveys indicate that more than 85 % of the pollution load in China comes from nine thousand point-source polluters. Major pollutants include organic matter, nutrients, heavy metals and other toxic chemicals. The presence of excess nutrients in wastewater discharge can cause algal blooms in water bodies. Algal blooms make the water unsuitable for consumption by humans and farm animals and for other uses, as occurred recently in Lake Dianchi in Yunnan province.

With increasing public awareness of the importance of environmental pollution control and the potential economic impacts of pollution, Chinese authorities have started introducing legislation requiring polluters to treat or reuse their wastewater.

Reuse of wastewater for irrigation can conserve scarce freshwater supplies, especially during dry periods. In northern China wastewater represents 20% of the total water supply during dry periods. Projections to the future indicate that this could increase in some river basins to more than 50%, due to increasing diversions of fresh water for urban and industrial use.

The economic benefits of re-using wastewater for irrigation have been demonstrated in many effluent irrigation projects around the world. When soil conditions are suitable, reuse of wastewater for irrigated cropping or forestry systems can be successfully practiced. However, where soil conditions are unsuitable or where inappropriate land application and reuse techniques are used, pollutants in wastewater can contaminate agricultural products, and degrade the irrigated lands and its surrounding as well as the downstream environments.

For example, on soils with restricted drainage and high watertables, effluent irrigation can lead to waterlogging. In addition, it can also lead to salinisation and sodification, where the leaching fraction adopted for removing the excess salts in the wastewater is inadequate to prevent salt accumulation in the soil. This reduces crop yields and nutrient removal, and hence the long-term sustainability of such sites, for wastewater irrigation. Furthermore, in effluent irrigation schemes where the wastewater needs to be stored on expensive urban and semi-urban lands during wet weather and low cropping periods, the cost of wastewater treatment increases markedly, thereby reducing its economic viability.

The Land-FILTER technique

To overcome the problems of waterlogging and salinisation in inadequately draining lands used for wastewater irrigation at some existing land application sites in semi-urban areas of Australia and where wet weather storage is expensive, the Land-FILTER (Filtration and Irrigated cropping for Land Treatment and Effluent Reuse) technique was developed for treatment and reuse of sewage effluent (Jayawardane 1995).

The Land-FILTER technique combines using nutrient rich effluent for intensive annual cropping, with filtration of excess applied water through the soil to a sub-surface drainage system during periods of low cropping activity and high rainfall. Trials on a poorly drained, heavy clay soil showed that the FILTER technique met the objectives of reducing pollutant levels in drainage water below EPA (Environmental Protection Authority) or other wastewater regulatory agency limits for discharge or local reuse, while maintaining adequate flow rates through the FILTER plots, crop yields and nutrient removal, thus providing a sustainable and cost-effective system. Field studies have also shown that the FILTER system can be used to ameliorate degraded waterlogged, saline and sodic soils, thereby increasing the long-term cropping potential of such soils of low agricultural value to provide a multiple agricultural benefit.

The urgent need to develop and evaluate novel economically and socially acceptable methods for wastewater reuse and treatment to increase agricultural crop production and minimise pollution of water bodies in China, was recognized by the China Institute of Water Resources and Hydropower Research (IWHR), Tianjin Water Conservancy Scientific Research Institute (TWCSRI) and CSIRO (Australia). They then collaborated on an ACIAR (Australian Centre for International Agricultural Research) research project on the Land-FILTER system for treatment and reuse of wastewaters, at a field research site in Wuqing County near Tianjin, China.

The results from this trial showed wastewater pollutant reduction rates comparable to those observed in Australian field trials, while maintaining adequate flow rates to the subsurface drains and high crop production. With good management of the FILTER system, the pollutant concentrations in subsurface drainage waters can meet EPA and local wastewater regulatory agency requirements for discharge to surface water bodies and for other reuses without pollution risks.

The Land-FILTER systems have the following potential advantages for use in China. The Land-FILTER system can be sustainably used on saline, sodic, waterlogged and other degraded low-cost lands, leading to amelioration of such land for future cropping. It can be used to treat saline wastewaters. It supports a high hydraulic loading rate and also eliminates wet weather and winter storage requirements, thus reducing the extent of expensive urban land area required. Due to the scarcity and high price of urban lands close to cities, effluent storage for wastewater irrigation schemes will be very expensive, even if suitable storage sites with non-leaking soils are available. The “cleaned” drainage waters from the FILTER system can be potentially reused for agricultural, industrial and other urban uses, thereby reducing the demand on fresh water supply requirements of urban areas in holistic planning of the water and wastewater resources to address current and future water scarcities.

The FILTER system could also be used to address site-specific wastewater problems. For example, producers of industrial wastewaters contaminated with heavy metals, organic chemicals or pathogens could be encouraged to install on-site FILTER systems for cultivation of non-edible crops and the cleaned wastewater from the subsurface drains reused for irrigation of edible cropping or be released for other local and downstream reuses. However, FILTER sites used for treatment of wastewaters containing heavy metals need to be very carefully monitored and managed to prevent potential long-term adverse effects on the local environment due to heavy metal accumulation and to meet the guidelines of local wastewater regulatory agencies. Thus, FILTER provides an additional option for Chinese wastewater managers that can be considered in planning of innovative optimised combinations of treatment systems, developed according to specific local situations.

The Catchment-FILTER technique

Catchment-FILTER is an adaptation of the FILTER technology for application in a three-dimensional landscape context. It can be used on sites with unrestricted soil drainage characteristics. The Catchment-FILTER combines high hydraulic loading of nutrient rich effluent for intensive annual cropping, with filtration through the soil to a carefully managed ground water system. The pollution removal rates in the Catchment-FILTER field trial site in Shanxi Province, China were similar to previously observed pollutant removal rates in Land-FILTER sites with high watertables in Australia and China. However, due to better soil aeration conditions at this Catchment-FILTER site with deep watertables, the concentration of NO3-N levels in drainage water was higher than at Land-FILTER sites, which needs to be carefully monitored to control the potential risk of groundwater pollution of the surrounding area. The groundwater management of Catchment-FILTER systems thus needs to be based on good understandings of the local hydrological conditions and groundwater flows. This will enable correct siting of FILTER plots, installation of any required vertical drainage systems and adoption of controlled irrigation, drainage and management procedures, with close monitoring of pollution risks to the surrounding catchment area. These considerations are especially important where the groundwater systems in the vicinity of the Catchment-FILTER sites, are potentially usable as potable water supplies.

The use of FILTER techniques in integrated wastewater management and reuse

The Land-FILTER and Catchment-FILTER systems in combination with other wastewater treatment and reuse schemes could be used to address the pollution concerns, in both new city planning and in solving problems of existing cities in China. The optimum combination of FILTER and other wastewater treatment practices will vary widely according to specific site conditions. In such integrated planning, both the concerns of the environmental authorities to reduce pollution of water bodies and the interest of wastewater managers to reuse the wastewater to yield economic benefits through agricultural cropping, need to be considered.

Where possible an integrated approach for combining water supply management and wastewater reuse should be adopted. This combined approach could reduce the demand on fresh water supplies in China by re-using adequately treated wastewater.

In a review of the collaborative ACIAR research project, there was found a need for preparing documented guidelines for the FILTER technique, to facilitate the adoption of this technique in China, in optimized combinations with other treatment systems.

This publication was prepared to meet that need.

ABOUT THIS REPORT

This publication provides guidelines for broad evaluation of FILTER systems for treatment and reuse of wastewater for agricultural cropping in China, and its potential for use in optimum combination with other wastewater treatment techniques by wastewater planners and managers.

The structure of this publication is based on that used in the "*New Zealand guidelines for utilization of sewage effluent on land*", which provides a very practical step-by-step presentation for wastewater planners and managers, in dealing with a complex problem and decision-making process (Robb and Barkle 2000). We have closely followed their presentation approach and style with modification for application to the FILTER techniques and its adaptation to use in different regions of China, in combination with other wastewater treatment and reuse techniques.

In this publication, we provide information on combining or choosing between FILTER techniques and other wastewater treatment options based on their advantages and disadvantages, depending on factors such as the agro-climatic zone, soil type, wastewater characteristics, hydrological features and other local conditions. It also provides information on the generalized design and operation of the FILTER systems. References are also provided on more detailed technical information on the common aspects of all land treatment systems utilising agricultural cropping, such as crop selection and their agronomic management, that need to be used by planners and managers of wastewater in the more detailed design, installation, operation and monitoring of the FILTER systems at specific sites.

The FILTER guidelines presented in this publication are broadly based on existing technical knowledge regarding the principles and practice of land application of wastewater, with adaptation of these procedures to the FILTER techniques. It also uses the data and on-field practical experiences acquired in running the trials of FILTER techniques in Australia and China. These guidelines are aimed at several potential user groups, as discussed below

Provincial and city council administrators and planners

The publication provides information on the advantages and disadvantages of different systems of land treatment of wastewater in comparison to the Land-FILTER and Catchment-FILTER technologies, considering factors such as the type and quantities of wastewater production, sensitivity of receiving waters and the availability of suitable land for the different technologies. It will also provide information on the general design and operation of the FILTER systems and on monitoring requirements to assess impacts on the environment. This information could help planners in developing a holistic approach to combining different wastewater treatment and reuse systems, in optimised management of water and wastewater resources of a specific area.

FILTER system operators

The publication provides information on the design, instalment, operation and monitoring needs of FILTER systems to meet the targeted objectives of individual sites. It also provides background information and relevant references on the management options that could maximize its efficiency of operation and minimise the impacts on the environment.

Researchers and Students

The information in this publication will be useful to researchers and students, and references to more detailed information are also provided.

Table of Contents

1. USING THE GUIDELINES

1.1. Stages and steps

The procedure to be adopted by planners and managers of wastewater in using the FILTER guidelines, which is based on an adaptation of the New Zealand (NZ) guidelines for wastewater reuse on land (NZLTC 2000, Robb and Barkle 2000) to the FILTER technology, is as follows. There are sixteen generalized sequential and iterative steps to be followed in evaluating the suitability, design, construction, operation and monitoring of a FILTER system in combination with other technologies, **Figure 1**. At each step, wastewater planners and managers may need to draw on additional technical details, which are provided in the list of publications in the reference list.

The steps described in this publication can be grouped under five sequential stages. These stages are:

- **A.** Establish decision making framework,
- **B.** Feasibility assessment,
- **C.** Site identification and evaluation,
- **D.** FILTER system design and environmental effects assessment and
- **E.** Design finalisation, installation and operation.

This publication provides separate sections for each step shown in **Figure 1**. Each section provides an account of the factors that need to be considered, the information required and the types of decisions that need to be made. The list of references provides specific detailed technical information required at different steps.

It should be emphasized that the best option or combination of treatment options for wastewater treatment varies widely according to the local physical and socio-economic factors at any location. Hence, the design of a system for land treatment of wastewater is an iterative and interactive process involving input of technical, physical, chemical, biological, economic and social information and expertise. Very few of the decisions in the design stage are independent of the other decisions. It is therefore often necessary to make some initial approximate assumptions and to iteratively revise and refine these assumptions until the final design is obtained.

Figure 1. Stages and steps in the FILTER guidelines

STAGE A *- Establish a decision making framework*

Step 1. Establish a decision making committee and consultative framework

STAGE B - ***Feasibility assessment***

Step 2. Examine the relative merits of different wastewater treatment systems

Step 3 Understanding the FILTER system and its potential applications

Step 4. Examine general suitability of the FILTER system in specific climatic zones, soil types and other local conditions

Step 5. Prepare inventory of wastewater problems and reclamation requirements

Step 6. Preliminary estimate of land area requirement for a FILTER system

STAGE C - ***Site identification and evaluation for FILTER systems***

Step 7. Identify potential land sites

Step 8. Screen potential sites and conduct preliminary field investigations

STAGE D – ***FILTER system design and environmental effects assessment***

Step 9. Design considerations for a FILTER system

Step 10. Develop FILTER system operation procedures and monitoring requirements

Step 11. Analyse potential environmental effects

Step 12. Conduct further field investigations

Step 13. Prepare cost and return estimates

STAGE E – ***Design finalisation, installation and operation***

Step 14. Finalise design and obtain resources

Step 15. Install the FILTER system

Step 16. Operate and monitor the FILTER system

When dealing with applications on a smaller scale, such as small wastewater sites in rural areas, it may not be necessary to go through all the steps that were developed for the broad-scale applications shown in **Figure 1**. For instance where a decision has been made to use a FILTER system to treat wastewater from a small sewage works in an adjoining land area, we can skip through the initial steps to step 9. The process can also be simplified at some sites according to the scale and importance of critical physical and social factors operating at each location, such as the degree of sensitivity to environmental impacts.

Table 1 shows the milestones that need to be reached at the end of each step. An important output in the application of the guidelines at any potential FILTER site, is the preparation of a site-specific FILTER Farm Operational Plan. Jayawardane et al. (2002b) presents a farm operational plan prepared for the Griffith Land-FILTER site, which thus illustrates the adaptation of the guidelines to meet the requirements of the local conditions at a specific site.

Table 1. Milestones to be met at the end of each step (steps 9-12 are iterative)

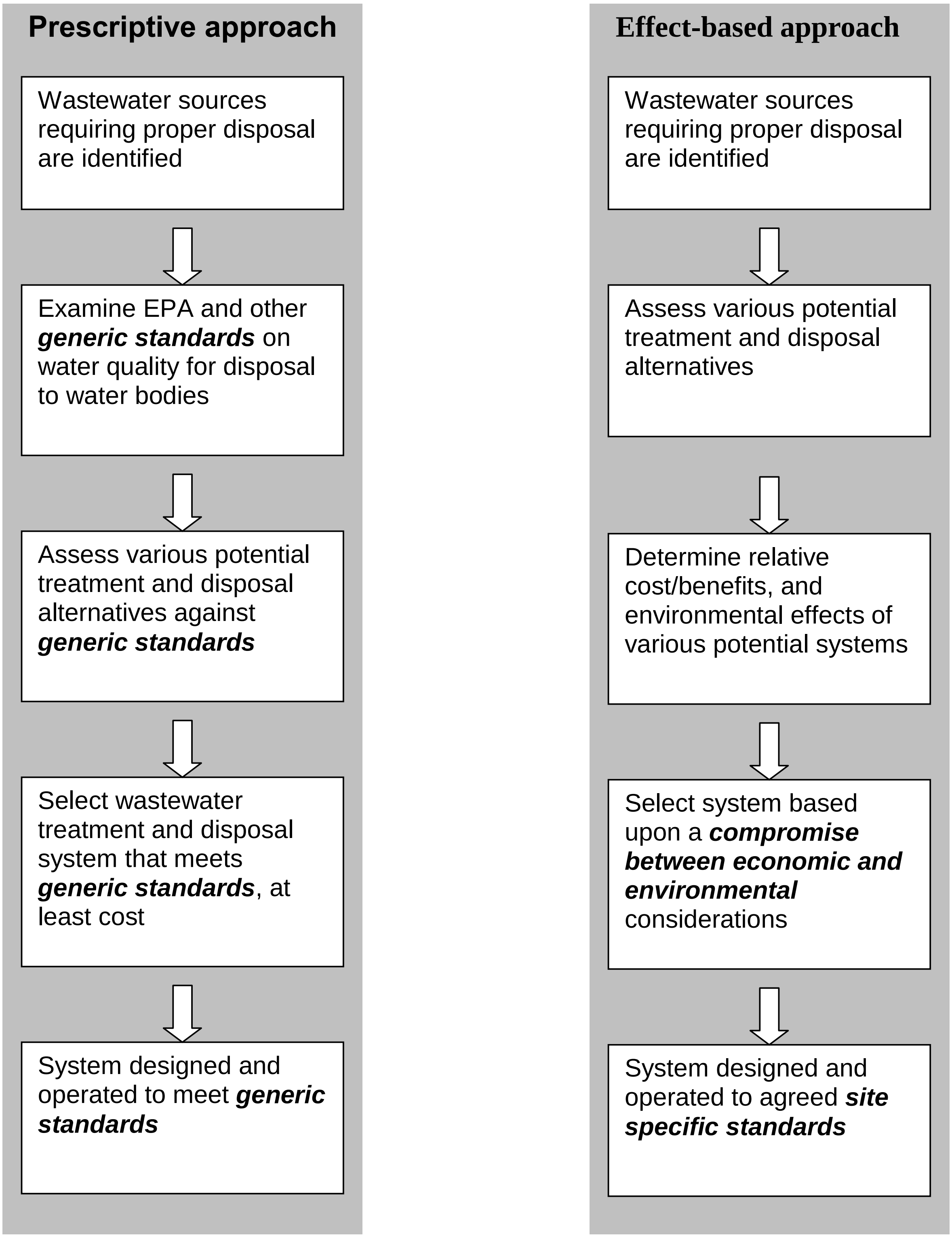
Step	Milestone
1	Decision making committee formed, and its operational protocol established
2	Relative merits of different treatment techniques and their potential for optimized combinations are understood
3	Understand the agro-engineering features and remediation capabilities of the FILTER system
4	Appreciation of limits placed by agro-climatic factors on FILTER application
5	Compile inventory and maps of wastewater problems of area, the reclamation requirements and potential for integrated solutions
6	An estimate of minimum area required for a sustainable FILTER system to meet hydraulic and pollutant loading calculated
7	Potential FILTER sites identified
8	Potential FILTER sites screened to select 1-2 sites
9	The engineering and agronomic aspects of FILTER system designed. Decision made on adoption of a “test-plot” approach.
10	FILTER farm operation manual prepared
11	Environmental impact statements prepared
12	Additional field studies completed
13	Costing of project prepared
14	FILTER design finalized and resources obtained
15	FILTER system installed
16	FILTER system operated and monitored

We have chosen the effects-based approach to assessing the effects of land application of wastewater on the surrounding environment used in the NZ guidelines (NZLTC 2000, Robb and Barkle 2000), instead of the standard-based or prescriptive approach adopted in many developed countries. The differences between these approaches are explained in the NZ guidelines (Robb and Barkle 2000) as follows:

"An effect-based approach assesses the environmental effects of an activity in the context of the receiving environment and the values associated with the environment. Whether an effect is considered significant depends on the uses of and values associated with the site, surrounding land, soil, air and water resources. The acceptability of an environmental effect therefore differs from location to location and it is not appropriate for this manual to give prescriptive values for such items as concentration of pollutants in drainage waters. Instead the guidelines provide sufficient information for the wastewater renovation effects at a land treatment site to be quantified and informed trade offs among potential sites and system designs to be made. Once a land system is designed, prescriptive site-specific standards such as water pollutant limits can be set through resource consent conditions and regulatory procedures".

The effects-based approach provides a more complex but more practical approach to balancing the environmental, economic and social impact considerations of wastewater treatment and reuse. The differences between the two approaches are outlined schematically in Figure 2. The effect-based approach is more suitable for use in China and other developing countries, where addressing the current widespread adverse effects of pollution needs to be done in a pragmatic and step-wise manner. Such an approach is in empathy with the growing realisation and recognition of the socio-economic cost of water pollution in China by the politicians and government organisations responsible for water and wastewater management, and the urgent need for introduction of integrated management of water and wastewater resources to meet the current and future water scarcity problems, especially in northern China. The relative economic costs and benefits of the available wastewater reuse and treatment technologies in relation to the current environmental costs of non-treatment at a given site is an important consideration in the effect-based approach, rather than aiming to meet international standards (Figure 2).

Figure 2. Comparison of effect-based and prescriptive approaches for defining pollutant limits in treated wastewater, for release to natural water bodies



2. Wastewater treatment selection, and generalised FILTER design and implementation

2.1. Stage A – Establish decision-making framework

2.1.1. Step 1. Establish a decision-making committee and consultative framework

The successful planning and operation of wastewater treatment schemes requires the active co-operation of many people in the local community. It is necessary to identify the stakeholders and to set up a decision-making committee of key personnel involved in planning and approving the wastewater treatment system. As indicated in **Figure 1**, this committee will be involved in decision making throughout the entire period and be responsible for guiding the project through all of the stages and steps. The make up of this decision-making committee could vary according to the scale of the project. If we look at the broadest scale application, involving for example wastewater management in the development of new cities or suburbs in China, the committee could include:

- Authorities and stakeholders such as city planners,
- Water and wastewater treatment agencies,
- Operators of engineering and chemical wastewater treatment plants,
- Existing land owners,
- Farmers,
- Specialists in FILTER and other land treatment technologies,
- Environmental authorities and environmentalists,
- Community representatives

It is important that a clear framework of responsibilities is agreed and documented by all parties involved in the development of major wastewater treatment systems. In smaller scale applications, the decision-making may be confined to some of the authorities and stakeholders mentioned above, and the others may only provide a consultative role during some stages of the project.

An important action for this committee is to decide upon a suitable course of community consultation. The application of FILTER systems will bring changes to the area, some of which will be taken as positive and others negative to some stakeholders. The committee needs to ensure that positive benefits are shared in a manner acceptable to the community and that negative aspects are discussed openly and honestly at an early stage of the project development.

2.2. Stage B - Feasibility assessment

2.2.1. Step 2. Examine the relative merits of different wastewater treatment systems

One option for wastewater treatment widely used in large urban cities in developed countries is the engineering and chemical wastewater treatment plants. The level of treatment could range from preliminary, primary, secondary or advanced tertiary treatment, providing progressively increased level of treatment (Pescod 1992), as discussed below.

Preliminary treatment involves removal of coarse solids using coarse screening, grit removal and pulverisation of large object. Primary treatment results in removal of settleable organic and inorganic solids by sedimentation, and the removal of materials that float by skimming. Approximately 25 to 50 % of the incoming biological oxygen demand, 50 to 70% of the total suspended solids, and 65% of the oil and grease is removed during primary treatment. Some organic nitrogen, organic phosphorus and heavy metals associated with solids are removed during primary sedimentation, but colloidal and dissolved constituents are not removed (Pescod 1992).

The aim of secondary treatment is to further reduce the residual organics and suspended solids. This could involve systems such as activated sludge processes, trickling filters and rotating biological contactors. Natural biological systems such as stabilisation ponds may also be used to reduce suspended solids and pathogens. Discharge of primary and secondary treated effluent can cause adverse effects on sensitive water bodies.

Tertiary treatment commonly involves use of engineering and chemical plants. Such plants are usually very expensive to build and operate. They produce treated effluent which can meet very high EPA or wastewater regulatory agency standards and requirements for reductions in nutrients and other pollutants in the treated effluent, making the effluent suitable for discharge into sensitive natural water bodies.

The preliminary, primary or secondary treatment systems may be combined in sequence with land treatment and reuse techniques, providing combined treatment options that are more economically acceptable than tertiary treatment plants for developing countries, and for rural areas in developed countries.

The existing land treatment/reuse techniques can be categorised into three groups, namely, *slow infiltration or irrigated cropping*, *rapid infiltration or soil-aquifer treatment*, and *overland flow systems*. The three types of land treatment differ in their capacity for hydraulic loading, adaptability to site conditions and the treatment processes involved (Iskander 1981, US EPA 1981), as discussed below. The relative advantages and disadvantages of these different land application systems are summarised in

Table 2.

The slow infiltration or effluent irrigation system involves total reuse of wastewater for irrigated cropping and forestry. It can be used on either permeable or moderately permeable soils that allow adequate leaching fractions to be maintained for soil salinity control. Wastewater is applied at low rates to meet the evapotranspiration and salt leaching requirements. The drainage water can carry the excess salt and other pollutants into the underlying groundwaters, which may require monitoring to ensure that EPA (Environmental Protection Authority) or other local wastewater manager regulations are met. The effluent can be applied as spray, drip or flood irrigation. Treatment of wastewater occurs by physical, chemical, and biological processes, as wastewaters move slowly into and through the soil profile. Vegetation is an important component in this type of treatment, particularly for the removal of nitrogen, phosphorus and other nutrients from the wastewater (Iskander 1978, Iskandar et al. 1976, 1977, US EPA 1981). An adequate extent of suitable land for irrigated cropping with suitable soil drainage and fertility characteristics to sustain long term crop production is needed. This system is not suitable for slowly permeable soils or on locations with high watertable, due to potential risk of water-logging and salinisation

Wastewater irrigation can thus supplement scarce freshwater supplies during dry periods while simultaneously preventing pollution of natural waterbodies through direct discharge of inadequately treated wastewater. However during periods where rainfall exceeds evapotranspiration the wastewater will need to be stored, for reuse during dry periods. Provision for wastewater storage can be expensive in urban and suburban areas, even where non-leaking wastewater storage sites are available close to the wastewater production sites.

Table 2. Comparison of land application techniques

Technique	Advantages and disadvantages
Slow infiltration or irrigated cropping	• Requires soils with moderate permeability that allows adequate leaching fractions to maintain salt balance • Not suitable for slowly permeable soils or on locations with high watertable, due to potential risk of water-logging and salinisation • Requires wet weather and winter storage of effluent, which can be expensive on semi-urban and urban lands • Does not generate treated wastewater to potentially offset urban requirement for fresh water supplies
Rapid infiltration or soil-aquifer treatment	• Requires coarse textured soils with high permeability that allows excess water to flow to aquifer storage, for subsequent reuse • Pollutant retention on sandy soils is limited • Aquifer pollution risks need to be considered according to reuse
Overland flow	• Suitable for soils with low permeability • Low nutrient removal capacity
Land-FILTER	• Requires soils with low permeability layers or locations with high watertables • Can be used with saline wastewater and to reclaim low-value degraded saline and sodic soils, and other degraded lands • Does not require wet weather storage, but requires installing subsurface drainage systems • Treated sub-surface drainage water can be reused
Catchment-FILTER	• Can be used on sites with highly permeable soils • Wet weather storage is not required • Design and operation needs a good understanding of the local hydrological conditions and risks of groundwater pollution

Inappropriate techniques for wastewater reuse through irrigation can also pose a risk to the valuable irrigated lands and their potential for producing edible crops, thus threatening their long-term usage, especially with heavily polluted wastewaters. For instance, where heavy metals are present in the wastewater they can accumulate in the soil and contaminate edible crops. On soils with low permeability, use of saline and sodic wastewaters can lead to soil degradation and crop yield decline through salinisation and sodification of the irrigated lands. On highly permeable soils, groundwater contamination with nutrients, chemicals and pathogens could occur, threatening underground drinking water supplies.

The rapid infiltration or soil-aquifer treatment system (SAT) is a wastewater treatment technique, that can be combined with aquifer storage (Bouwer et al. 1974, Pescod 1992). The recovery of treated water from underlying aquifers for subsequent reuse is a beneficial aspect of the system. Vegetation or cropping is usually not a major component of this type of land treatment. It can be used on coarse-textured and the more permeable fine-textured soils at high application rates of 10-250 cm/week (Bouwer et al. 1974, Aulenbach et al. 1975, Baillod et al. 1977, Satterwhite et al. 1976, Aulenbach and Clesceri 1979). The wastewater is usually applied by flooding. Renovation occurs mainly through physical, chemical, and microbiological processes as the water passes into and through a deep soil profile. The pre-treatment of the effluent applied varies from primary (Baillod et al. 1977) to secondary (Aulenbach and Clesccri 1979). It has been reported that rapid infiltration systems can be operated year-round, with no storage requirement even under freezing conditions (Baillod et al. 1977 Satterwhite et al. 1976, Aulenbach et al. 1975), with suitable modifications at the soil surface. Commercial systems are found in the South-west and the West Coast of the United States, where the main purpose is to recharge the groundwater for future reuse (Asano and Roberts 1980).

The overland flow system involves partial wastewater reuse, combined with release of excess treated wastewater. The soil must have low permeability, to limit deep-water percolation. Raw or partially treated wastewater, is usually applied at a rate of 5-15 cm/week on sloping, vegetation covered soil and recovered in collection ditches at the base of the slope for further treatment, reuse, or discharge. Treatment is achieved through physical, chemical, and biological processes as the wastewater flows down the slope and interacts with the vegetative layer and surface soil layers. The first overland flow system was built in Melbourne, Australia, in 1930. In the USA, several small full-scale municipal systems have been constructed in Oklahoma, Mississippi, and South Carolina. Previous studies (Jenkins et al. 1978, Jenkins and Martel 1979, Martel et al. 1980) on system performance demonstrated that overland flow could be used to obtain secondary or better effluent from screened primary-treated or lagoon-treated wastewater. In many instances this method of land treatment is not as good as the other two methods (slow and rapid infiltration) in removing phosphorus and faecal bacteria (Jenkins et al. 1978), due to limited contact with the soil. Treated wastewater from lagoon and overland flow systems at Werrribee, Melbourne show high level of total-P (6 mg/L) and total-N (25 mg/L), compared to land filtration systems where the treated wastewater had total-phosphorus of 0.8 mg/L and total-nitrogen of 10 mg/L (Melbourne Water – undated publication).

The FILTER technique can be categorised as a rapid, controlled flow system, which is a hybrid system that combines some of the hydraulic flow characteristics and wastewater renovation process of the slow infiltration, rapid infiltration and overland flow systems. The system is described below.

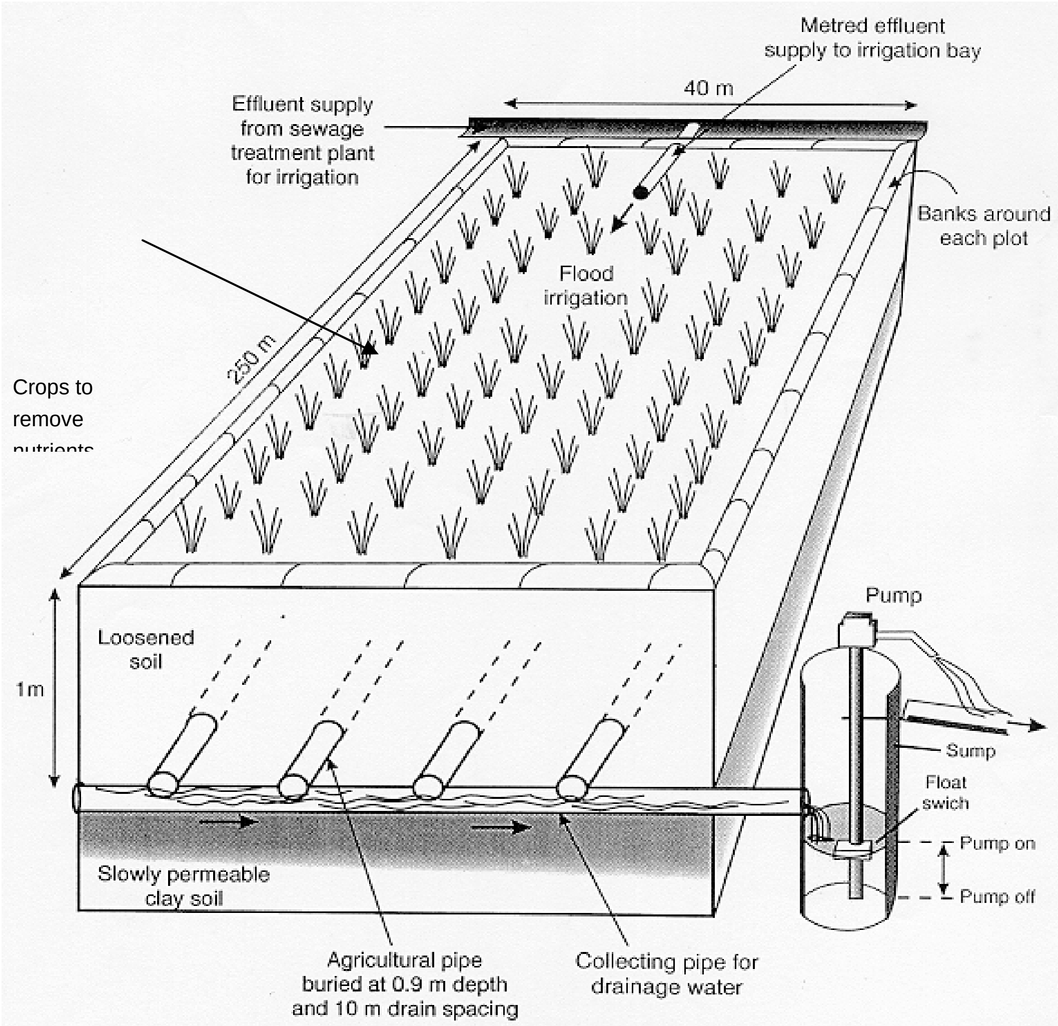
2.2.2. Step 3. Understanding FILTER systems, and their potential applications in China

How Land-FILTER systems work

The Land-FILTER (Filtration and Irrigated Cropping for Land Treatment and Effluent Reuse) technique involves wastewater reuse for agricultural cropping with release of excess treated wastewaters for local or downstream reuse (Jayawardane 1995). The technique combines using the nutrient-rich effluent to grow crops, with filtration of excess water through the soil to a sub-surface drainage system (Figure 3). It was developed to provide a sustainable land treatment system on soils with restricted drainage, to reduce nutrients and other pollutant levels in drainage water, below the stringent Australian EPA pollutant limits that apply to discharge of treated effluent to sensitive inland waterbodies. It can also be used on degraded saline and sodic soils, where the leaching of the excess salts in the drainage waters can lead to soil amelioration. However, where the land-FILTER system is used to ameliorate degraded saline and sodic soils for agricultural cropping, the subsurface drainage water containing the leached excess salts needs to be carefully monitored to prevent excessive pollution of the receiving waters, or be contained and managed in constructed salt disposal basins.

The FILTER system requires less land area than effluent irrigation systems, due to removal of part of the effluent applied as subsurface drainage for potential downstream reuse. Thus the FILTER system is capable of handling high volumes of effluent even during periods of low cropping activity or high rainfall, thereby eliminating the need for costly wet weather storage on expensive urban lands. In this system, the rate of effluent application and drainage can be regulated to ensure the required level of pollutant removal, thereby producing low-pollutant drainage water to meet EPA and local wastewater regulatory agency standards for discharge to surface waters, as discussed below.

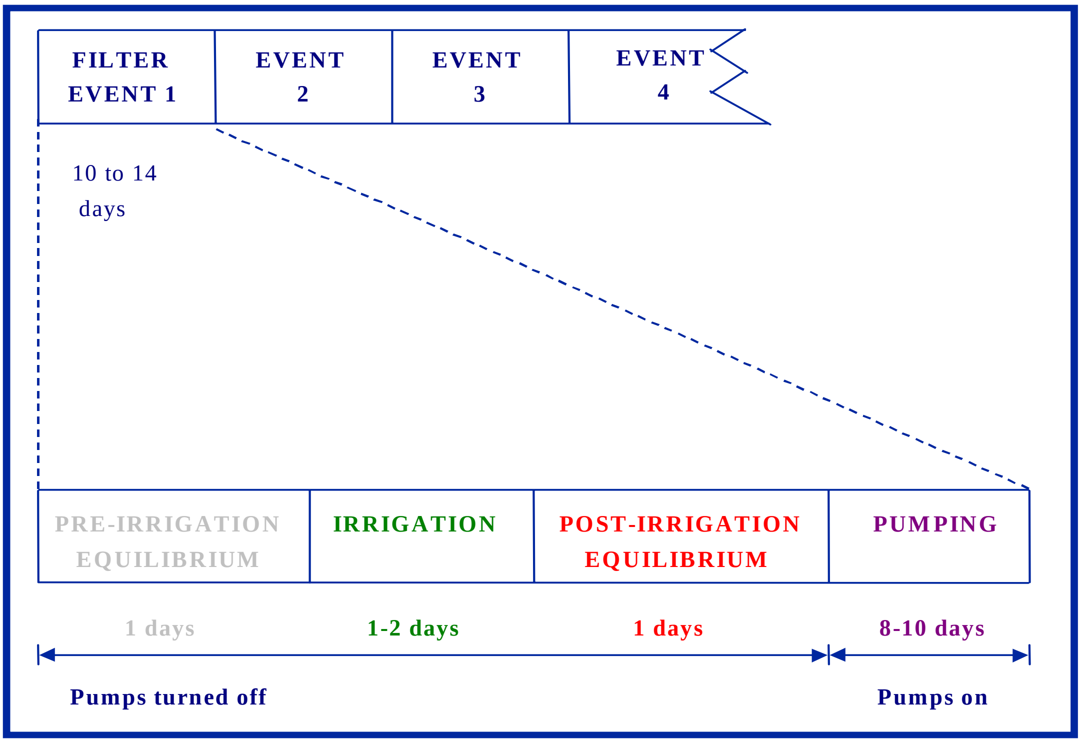
Figure 3. Schematic of a FILTER plot



For the Land-FILTER system, the land at the effluent application site is prepared as follows. Physical loosening and chemical amelioration of the slowly permeable soil to about one metre depth is used to increase soil macro-porosity and hydraulic conductivity. A network of sub-surface drains is installed at the bottom of this loosened layer, with control valves to allow for the regulation of leaching rates through the soil. Alternately, controlled pumping from a drainage sump can be used to regulate the outflow, to match the net hydraulic loading of the system, Figure 3. The effluent is applied to each FILTER plot on a weekly or fortnightly rotation. The watertable resulting from the input of effluent is drawn down in the soil by controlling the rate of outflow (via the subsurface drains), to approximately balance the net inflow.

The controlled drainage systems enable manipulation of the watertable, and hence control of the depths of the aerated and anoxic soil layers above the drains. This facilitates management of the system to maximise pollutant removal and to provide adequate root zone conditions for crop production. This regulated flow of effluent through the soil allows nutrients to be sorbed on the surface of soil particles; or to be taken up by the crop; or to be lost through microbial degradation, ammonia volatilisation and denitrification. These processes are used to reduce the concentrations of nutrients such as of phosphorus and nitrogen in the drainage outflow. The filtration and subsequent removal processes could also be used to reduce the concentration of other contaminants in the sewage effluent below the EPA or wastewater regulatory agency specified limits. Each weekly or fortnightly effluent application cycle or filter event consists of four consecutive stages, Figure 4. These four stages are effluent application (irrigation), followed by a post-irrigation equilibration period and by a pumping period (until drainage outflow approximately matches the net inflow) and finally a no-pumping equilibration period (leading to flattening of the watertable). The manipulation of these four-stage effluent application and drainage operations is used to maximise the removal of nutrients, and to increase the uniformity in nutrient distribution and retention in the soil across the FILTER plots, for future crop uptake.

Figure 4. Land-FILTER operation procedures



Crops play an important role in contributing to the efficient performance of the Land-FILTER system through removal of nutrients to prevent their accumulation in the soil, removing water through evapotranspiration to allow increased hydraulic loading, contributing organic matter to increase soil structural stability and providing an economic return through cropping.

The success of the FILTER technique at any given site is dependent on achieving the following targeted objectives, which are discussed in the following sections of the report.

- Reduce the concentration of pollutants in the sub-surface drainage waters below EPA or wastewater regulatory agency specifications for the receiving waters or other use;
- Achieve a long-term balance of pollutants entering with the effluent and leaving the FILTER system in plants, drainage water and breakdown processes to ensure pollutants do not accumulate in the soil
- Maintain soil stability to allow adequate flow rates through the FILTER system to meet the hydraulic loading requirements, which needs careful management with sodic wastewaters;
- Maintain adequate root zone conditions such as aeration and nutrient balance to maximise crop production and nutrient removal;
- Address any other site specific problems. For instance, if the chosen site is salinised, the initial reclamation under the FILTER system will require removal of the accumulated salts in the subsurface drainage waters. This salt removal has to be done in a way that minimises any adverse effects on downstream reuses of the drainage waters (Jayawardane and Blackwell 2002).

The prioritization of these objectives and the manner in which the FILTER system is designed and run at specific sites varies widely depending on the wastewater manager's specific goals at each site. For example, if the goals are to maximize the volume of treated drainage water for reuse locally and to minimise the urban land area so that the capital costs are reduced, the highest hydraulic loading needs to be used with cultivation of water-logging tolerant crops. However, if the aim is to maximise cropping and to increase the area of degraded land reclaimed using the FILTER system, a low hydraulic loading could be used. The FILTER system is thus an agro-engineering system, in which the efficiency of wastewater renovation is dependent on the manipulation of bio-chemical processes within the FILTER soil. Optimising the root zone conditions for these biochemical processes and for maximizing crop production and nutrient removal, is an important goal of FILTER management. This may require some compromises with the engineering manipulation of the system which aims to maximize drainage flows and minimize costs, as discussed in the section on Step 6.

The drainage water from the Land-FILTER system installed at sewage and industrial wastewater sites in cities can be reused, which thereby reduces the water supply requirements to the cities, providing an economic incentive for consideration by city planners. The potential reuse will vary according to the pollutant levels in the drainage waters and possibly require adoption of other simple treatment systems to meet the reuse quality standards. A summary of the performance of the Land-FILTER systems observed in field trials in Australia and China is provided below to illustrate the potential of the system for wider use.

Land-FILTER trials in Australia

Preliminary testing of the Land-FILTER technique was carried out at the Griffith Sewage Works site in central New South Wales, Australia, on eight 1-ha preliminary experimental plots (Jayawardane et al. 1997a,b) and on a 15-ha pilot commercial scale trial (Jayawardane et al. 2002a). The trials were conducted on a highly salinised, heavy clay soil with impeded drainage and a high watertable. The results from the preliminary trials and pilot commercial scale commercial scale trial showed that the FILTER system met its primary objectives of providing pollutant concentration reductions in drainage waters below Australian EPA limits (Table 3), while maintaining adequate drainage flow rates and crop production.

Thus, during the five cropping seasons on the 15-ha pilot commercial scale commercial scale trial, the total-phosphorus in the effluent applied varied between 2.0 and 8.2 mg/L, while the mean value in the drainage waters was 0.31mg/L (Figure 5). The total-nitrogen concentration in the effluent applied ranged from 4.6 to 33.1mg/L. The total-nitrogen concentrations in the drainage waters was initially high due to leaching of pre-FILTER soil accumulations of nitrogen, but fell below 11 mg/L after filter event 5 of the first cropping season, and remained well below this value for the next four cropping seasons of the trial. Pollution concentrations of Suspended Solids, BOD_5, $Chlorophyll_a$ were also markedly reduced in the drainage waters. Pollution load reductions during the five cropping seasons of the pilot commercial scale trial for total-P, total-N, Suspended Solids, BOD_5, $Chlorophyll_a$, and Oil and Grease ranged from 60-100% (Table 3), resulting in a significant reduction in annual pollutant loads discharged.

Chemical analysis of the soil at the Griffith trial site showed that by intensive irrigation and drainage under the FILTER system, the pre-FILTER salt accumulations due to previous effluent irrigations without provision of subsurface drainage, were reduced (Figure 6). Soil analysis also indicated a reduction of the pre-FILTER soil sodicity after installation of the FILTER system, due to removal of excess sodium salts in the subsurface drainage water.

This shows that the FILTER system can ameliorate degraded salinised and waterlogged land (Jayawardane et al. 1997a, 2001), thereby increasing the value of the land for agricultural cropping. This is in contrast to wastewater irrigation schemes, where high quality agricultural lands with adequate drainage characteristics are required to provide a sustainable system.

In field trials, substantial crop yields comparable to district averages were obtained in FILTER trials, which can be used to offset costs of installation and operation of commercial systems (Jayawardane et al. 1997a).

Figure 5. Mean total-phosphorus in sewage effluent applied and subsurface drainage discharges. Results from pilot commercial scale FILTER trial at the Griffith site, during successive filter events of five cropping seasons.

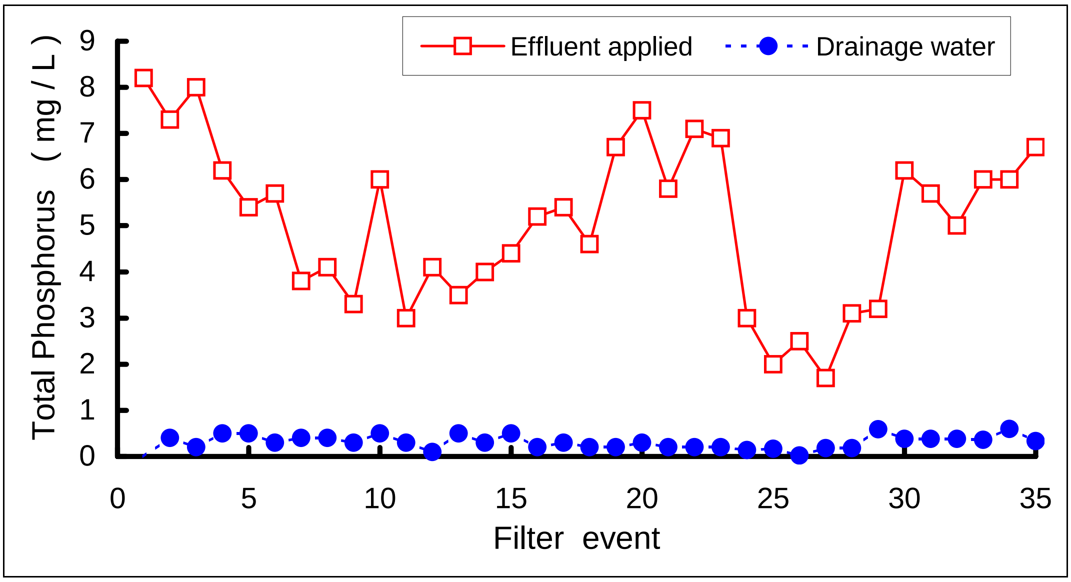
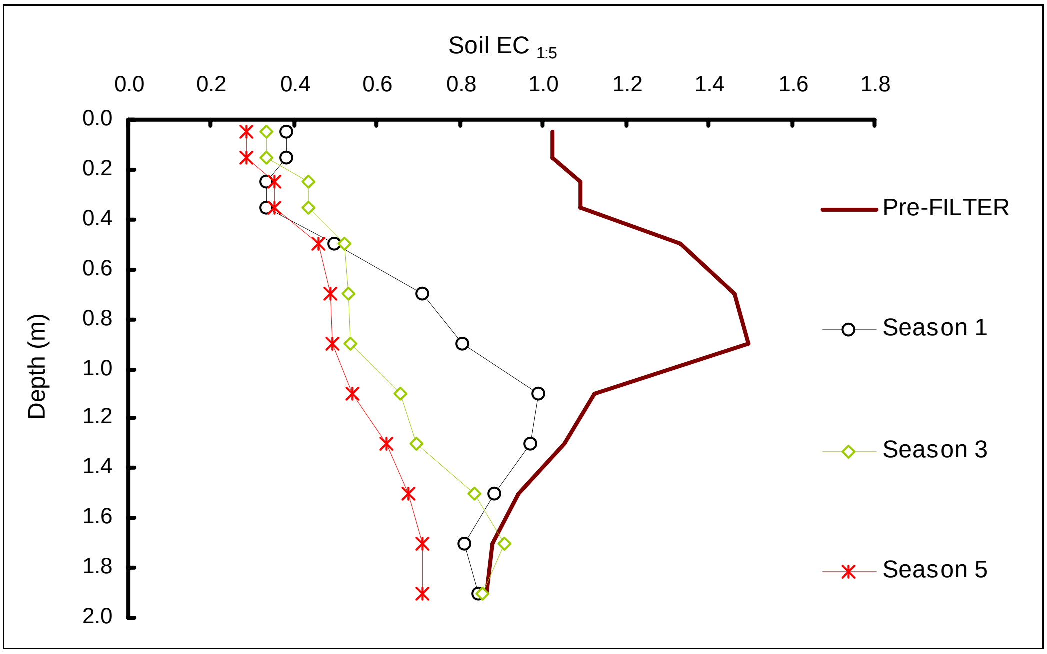


Table 3. Pollutant load reductions during FILTER trials at Griffith and Wuqing sites.

Pollutant	Pollutant load reduction (%)			
	Griffith preliminary trial	Griffith Pilot commercial trial	Wuqing trial (5m drain spacing)	Wuqing trial (10m drain spacing)
Total-P	96	96	99	99
Total-N	75	60	82	86
Suspended solids		81	68	81
BOD_5		93	61	79
COD			75	86
Grease and oil		60		
Chlorophyll a		100		
Malathion	99.4			100
Chlorpyrifos	100			99.8
Other pesticides	98-100			
E. coli		100		

Figure 6. Soil salinity decreases during operation of Griffith Land-FILTER system



Trials to evaluate the efficiency of pesticide removal through the FILTER system were conducted with a large range of locally used pesticides. The pesticides bensulfuron, molinate, malathion, chlorpyrifos, diuron, bromacil, atrazine, metolachlor and endosulfan were introduced into the wastewater at high levels. The FILTER reduced pesticide concentrations by more than 92% and pesticide loads by more than 98%. Field studies with malathion and chlorpyrifos to evaluate the long-term fate of the pesticide absorbed on the FILTER soils showed that the pesticide levels in the soil degraded to negligible levels within eight weeks.

Land-FILTER trials in China

A research trial of the FILTER system was conducted in Wuqing county near Tianjin, China. The field site was located in an area where intense competition for scarce fresh water resources occurs and extensive pollution of water bodies from wastewater discharges is prevalent. The area also had saline wastewaters, and extensive areas of agricultural lands with saline soils and high watertables. The field trial was irrigated with water from Beijing City "sewage river", which also collected untreated sewage effluent from a nearby township.

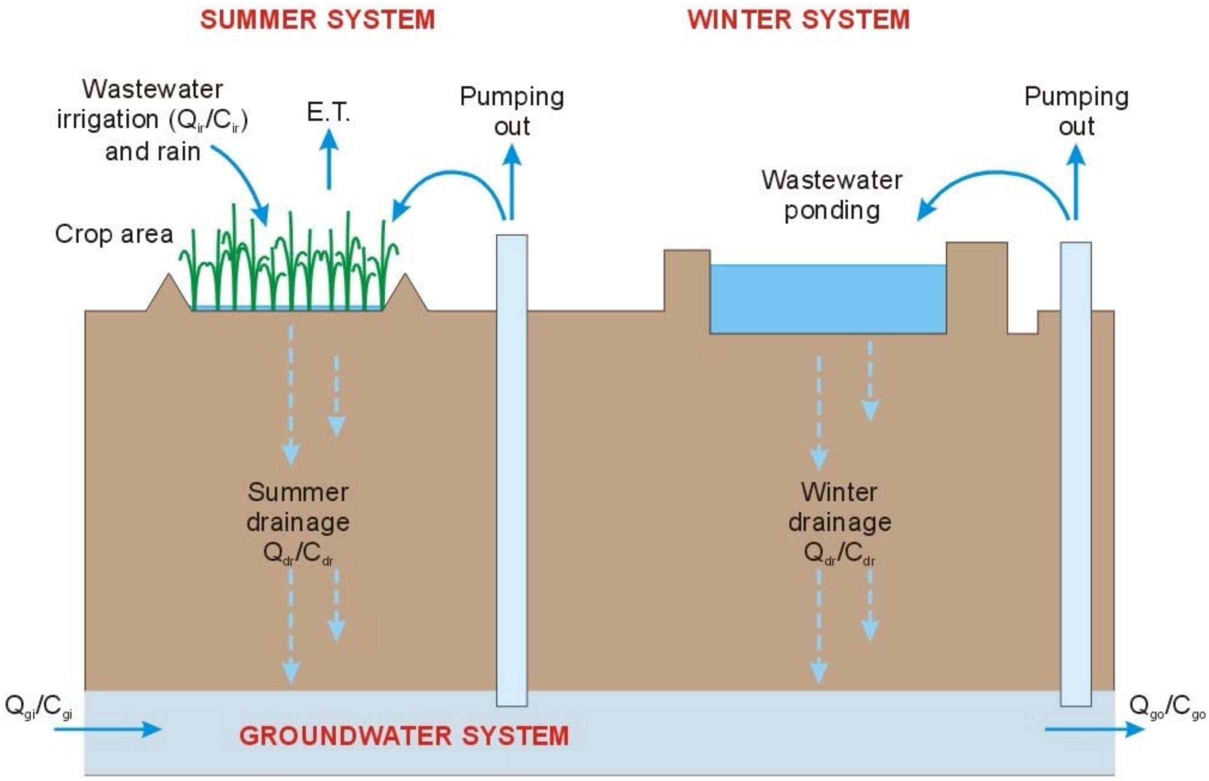
The main aim of the Tianjin trial was to evaluate the FILTER technique for pollutant removal and sustainable crop production (Gao et al. 2000). The results indicate pollutant reduction rates comparable to those observed in the Australian field trials (Table 3) while maintaining adequate flow rates and crop production. Increasing the spacing of drains from 5m to 10m resulted in a slight increase in pollutant load removal, possibly associated with the longer travel path of the wastewater through the soil. The FILTER site at Wuquin was also used to treat wastewater from a nitrogen fertilizer factory that was known to be polluting the Luanhe River near Tianjin. The FILTER system markedly reduced the nitrogen pollutants in the wastewater, and the yield of crops grown increased due to high nitrogen in the wastewater.

How Catchment-FILTER systems work

Catchment-FILTER is a modification of the two-dimensional Land-FILTER technology, for application in a three-dimensional landscape context. It can be used on sites with unrestricted soil drainage characteristics, which are thus unsuitable for the Land-FILTER system. Catchment-FILTER site operations combines high hydraulic loading of nutrient rich effluent for intensive annual cropping, with filtration through the soil to a carefully managed groundwater system. The excess drainage water can be stored in the groundwater system for potential utilisation for irrigation in drought years. Vertical subsurface drainage could be installed, designed to meet the site-specific hydrological conditions where watertable rises or potential groundwater pollution risks to the surrounding areas needs to be carefully controlled and managed.

Field studies on the Catchment-FILTER system were carried out at Yanggao County near Datong City in Shanxi Province, China. The main aim of the field trial was to develop a holistic, integrated system for using the wastewater in a sustainable irrigated cropping system, combined with reduction of pollutants in the drainage water to low concentrations that meet the standards for potential immediate discharge from the FILTER site or for accumulation in the groundwater storage for future reuse. A preliminary inspection of the field site and the available information indicated that the following two considerations need to be addressed in developing the appropriate FILTER technology to meet the site requirements in Yanggao County, namely (a) subsurface drainage designed according to the regional groundwater hydrology of the site, which has more permeable soils and had deeper piezometric levels than on sites previously used for Land-FILTER systems and (b) maintaining adequate infiltration rates during wastewater application under freezing conditions in winter. The Catchment-FILTER system was designed with adequate modification to suit the specific site conditions in Yanggao County.

Figure 7. Schematic of a Catchment-FILTER plot



The Catchment-FILTER at the Yanggao site has three design components (Fig. 7). These are a summer component, a winter component and a groundwater component, in which the following research studies were carried out.

The studies on the summer component of the Catchment-FILTER system were carried out at the Yanggao field site under a maize crop, on field plots instrumented to monitor the pollutant concentrations in the wastewater applied and in the drainage water moving beyond the crop rooting depth. Wastewater irrigation was applied during nine irrigation events at very high hydraulic loading rates of around three times the crop water requirement. The concentration of the major pollutants in the wastewater of Total-P, Total-N, NH_4-N, Organic-N, and COD concentrations was markedly reduced by 97%, 77%, 99%, 50% and 75% respectively (Table 4) in the drainage water flows beyond the root zone. These pollution removal rates in the Catchment-FILTER system are similar to previously observed pollutant removal rates in land-FILTER sites with high watertables in Australia and China. However, due to better soil aeration conditions at this Catchment-FILTER site with deep watertables, the concentration of NO_3-N levels in drainage water increased from near zero to around 9 mg L^{-1}, apparently through conversion of other nitrogen compounds to nitrate-nitrogen. This NO_3-N leaching needs to be monitored in relation to its potential for groundwater pollution of the surrounding area.

Table 4. Pollutant concentrations (mg L^{-1}) in wastewater applied and drainage water flows below the root zone, in a Catchment-FILTER system at Yanggao

Pollutant	EC (dS/m)	Total-P	Total-N	NH4-N	Org-N	NO3-N	COD
Wastewater	1.66	2.8	43.3	41.3	1.7	0.2	191.3
Drainage	1.93	0.1	10	0.4	0.9	8.8	27.9
Reduction %		97	77	99	50	Increase	75

In spite of the very high hydraulic loading rates of wastewater, maize crop yields of 9.6 t ha^{-1} were obtained in the FILTER plots which were comparable to the district yields of 10.7 t ha^{-1}. Cropping can provide removal of nutrients applied to balance inputs in the wastewater irrigations, and also provides a financial return to offset capital and operating costs.

During the non-cropping winter period, studies were carried out on infiltration rates under the very cold conditions, using pumped groundwater for ponding on the soil surface. Shallow ponding techniques currently in use in northern America, were not successful, due to very heavy frosts in the Shanxi Province. Ponding of water to around one meter prevented the soil surface from freezing with the formation of a 0.3m ice-cap floating at the water surface, resulting in maintenance of a wastewater infiltration rate of around 0.2m/day into the soil. Such ponding experiments need to be pursued further and combined in the future with monitoring and associated modelling studies of pollutant movement within and beyond the FILTER plots during such high winter hydraulic loading, to develop appropriate management techniques to restrict pollutant containment to designated areas, and thus provide the critical need for protection of the surrounding sensitive groundwater sources from pollution.

The management of groundwater around the Catchment-FILTER site is a very critical component of the Catchment-FILTER system, which needs to be based on a good understanding of the local hydrological flows, for control and containment of potential pollution risks (Khan et al. 2006). This allows correct siting of FILTER plots for both summer cropping and winter ponding, optimised designing of any vertical drainage systems and controlled irrigation/drainage, with close monitoring of potential pollution risks to the surrounding environment during operation of the Catchment-FILTER system. These considerations are especially important where the groundwater systems in the vicinity of the Catchment-FILTER sites, are currently or potentially usable as potable water supplies. Such hydrological studies need to be site specific.

Hydrology studies were carried out at the Yanggao Cathment-FILTER site to quantify the groundwater hydrology of the trial site, the specifications of any vertical subsurface drainage system and potential effects of operating a wastewater reuse system on the surrounding areas (Khan et al. 2006). The potential hydrogeologic impacts of the proposed FILTER system on the surrounding area were investigated using a sub-regional MODFLOW/MT3D flow and salinity transport model of the site. Data available from an existing long-term pond experiment was used to characterize aquifer properties using inverse modeling techniques with MODFLOW, which yielded values for the horizontal hydraulic conductivity and specific yield of 4.17m/d and 0.262 respectively. Boundary flux analysis carried out to quantify the net impact of FILTER on the surrounding areas, indicated that a well designed and managed vertical drainage system could be used in a catchment-FILTER approach for domestic wastewater renovation at the site. During the proposed future commercial use of the site, there is a need to combine the hydrology modeling with detailed monitoring of biological and chemical contaminants present in the wastewaters, under the management practices proposed and adopted for the site to ensure long-term sustainability.

Hence, it is emphasised that when the “business plan” being developed by the Yanggao local authorities is finalised, further site-specific detailed studies are needed in developing the final planning of the design and operation of the commercial Catchment-FILTER site. Such studies should include very detailed assessment of current domestic water usage from groundwater sources in the area and their potential future usage. The planning needs to consider the combined current and future utilisation of water and wastewater resources in the area.

Related research studies on Land-FILTER and Catchment-FILTER systems

Collaborative research between the Australia and Chinese scientists is being carried out to develop FILTER pollutant removal models to provide improved understanding and management of FILTER systems to treat different wastewater (Yang et al. 2002). Collaborative studies were also conducted on optimisation modelling approaches to assist wastewater managers in optimising the land-FILTER design and management according to the needs for pollutant removal and wastewater reuse at specific sites (Gao et al. 2002).

In relation to very cold winters in northern China, another option to maintain infiltration of wastewater during the winter period is to establish the FILTER plots beneath the polyhouses used for protected cropping. A field trial was carried out in a suburb of Beijing (Jayawardane et al. 2006). The trial indicated a satisfactory level of removal of pollutants and adequate crop yields, indicating the promise of this combined FILTER and polyhouse technology to address the difficult problem of wastewater renovation and reuse during very cold winters in northern China, in a cost-effective manner.

It is emphasized that the optimum wastewater treatment system for any city or a specific wastewater discharge site could be a selected combination of preliminary, primary, secondary treatment, existing land application and FILTER systems operating in sequence or parallel (Jayawardane et al. 2006). Technical experts in each of these areas will need to work together to develop such integrated systems.

However, as the technical details of other treatment systems are described in detail in other publications (USEPA 1981, Pescod 1992, Iskander 1981), the integration of other treatment systems with FILTER will not be discussed in detail in this publication. The rest of this publication will focus on guidelines for field application of the FILTER systems for wastewater treatment and reuse, and provides the basic information needed to design, construct, operate and monitor FILTER systems.

2.2.3. Step 4. Examine general suitability of the FILTER systems in specific climatic zones, soil types and other local conditions in China

The potential for application of the FILTER systems to addressing wastewater pollution problems at specific sites depend on factors such as climate, soil type and the hydrological conditions in the area. Climatic regions without cold winters will allow the use of the Land-FILTER technique for wastewater treatment throughout the year. The technique can be used to treat the around-the-year release of wastewater even in regions with high rainfall, as the excess rainfall and treated wastewater can be drained through the subsurface drains.

In relation to soil factors, the Land-FILTER technique was developed for application at sites with a high groundwater table or where a presence of soil layers with restricted permeability creates a perched watertable. It is unsuitable for soils with soil layers of high permeability to depth in areas without a high regional watertable, as the effluent applied will drain rapidly beyond the subsurface drains. Ideally the soil above the low permeability layer should have high permeability to allow a wider spacing of the subsurface drains, thereby reducing the cost of installation of the drainage network and increasing the travel path through the soil to enhance pollutant removal (Gao et al. 2000). Upper soil layers with high absorptive characteristics for the pollutants will be beneficial in filtering the pollutants. In contrast, the Catchment-FILTER technique is suited to sites with permeable soils to depth and deep watertables.

The evaluation of suitability of specific local sites has to be done using large-scale detailed soil and land mapping of the local area of the wastewater pollution source. However, a preliminary assessment can be made using the generalized characteristics of the agro-ecological regions of China, as indicated in part 3 of Table 5.

Table 5 (Part 1) Agro-climatic zones in China (extracted from Li Shikui (1993))

Region	Crop property and crop system	Sum of temp. ≥0 °C	Mean temp (°C)		Annual Rain (mm)
			Jan	Jul.	
Qinghai-Xizang Plateau	Cryophilic - one crop a year	1500~ 3000	-5 ~0	11~ 17	40 ~ 700
Medium highland - N. China	semi-arid weakly cryophilic - one crop a year	2500~ 3500	-18 ~0	18 ~ 22	300 ~ 450
Low highland - NE and NW China	semi-arid moderately thermophilic - one crop a year	3000~ 4200	-14 ~-3	21 ~ 25	400 ~ 600
Plains and hilly land – NE China	semi-humid moderately thermophilic - one crop a year	2500~4000	-25 ~-7	19 ~ 24	500 ~ 800
Irrigated arid land - NW China	Moderately thermophilic - one crop a year(two crops in S Xinjiang)	3200~4000 (>4000)	-15 ~-6	20 ~ 27	50 ~ 400
Huanghe-Huaihe-Haihe Plains	Cryo- and Thermophilic - 2 crops a year on irrigated and dry land, 1 crop on dry land	4000~5500	-7~-2	24 ~ 28	500 ~ 900
Plateau of SW China	Cryo-and Thermophilic (dry and watered land) -2 crops in paddy field, 1 or 2 on dry land	4500~6100	1 ~ 10	20~28	600 ~ 1400
Changjiang–Huaihe Valleys	Cryo-and Thermophilic (dry and watered land) - 2 crops (rice and wheat) / 3 early maturing crops annually	5500~6100	0.4 ~ 5	27 ~ 28.5	900 ~ 1200
Sichuan Basin	Cryo-and Thermophilic (dry and watered land) - two or three crops a year	5900~6600	5~8	25 ~ 28	950~1300
Mid and lower reaches of Changjiang River	Cryo-and Thermophilic (dry and watered land) - three or two crops a year	5700~6500	2.5~6	28 ~ 30	1000~1600
Hilly and mountain	Cryo-and Thermophilic (dry and watered land) - Two or three crops annually	6500~7500	5~12	22 ~ 29	800 ~ 1800
S China	Cryo-, thermo- and very thermophilic - 3 or 2 late ripening, or 3 tropical crop s a year	7500~9000	11~20	27.5~ 29	1100 ~ 2500

Table 5 (Part 2) Land forms, soil types and crops in agro-climatic zones in China (extracted from Li Shikui (1993))

Region	Characteristic landform in agricultural area	Soil type in agricultural area	Main crops
Qinghai-Xizang Plateau	High plateau, valleys and basins at 2000~4000msl	alpine and subalpine meadow soil, prairie soil	highland barley, spring wheat, pea, rape
Medium highland - N. China	medium highland gentle sloping land and loess hilly land at 1000~1500msl	chestnut and brown calcic soil, Aeolian sandy soil	spring wheat, potato, sesame, millet
Low highland - NE and NW China	Low-plateau small-area plain, hilly land, basins and valleys at 500~1200 m amsl	loessial soil, yellow Lu soil, chestnut soil	Spring wheat, corn, millet, Indian millet, winter wheat
Plains and hilly land of NE China	mainly plains, gentle hilly land before mountains	chernosem, meadow soil and Beijing soil	corn, soybean, spring wheat, millet, Indian millet, millet, beet, sunflower
Irrigated arid land - NW China	plans before mountains, Hetao plain for oasis agriculture	chestnut soil, prairie serozem, meadow colonchak, brown desert	Winter/spring wheat, corn, beet, sunflower, cotton
Huanghe-Huaihe-Haihe Plains	mainly plains, with hilly and mountainous land, and basins	yellow Chao soil, cinnamon soil, brown earth, solonchak, black sandy Jiang soil	winter wheat, corn, cotton, sweet potato, soybean, peanut, millet
Plateau of SW China	plateau mountainous land at 500~3000m amsl	yellow earth, red earth, Paddy soil	corn, paddy rice, winter wheat, sweet potato, rape, broad bean
Changjiang–Huaihe Valleys	plains in the main with hilly and mountainous land	Mainly paddy earth, with yellow-brown soil in the main on arid land	rice, wheat, cotton, rape
Sichuan Basin	Basins at 200~700m amsl	purplish soil, paddy earth	rice, wheat, rape, corn, sugarcane, citrus, sweet potato
Mid and lower reaches of Changjiang River	mainly plains, with hilly and low mountainous land	mainly paddy soil, with red earth, yellow earth and yellow-brown soil	rice, wheat, rape, cotton, green manure crop
Hilly and mountain	mainly low-mount. & hilly and with cultivated fields on intramountain basins and gentle sloping land	red earth and paddy soil in low-lying level, yellow earth and yellow-brown soil at high-lying level	rice, corn, sweet potato, rape, green manure crop, winter wheat, citrus, rape
S China	Low –moutainous and hilly land, and coastal plains	Red earth and lateritic soil of red-earth-nature, paddy soil, aggradation soil	rice, wheat, sugarcane, peanut, forage crops

Table 5 (Part 3) General Land-FILTER suitability per agro-climatic zone in China

Region	General potential for Land-FILTER *
Qinghai-Xizang Plateau	Low
Medium highland in N. China	Low
Hilly and mountain	Low
Low highland in NE and NW China	Low – moderate
Irrigated arid land in NW China	Moderate
Huanghe-Huaihe-Haihe Plains	Moderate
Plains and hilly land of NE China	Moderate-high
Plateau of SW China	High on paddy soil, moderate-high on others
Changjiang–Huaihe Valleys	High on paddy soil, moderate-high on others
Sichuan Basin	High on paddy soil, moderate-high on others
Mid and lower reaches of Changjiang River	High on paddy soil, moderate-high on others
S China	High on paddy soil, moderate-high on others

*Requires in addition, suitable local hydrological conditions to maintain a natural or perched watertable for Land-FILTER system

In

Table 5, the first five agro-ecological in the northern region have cold winters that will restrict use of Land-FILTER systems to only part of the year, unless they are established under the polyhouses. In addition the hilly topography is less suited for the technique. In the southern regions, the warmer climates throughout the year, flatter topography and prevalence of paddy soils that could be associated with high watertable shows a higher potential for Land-FILTER systems. However, field trials need to be conducted to evaluate the performance of Land-FILTER systems on the paddy soils of the different regions in China and to develop site specific management systems. Catchment-FILTER systems could be adopted on more permeable soils with deeper watertables, where it is specifically designed to meet the local hydrological features.

The markedly higher evapotranspiration compared to rainfall in the southern regions indicate opportunities for increased effluent loadings that would result in reduced land area requirement of Land-FILTER systems.

The wide range of cereal and fodder crops that are grown in different regions (part 2 of Table 5) allows optimised adaptation of FILTER systems to local conditions, with use of appropriate hydraulic loading rates.

2.2.4. Step 5. Prepare inventory of wastewater problems and reclamation requirements

This step results in a compilation of an inventory and maps of wastewater problems of the area, the reclamation requirements and the potential for integrated holistic solutions for wastewater treatment and reuse.

The main aim of FILTER systems in many locations will be to treat the wastewater to meet appropriate standards for the drainage water discharge to surface and underground water bodies, or for local reuse. It is therefore essential to have a detailed physical and chemical characterization of the wastewater and a clear understanding of the local EPA or other wastewater regulatory agency guidelines that applies to treated wastewater discharges to natural water bodies, groundwaters and for specific reuses.

The wastewater needs to be characterized in terms of flow volumes and pollutant concentrations, to plan the treatment requirements. It is also necessary to characterize the seasonal fluctuations in wastewater volumes and its pollutant constituents to develop the engineering design criteria such as the land area required and the subsurface drain spacing and depths, as discussed in subsequent steps (steps 6 and 9). This information of wastewater characterization is also needed in developing the detailed FILTER operation procedures (step 10). The pollutants characterization generally includes pH, phosphorus, nitrogen, other nutrients, heavy metals, pesticides, organic matter, suspended solids, BOD5, COD, TOC, chlorophyll a, oil and grease, EC, total dissolved solids, SAR (sodium absorption ratio), E coli and other pathogens. Table 6 indicates the influence of specific wastewater characteristics on FILTER design and operation considerations, and is further discussed in step 6.

The information on wastewater characterisation at individual sites can be compiled into inventories and maps showing the wastewater problems of the area that need renovation. This information and maps provide a basis for planning of integrated solutions to the wastewater problems of the area. Figure 7 shows a schematic representation of the potential wastewater pollution problems of an urban area.

Figure 8 shows conceptual planning of potential integrated solutions to the problems illustrated in Fig. 7, combining FILTER with other treatment techniques.

Table 6. The influence of wastewater characteristics on FILTER design considerations.

Pollutant	Design considerations
pH	Where pH is outside the range 6 – 8, soil acidification or sodification will occur. Mixing wastewaters can be used to neutralise, if necessary
Phosphorus	Phosphorus removal during flow to drains occurs through soil absorption. To prevent excessive soil accumulation and consequent leaching, crop uptake needs to match net additions. Phosphorus absorptive capacity indicates available soil storage capacity to saturation.
Nitrogen	Removal of different nitrogen components during flow to drains occurs through soil absorption (NH4-N), soil filtering (Organic-N) and gaseous losses (NOx-N and NH4-N). NO_X-N is very mobile. To prevent soil accumulation and consequent leaching, crop uptake rates and other losses needs to match net additions.
Heavy metals	Heavy metal removal during flow to drains occurs through soil absorption. Removal through most crops is small and hence heavy metals can accumulate to toxic levels for crops or in consumable crop products. Use of non-edible crops on FILTER lands, and pre-treatment through removal in sludge needs to be considered.
Pesticides and other chemicals	Removal during flow to drains occurs through soil absorption. To prevent excessive soil accumulation and consequent leaching, the rate of subsequent degradation in soils needs to match net additions
Suspended solids, BOD_5, COD, TOC	Removal during flow to drains occurs through soil filtration. Excessive loading over decomposition rates can leads to blocking of soil macropores, thereby reducing drainability and hydraulic flow rates.
Salts (EC, total dissolved solids)	Soil salinisation is dependent on wastewater EC levels and the leaching fraction adopted. Soil EC can affect crop production depending on crop tolerance.
SAR	SAR affects soil sodicity (ESP). Soil stability of swelling soils is dependent on factors such as the EC to ESP relationship, the type and amounts of swelling clays, cementing agents etc.
Pathogens	Pathogen removal occurs through soil filtering and absorption, followed by break down.

Figure 7. Schematic representation of the potential wastewater problems of an urban area

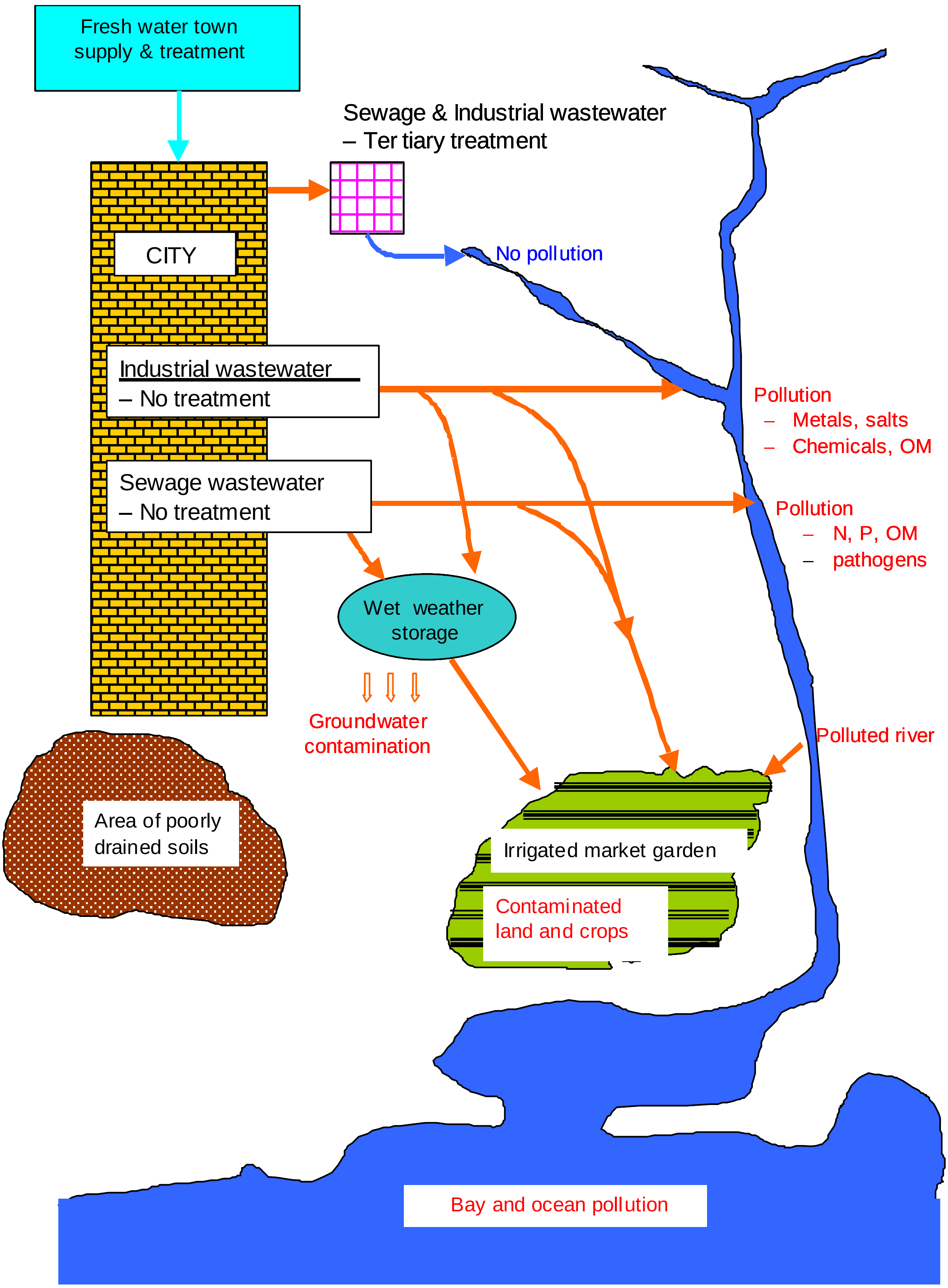
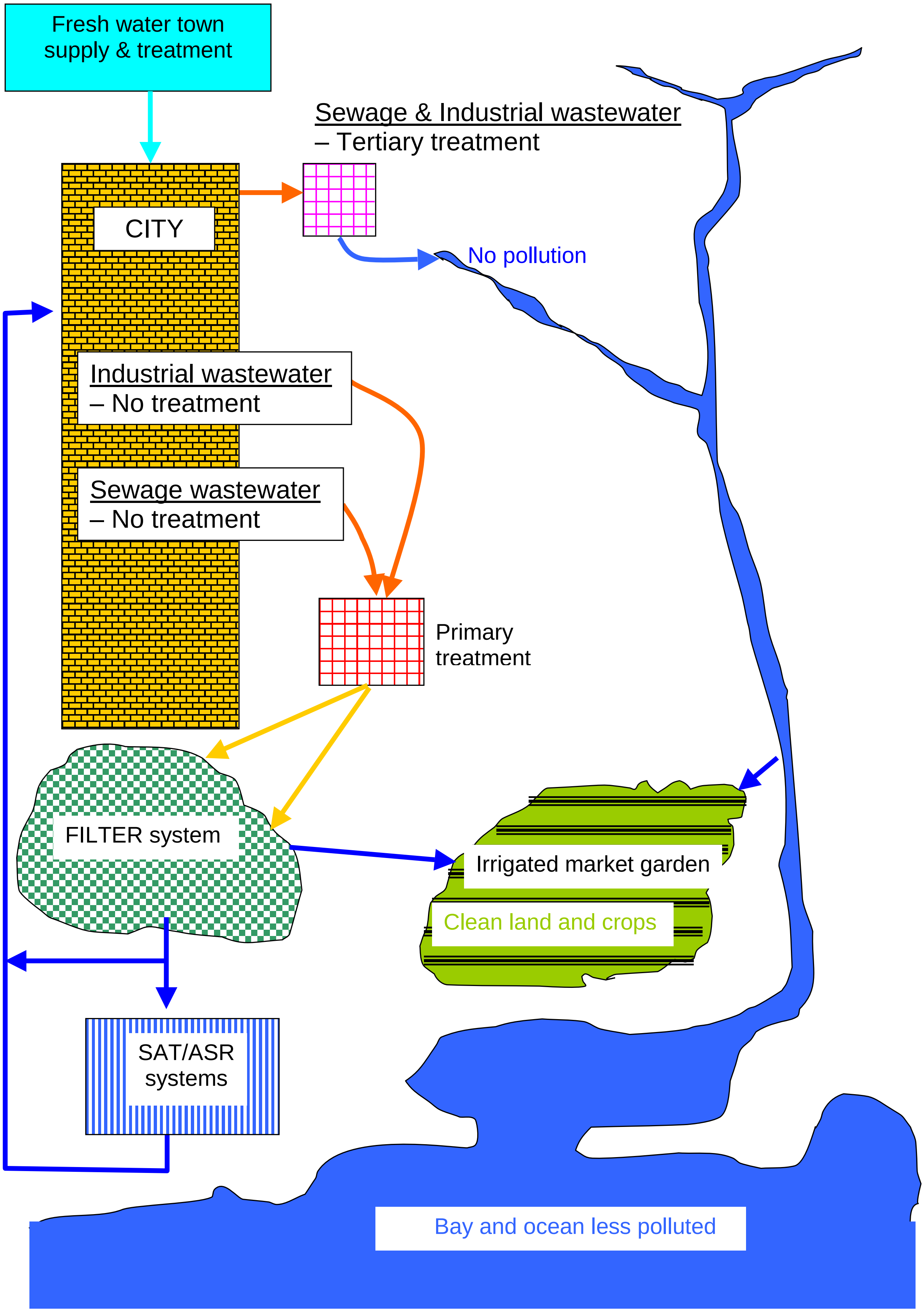


Figure 8. Conceptual planning of potential integrated solutions to wastewater problems illustrated in Fig. 7, combining FILTER with other treatment techniques



2.2.5. Step 6. Preliminary estimate of land area requirement for FILTER system

In this step an estimate of the minimum land area requirement is made. The exact land area required depends on many factors, including site-specific factors at the land application site, such as the soil types and their characteristics. Therefore the initial estimates made of land area requirement to select potential sites, will need to be refined during detailed design studies, based on detailed characterization of site factors in the final selected site. All assumptions, sources of data and methods used in the calculation should be recorded to facilitate their review and fine-tuning in the later stages of the design process.

To obtain an estimate of the minimum land area required for a FILTER system, we need to first calculate the minimum land area needed to accommodate the maximum hydraulic loading of effluent and rainfall at the site. We then look at the minimum land area required to sustainably accommodate the loading of pollutants such as phosphorus, nitrogen and organic matter at the site. The higher value of these two figures is selected as the minimum land area required to manage the combined hydraulic and pollutant loading. The pollutant loading is only likely to be the constraint with high strength pollutants.

Hydraulic loading considerations for Land-FILTER systems

The minimum land area required for Land-FILTER based on hydraulic loading considerations can be calculated as follows.

(1) Assess *Peak Effluent Flow Rate* in (m^3/d)

(2) Determine *Drainable Soil Porosity* with depth (m^3/m^3)

(3) Select *Drain Depth* (m)

(4) Calculate *Drainable Depth* (mm) – obtained by multiplying depth-weighted *Drainable Soil Porosity* by *Drain depth*

(5) Select a suitable FILTER *Cycle* (days) as discussed below

(6) Calculate *Cycle Drainage Rate* (mm/d) by dividing (4) by (5)

(7) Determine *Net Evaporation* (mm/d)- take average ETc minus rainfall over cycle period

(8) Assess *Groundwater Flow* (mm/d), to the site or from the site

(9) Calculate *Hydraulic Drainage Capacity* (mm/d)- add (7) and (8) to (6) and convert to m/d

(10) Calculate *Base Area* (ha) - Divide the *Peak Effluent Flow* (1) by the *Hydraulic Drainage Capacity* (9) to determine Base area required and convert to ha

(11) Determine *Agricultural Area* (ha) - increase *Base Area* by appropriate allowance for harvest, sowing and other operations e.g. 10%

(12) Assess *Gross Area* (ha) – increase *Agricultural Area* by an allowance for roads, channels, storage areas etc, e.g. 10%

Repeat these calculations for different months, using the effluent flow rate for different periods of the year. Select the highest land area. Where the drainage period is less than the length of the FILTER cycle, the *Design Drainage Rate* needs to be determined and used in the above calculations. The *Design Drainage Rate* is usually higher than the *Cycle Drainage Rate* because there are usually at least three days in the cycle when drainage is prevented, namely; the irrigation day, a post-irrigation equilibrium day and a post-drainage equilibrium day before the next irrigation starts. The modified calculation procedure is as follows.

(13) *Drainage Period* (days) – deduct 3 days from FILTER *Cycle* (5)

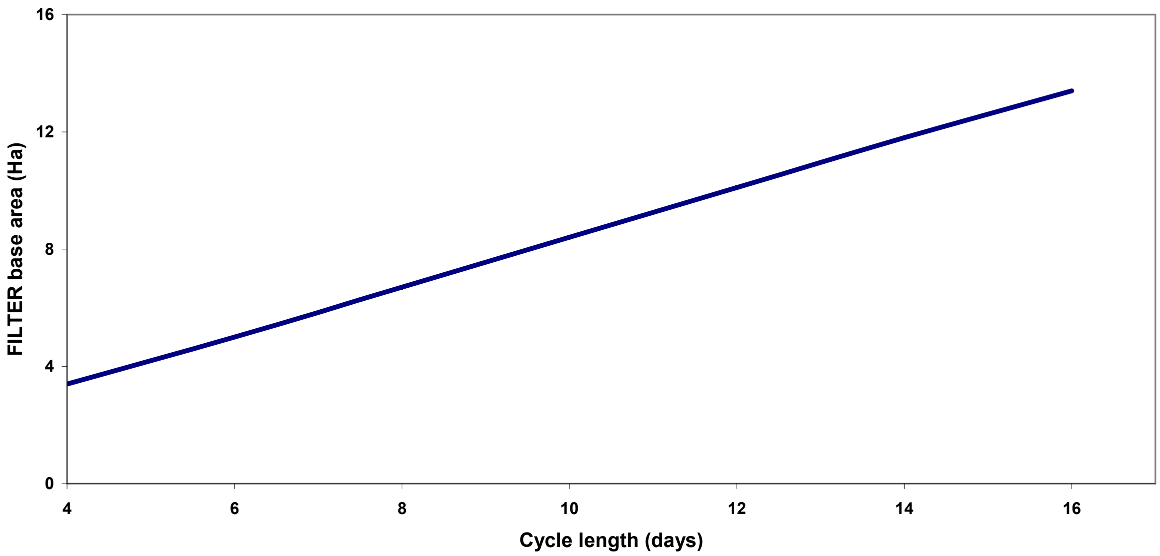
(14) *Design Drainage Rate* (mm/d) - divide (4) by (13)

(15) Use the *Design Drainage Rate* in the above calculations

These calculations provide an estimate of the area of land required for a specified hydrological loading of a FILTER system. The land area required is sensitive to the effluent volume, soil porosity, drain depth and cycle length. Once the volume of effluent to be treated is chosen, then only the others are variables. The soil porosity may vary from site to site and as such can affect the land area required by choosing different sites. Soil porosity can be changed by undertaking soil loosening and chemical amendment application to the site. At any particular site only the drain depth and cycle length can alter the land area required. Usually the cycle length needs to be an appropriate period between irrigations that allows good crop growth and farmer access to the fields. This would normally be in the region of 7 to 20 days. Changing the cycle length can have a large impact on land area required, **Figure 9**.

It may be tempting to design a very short cycle length in order to minimise the land area. However, there are severe limitations such as the risk of waterlogging, providing adequate time for normal farming and trafficking operations and the cost of the drainage system. At a 5 day cycle the risk of waterlogging will be severe as there will be 3 non-drainage days and 2 drainage days. Agronomically a longer 10 to 20 day cycle is more acceptable for crops which do not tolerate waterlogged conditions.

Figure 9. Effect of cycle length on Land-FILTER area, for effluent volume 1 ML/d, drainable porosity 0.07 and drain depth 1.8 m

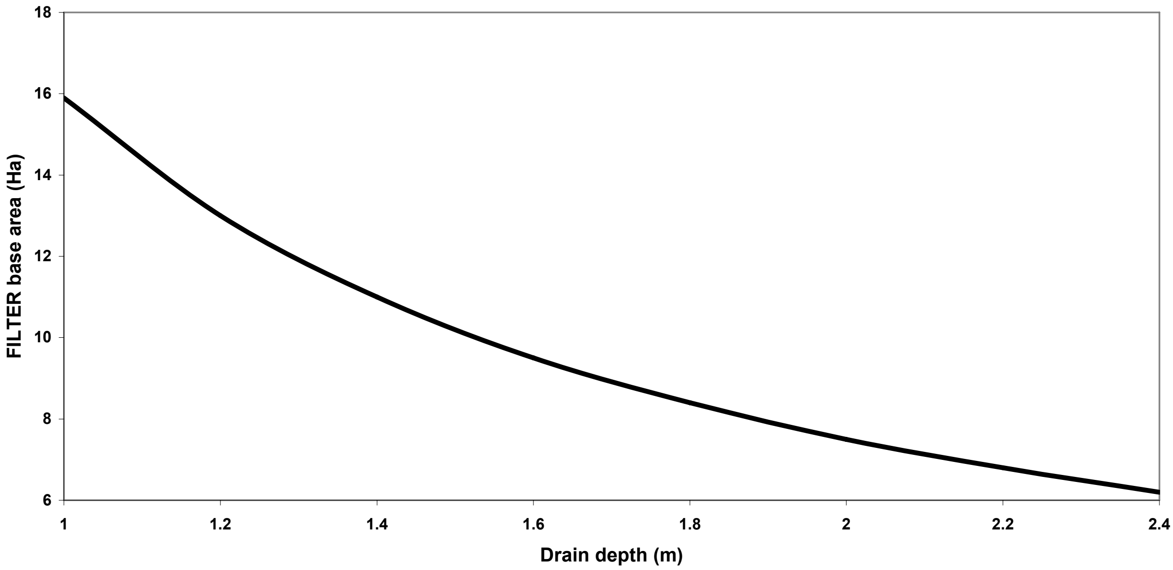


The shorter the cycle length the more intensive the drainage system required. For example, a five day cycle will require the drainage system to drain the profile in only two days. This will require very closely spaced drains and hence have higher cost. An analysis is required of the trade off between cost savings with reduced land area and cost increases with higher drainage intensity.

Changing the drainage depth also has a major effect on the area required as this alters the volume of water that can be treated per irrigation cycle, Figure 10. There may be limitations to increasing the drain depth. These may be the type of machines available for installing the subsurface drains to different depths or the physical characteristics of the site, e.g. a heavy impermeable layer, or cost, as installing drains deeper is more expensive. Again this will require analysis between reduced costs of land and increased drainage installation costs. In general, installing the drains at the maximum depth of available machines is beneficial, to maximize the flow path and the volume of effluent treated during each filter cycle. The longer flow path will provide more efficiency in pollutant removal and pollutant storage in the soil profile. In saline soils, installation of drains to greater depth will lead to more salts leaching in the drainage waters during the initial soil reclamation period, which needs safe disposal.

The FILTER system eliminates the need for winter and wet weather storage of wastewater. Hence, the requirement of an adequate area of suitable additional land for wastewater storage does not need to be considered, unlike in effluent irrigation systems where this is an important design consideration.

Figure 10. Effect of drain depth on Land-FILTER area. Effluent volume 1 ML/d, drainable porosity 0.07 and cycle length 10 days.



Hydraulic loading considerations for Catchment-FILTER systems

With the Catchment-FILTER systems the maximum hydraulic loading depend of factors such as the vertical infiltration rate, capacity of the soil to remove pollutants during flow through the soil to the groundwater, capacity of the crops grown to withstand temporary surface water-logging and poorly aerated conditions in the root zone, and site hydrological conditions.

The site hydrological factors that need to be considered are the existing hydrological flows and water storage capacities, pumping design and management and movement of pollutants into and in the groundwater in relation to pollution risks of this drainage water source for other uses. The hydrological loading considerations in Catchment-FILTER systems at the Yanggao site are discussed in detail in an associated report (Khan et al. 2006).

Nutrient and other pollutant loading considerations

The minimum land area to accommodate loading of phosphorus and nitrogen need to be based on maintaining a balance in the system and on consideration of the consequences of any imbalance on the short-term and long-term on-site and off-site environmental effects, on the FILTER plots, groundwaters and receiving waters.

Maintaining the concentration of nutrients in the drainage waters below EPA or wastewater regulatory agency limits through adequate filtration and breakdown in the soil is the main short-term goal. The results from the FILTER trials and associated modelling studies can provide an indication of the rates of reduction in nutrient concentration and loads that could be expected during effluent flow through the soil to subsurface drains and subsequent changes during annual cropping cycles (Gao et al. 2000, Jayawardane et al. 1997a, 2006). A long-term concern is the accumulation of nutrients and other pollutants in the soil, which could result in subsequent leaching of these pollutants in the drainage water. Pollutants will accumulate in soil where the additions in the effluent exceed pollutant removal through processes such as crop uptake, subsurface drainage and breakdown in the soil.

In order to calculate the long-term pollutant balance we need to estimate the pollutant additions and removal rates on a unit area basis. This could initially be done on the basis of the minimum land area for hydraulic loading rate derived in the previous section. To calculate the pollutant additions, we could use the estimated minimum land area for hydraulic loading rate, effluent loading rates and data on the concentration of pollutants in the effluent that were collected in step 5. The removal of pollutants in subsurface drainage, crop uptake and breakdown in the soil could be estimated from the previous FILTER studies, information available in the literature and results of local research studies. For instance, the average crop uptake of nutrients such as nitrogen and phosphorus are given in Table 7 for selected crops. If the load of a given pollutant exceeds the rate of removal, the minimum land area has to be increased until balance is reached. This higher land area value should then be accepted as the minimum land area. Detailed procedures for pollutant loading calculations are given in USEPA (1981) and other manuals on land application of wastewaters.

Table 7. Nutrient removal rates of different crops (US EPA 1981)

Crop Type	**Removal rate (kg/ha/yr)**		
	Nitrogen	**Phosphorous**	**Potassium**
Wheat	160	15	20 – 45
Maize	175 - 200	20 – 30	110
Ryegrass	200 - 280	60 – 85	270 – 325

In the case of phosphorus, applications that exceed crop uptake will result in the excess phosphorus being initially being absorbed on the soil. However, when the phosphorus absorption capacity of the soil is filled, the excess phosphorus will tend to leach through the system. This could then result in the phosphorus concentration in the drainage waters exceeding EPA or wastewater regulatory agency limits. Soil phosphorus absorption capacity measurements can be used to indicate how long it will take for phosphorus saturation of the soil to occur. The time to phosphorous saturation depends on the land area, its hydraulic loading rate and the phosphorous concentration in the wastewater. However, preferential flow pathways could severely diminish the capacity of soils to store phosphorus. For long-term phosphorus balance, the FILTER land area has to be adequate to match crop phosphorus uptake rate to net phosphorus application rate in the wastewater.

In the case of nitrogen, it is necessary to maintain a crop-season nutrient balance as accumulations of nitrogen in the soil could lead to formation and leaching of nitrate-nitrogen. In addition to crop uptake, gaseous losses could provide significant removal. Land application of wastewater usually result in about 15% of the nitrogen applied in being lost through gaseous losses, but these losses could be higher with some wastewaters and soils.

The balances of other degradable pollutants such as organic and inorganic chemicals can be considered in the same manner as nutrients, as discussed in wastewater irrigation manuals (USEPA 1981, Pescod 1992).

With regard to suspended solids, the main concern is that they will block soil macropores. This will result in a reduction in water flow rates through the soil and could lead to poor soil aeration affecting cropping. The suspended solid loading rate should be less than the rate of breakdown of this material in the soil, which in turn depends on factors such as the climate of the area. The EPA in New South Wales, Australia recommends a maximum loading rate of 280 kilograms of BOD per hectare per week (NSW EPA 1995).

In the case of heavy metals, the loading rate needs to be maintained below the levels where the soil accumulation and crop uptake remains below acceptable limit, where the crops are used for human consumption or for animal feed. Removal of sludge in wastewater pre-treatment can be used to reduce heavy metal loading rates. Selection of non-edible crops allows short-term increase in loading rates that leads to storage in the soil, according to the soil absorptive capacity. As this capacity is filled, the heavy metals will leach in the drainage water. FILTER sites used for treatment of wastewaters containing heavy metals need to be carefully monitored and managed to prevent potential long-term adverse effects on the local environment and to meet the requirements of wastewater regulators

When the approximate effluent application land area requirement based on hydraulic and pollutant loading considerations has been calculated, additional land areas required to provide for buffer zones, service roads etc needs to be added. An additional area of approximately 10-25% should be sufficient.

2.3. Stage C - Site identification and evaluation for FILTER

2.3.1. Step 7. Identify potential land sites

This is a broad-scale assessment of the suitability of land within reasonable distances of the wastewater sources, combining design experience of the technical experts with local knowledge of the area. The aims are to assess the technical feasibility of the FILTER system under existing combinations of climate, soil, groundwater and other local conditions at the potential sites. It also considers in a preliminary manner the sensitivity of the surrounding environment to the treatment system.

This step involves bringing together all available information on seasonal climatic fluctuations, soil, groundwater and crop information, and carries out a preliminary evaluation in a broadly integrated manner. This will allow a quick screening of potential sites, based on a matching of the critical requirements of the FILTER system with the features of the potential sites, where an adequate land area calculated in step 6 is available. The aim will be to eliminate sites that are obviously unsuited due to adverse site features, and identification of promising sites that can be subject to further consideration and investigation.

The presence and sensitivity of receiving water bodies, indicated by the EPA or wastewater regulatory agency specifications on the quality standards that must be met to accept the drainage water from the sub-surface drains of the FILTER system, is also an important consideration. Where the sensitivity of the receiving waters is low, the specific pollutant removal expectations from the FILTER system are reduced, allowing more flexibility in design and management of the system.

The integration of the FILTER system into the enterprises in the area and their economics could be important considerations. For instance, if a broad-scale application for planning a new township in China is being considered, reuse of the FILTER drainage water in the local industry and other reuses could provide a significant economic saving in the town water supply needs. Alternately a reduction in chemical pollutant and pathogen levels in the FILTER drainage water could make it suitable for irrigation reuse in market crops for the town, providing a significant economic benefit. Where low-value degraded waterlogged, saline or sodic lands are present in the vicinity, the dual benefit of reclaiming this land for sustainable agriculture and simultaneously treating the wastewater could provide an attractive economic incentive (Figs. 7 and 8).

The range of crops and cropping enterprises, as well as the availability of local markets can have significant effects on the economic viability of the wastewater treatment system or combination of systems. For instance, the opportunity for producing of green-feed such as pasture silage and grain for off-site animal husbandry in the surrounding area will allow regular harvesting and nutrient removal to maintain long-term nutrient balance for ensuring sustainability of the FILTER site, provided there are sufficient potential buyers within reasonable distances. Where pumping of the subsurface drainage waters from the FILTER system is required, availability of electricity and the costs of electricity supply to each site needs to be considered.

2.3.2. Step 8. Screen potential sites based on preliminary field investigations

Site screening involves combining all the existing information on the potential sites into an assessment framework to select 1-2 sites, from the potential sites identified in step 7.

In relation to soil factors, the Land-FILTER technique is best suited for sites with a high groundwater table or where a presence of soil layers with restricted permeability creates a perched watertable. It can be used to reclaim waterlogged, salinised and degraded lands. It is unsuitable for soils with soil layers of high permeability to depth in areas without a high regional watertable, as the effluent applied will drain rapidly beyond the subsurface drains. The Land-FILTER system was also successfully tested in a moderately permeable soil, where part of the excess effluent applied was removed through the sub-surface drainage system, and the balance flowed to the deeper ground water. In such situations, the effect of the water flowing beyond the subsurface drains on the quality of groundwater need to be meet the standards set by the EPA or wastewater regulatory agencies for that specific location. Ideally the soil above the low permeability layer should have high permeability to allow a wider spacing of the subsurface drains, thereby reducing the cost of installation of the drainage network. Upper soil layers that have finer textures with high absorptive characteristics for the pollutants will be beneficial in filtering the pollutants, provided that they have adequate permeability. Land sites with freely draining soils and deep watertables are more suited for the Catchment-FILTER systems.

The nature and details of the field data collected will depend on the level of existing information and dominant environmental considerations. If soil maps are not available, a soil survey and mapping should be carried out to determine the geographical distribution of the soils types over the sites. For each soil type, the main soil profile features need to be described. The field soil characterization includes identification of layers in the soil profile and a description of each soil layer in terms of soil properties such as texture, structure, colour, organic matter content and porosity characteristics. Soil layers should be sampled to measure the chemical properties, especially those relating to the nutrient and other pollutant retention properties. The soil properties measured should include pH, EC, ESP, phosphorus, nitrate-nitrogen, NH_4-nitrogen and any other pollutants that could leach out during the initial reclamation period.

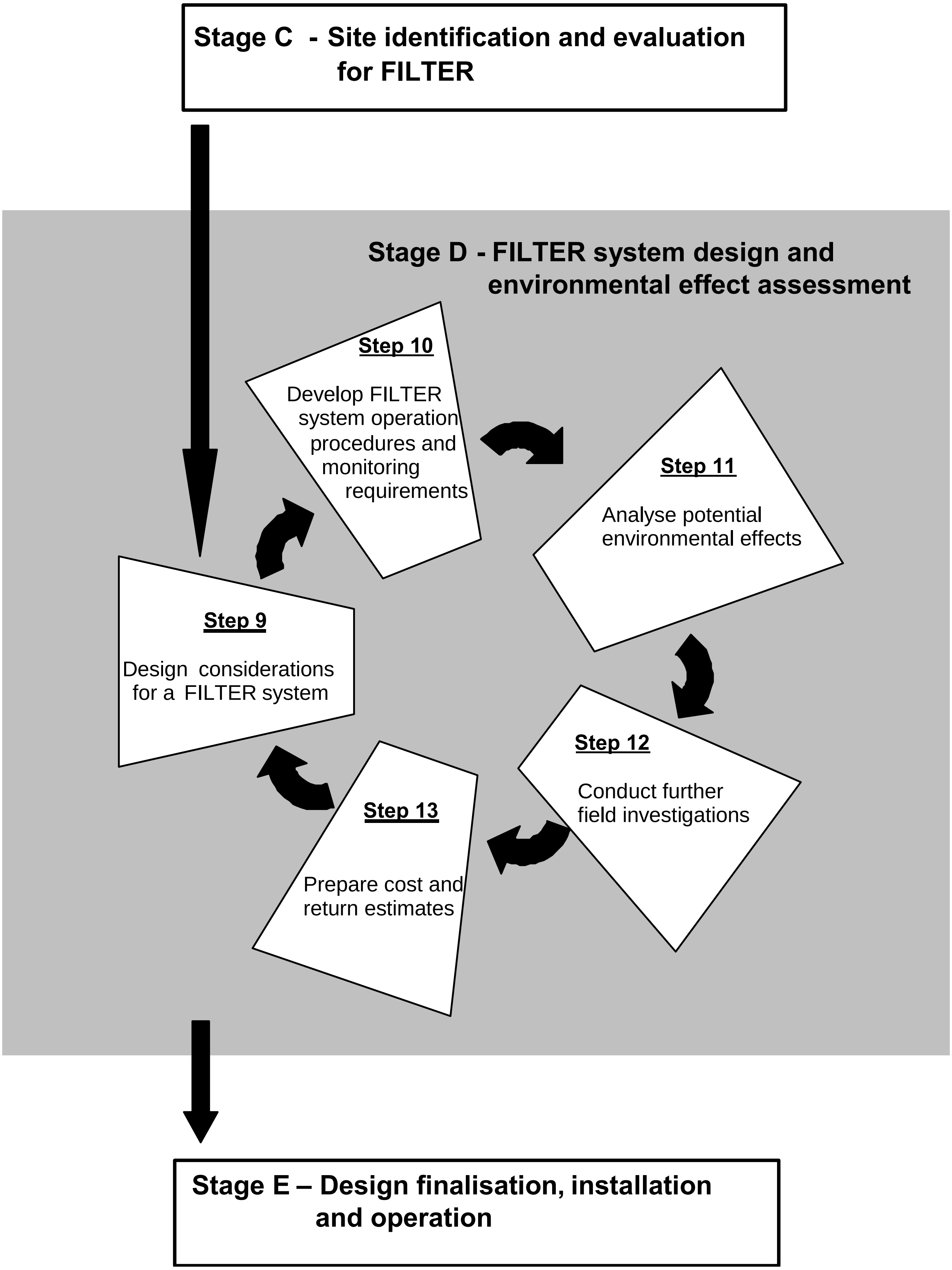
Additional measurements should be carried out in-situ or on undisturbed soil cores to evaluate the soil properties that affect water flow through the soil and hence the drainage design. These include the hydraulic characteristics of each layer of the soils, such as the moisture release curves and the soil hydraulic conductivities.

The presence of soil layers which are restrictive to water flow have an important bearing on the design of the FILTER systems and need to be identified. If existing information does not provide a clear picture of groundwater conditions and movement, hydrological field investigations need to be carried out.

2.4. Stage D – FILTER system design and environmental impact assessment

Steps 9 to 12 involve an iterative approach to progressively fine-tune the system design and to make the necessary design adjustments to meet the hydraulic loading and environmental standards for drainage discharge, Figure 11. It may be necessary to go through the steps in the loop illustrated in Figure 11 several times, to move towards the final design and operation system. For example, the land area selected to meet the FILTER hydraulic loading requirements based on soil and hydrological characteristics, may be inadequate to meet the crop nutrient removal capacity of the preferred crop rotation to maintain balance for a sustainable system. This may require changes in crops or the FILTER land area or both, which in turn may need adjustments in the FILTER engineering design. Unacceptable potential impacts of the FILTER design on the surrounding environment, will require re-adjustment of the FILTER design. Optimisation studies provide an effective mechanism to choose between different options, and to reach the optimal results that meet defined goals.

Figure 11. Stage D is an iterative process



2.4.1. Step 9. Design considerations for a FILTER system

There are two approaches that could be used in developing the design of a commercial FILTER system. One approach is to utilise the information collected during the field soil characterisation in step 8 and the information from previous field trials to design the commercial system. The other approach is to use a “test-plot” approach at the selected site, where the results from a scaled down version of the system is operated and the data utilised to develop the design of the commercial system.

Design subsurface drainage flow rate for the Land-FILTER system

The flow rate through the Land-FILTER system depends upon factors affecting the flow rate to the subsurface drainages. These are the hydraulic conductivity and the moisture release characteristics of the soil, depth and spacing of the drains and the depth to the impermeable layer below the drain depth. Based on the soil properties and the actual land area available at the sites selected in step 8, the drainage design required to meet the flow rates to the subsurface drains can be assessed, using methods described by Bouwer and Schilfgaarde (1963), Youngs (1985) and Smedema and Ryecroft (1988).

The following key drainage design criteria need to be determined as described in step 6 :

- Drainage Period (days)
- Design Drainage Rate (mm/d)
- Drainage depth (m)
- Drainable Porosity (m^3/m^3)

Using the above design criteria, a drain spacing can be established. This can be done by assuming that after the post irrigation equilibriation period there is no further recharge and the discharge is related to the rate of fall of the watertable. Using the Bouwer and Schilfgaarde (1962) formula and combining with full Hooghoudt steady state formula yields an equation that takes into account flow below and above the drains (Smedema and Rycroft, 1988), for a non-layered soil.

$$L^2 = 10\ K\ d\ t\ /\ p\ [\ \ln \{h_o (2\ d + h_t)\ /\ h_t (2\ d + h_o)\}\ ]^{-1}$$

Where: L is the drain spacing (m), K is saturated hydraulic conductivity (m/d), d is equivalent depth (m), t is time in days for water table to fall from h_o to h_t , p is the drainable pore space

(m^3/m^3), h_o is the starting watertable height above the drain (m) and h_t is the watertable height above the drain after time t (m).

The equivalent depth can be calculated using:

$$d = D/ [\{8D/ \Pi L\} \ln \{D / p+1\}] \quad \text{for } D<1/4L$$

and $$d = \Pi L / [8 \ln \{L/p\}] \quad \text{for } D>1/4L)$$

where D is the depth to an impermeable layer and Π approximately equals 3.14.

The drainage design needs to fit the FILTER design criteria. This first step is to use the above formula to determine a drain spacing that allows the watertable to drop from the soil surface (the point at which it will be after the post irrigation equilibrium period) to 0.1m above the drain (0.1m above the drain is to allow for the residual watertable head above the drains). When undertaking this analysis a depth weighted drainable porosity should be used. The interval *t* is set at the previously determined Drainage Period.

This provides an initial drain spacing that will provide drainage at the Design Drainage Rate criterion. This drain spacing must then be checked against a root zone aeration (waterlogging) control criterion, see next section. When soils are layered the drainage design is more complicated as the flow patterns may be quite different to those assumed in the Hooghoudt formulation.

Root zone aeration criteria

In the FILTER system the risk of poor root zone aeration is potentially high because the hydraulic loading is high and as explained before the system has to retain all rain and effluent water on the treatment plots. Poor root zone aeration occurs when the air content of the soil is low because most pores are filled with water. Root zone aeration can be said to be inadequate when the air filled pore volume falls below 5-10%. This is often referred to as waterlogging. This generally occurs when the watertable rises into the root zone.

Generalised criteria have been developed as to how quickly the watertable should be drained out of the root zone. For crops that are not tolerant to waterlogging, generally the watertable should drain from the upper root zone in 1 to 2 days and after 2 to 3 days the entire main root zone should be drained, Smedema and Rycroft (1988). Because of the nature of the FILTER system it is necessary to design for good waterlogging control. It is suggested that the drainage design should ensure that the watertable can drop from the soil surface to 0.3m depth in one day.

Using the same criteria and equations as for the initial drainage design, the drain spacing should be calculated that ensures that the watertable can drop from the soil surface to 0.3m below the surface in one day. When undertaking this analysis the appropriate drainable porosity for the top 0.3m of soil should be used.

If this analysis results in a wider drain spacing than already determined then the initial design spacing is taken. If this analysis results in a closer drain spacing than already determined then the closer design spacing is used. If a closer spacing is chosen then this will result in a higher drainage rate than required for the Design Drainage Rate. Using the closer spacing, the time in days for the watertable to drop from the soil surface to 0.1m above drain depth should be calculated and hence the new drainage rate determined. This may then be used to shorten the Cycle length and hence reduce the land area required, if appropriate.

Improving soil properties

Where soils have low porosity and hydraulic conductivity (e.g. most clay soils) soil loosening can be undertaken when installing the FILTER system. In this way the hydraulic conductivity of the soil can be improved as can its adsorption properties. Soil loosening can be done by deep ripping (to about 1.0m) at close spacing (about 0.5m). This should be done progressively e.g. 0.3m, 0.6m, 0.9m, in order to maximum soil loosening and avoid creation of very large soil blocks. For sodic soils gypsum can be applied at adequate rates (e.g. 5t/ha on heavy swelling clay soils) before ripping. After ripping, cultivation with tines and discs can be used to break down any large soil blocks created.

Maintaining drainage flow rates

In unstable swelling soils, maintaining the long-term hydraulic flow rates is dependent on the combined effect of soil salinity and the exchangeable sodium percentage on soil structural stability (Jayawardane et al. 2001). Therefore, the management of these soils needs to be take into account the changes in soil salinity and sodicity with time. For example, saline-sodic soils may be highly permeable initially due to a high level of salts. When these salts are leached from the system the soil may swell due to the high sodium levels thus reducing the hydraulic conductivity, unless there is a corresponding reduction in soil sodicity. This may mean designing the drainage system for a lower hydraulic conductivity than is measured at the site before reclamation or adding suitable chemical amendments like gypsum to the FILTER plots.

It is also important to maintain the required surface infiltration rates of the FILTER plots. Any factors likely to contribute to reduced infiltration at specific site such as clogging with suspended solids, trafficking damage etc needs to be corrected or avoided to prevent surface ponding that could adversely affect crop growth.

Concentration of pollutants in the sub-surface drainage water

The concentration of pollutants in the drainage water depends on several factors. These include the concentration of pollutants in the effluent applied and the rate of removal of pollutants during flow through the soil to the sub-surface drains. Removal is by cropping, adsorption, crop uptake and degradation processes in the soil. Increasing the spacing between the drains can lead to increased pollutant removal, along the longer flow path to the drains. The adsorption coefficient of the soil to specific pollutants is an important factor.

Maintaining adequate root zone conditions to maximize crop production and nutrient removal

As discussed previously, a balance needs to be maintained between imposing high loading rates to minimise the land area and the need to provide adequate drainage for soil aeration that will not limit crop growth and production. This depends on the characteristics of different crops, soils and weather conditions. Drain spacings, pipe and pump sizings can affect the rate at which water can be removed from the FILTER system. For most crops, the watertable should be reduced from the soil surface to 0.3m depth in about one day.

Any imbalances in essential crop nutrients will need to be corrected by suitable agronomic management practices. For instance, if the nitrogen loading is inadequate for optimum crop growth, the uptake of phosphorus could be reduced. In such situations the application of supplementary fertilizer nitrogen is required.

The drainage design should allow adequate control structures so that watertables can be maintained at any height above the drains. The design should ensure that it is possible to stop the drainage outflow, without causing flooding at the lower end of the drainage system.

The long-term removal of pollutants through the FILTER system

To maintain a sustainable FILTER system, the long-term pollutant load removal through the FILTER system should match the load input in the wastewater applied. Pollutant removal occurs through crop uptake, degradation in the soil and subsurface drainage outflows. The procedures for calculating these inputs and outputs are discussed in step 6, and these calculations could be refined using the additional site specific data collected in the field studies.

Crop selection

Plants play an important role in FILTER systems, by taking up water and nutrients and maintaining soil physical properties and biological activities in the root zone. By ensuring good growth and yields, the nutrient removal and economic returns can be maximised. Factors affecting crop selection are:

- Crop uptake of wastewater constituents, especially nutrients
- Crop tolerance to nutrient availability, salinity and sodicity problems
- Crop drainage requirements for soil aeration, and tolerance to waterlogging
- Crop tolerance to pH and heavy metals
- Crop establishment, cultivation and harvest requirements and timing
- Crop marketability
- Suitability and ease of double or multiple-cropping in each year

In the first instance, the range of cropping will be limited to those specified by the EPA or wastewater regulators as safe from health standards and those suited to the selected FILTER design and operation conditions. Within this range the preference would be to grow the suitable crops with highest financial returns, where the emphasis in agro-engineering management of the FILTER system is to maximise the use of the wastewater resource. However the need for ease of management may necessitate cultivation of crops such as pasture in a section of the farm. If the aim of the FILTER management is to maximise the treated drainage waters that could be reused on a limited land area, water logging tolerant crops with high nutrient uptake capacity would be preferred.

The generalised and detailed procedures for selection of crops for FILTER systems and their agronomic management are similar to the procedures used in wastewater irrigation projects, which are described in standard wastewater irrigation manuals (US EPA 1981, Pescod 1992, NSW EPA 1995). Information provided by local and regional wastewater reuse authorities in

China should also be utilised in selecting the appropriate crops for FILTER sites and their agronomic management.

Selection of the number of irrigation blocks and the irrigation/drainage scheduling in Land-FILTER systems

To implement the cyclic irrigation and drainage regimes in Land-FILTER systems, it is necessary to divide the land area into several irrigation blocks. In the first instance, 7 blocks could be chosen to fit into a fortnightly routine of two-day irrigation followed by post-irrigation equilibrium, pumping, and pre-irrigation equilibrium periods (Figure 4). Adjustments in the block layout can be made according to the sizes and shapes of the land.

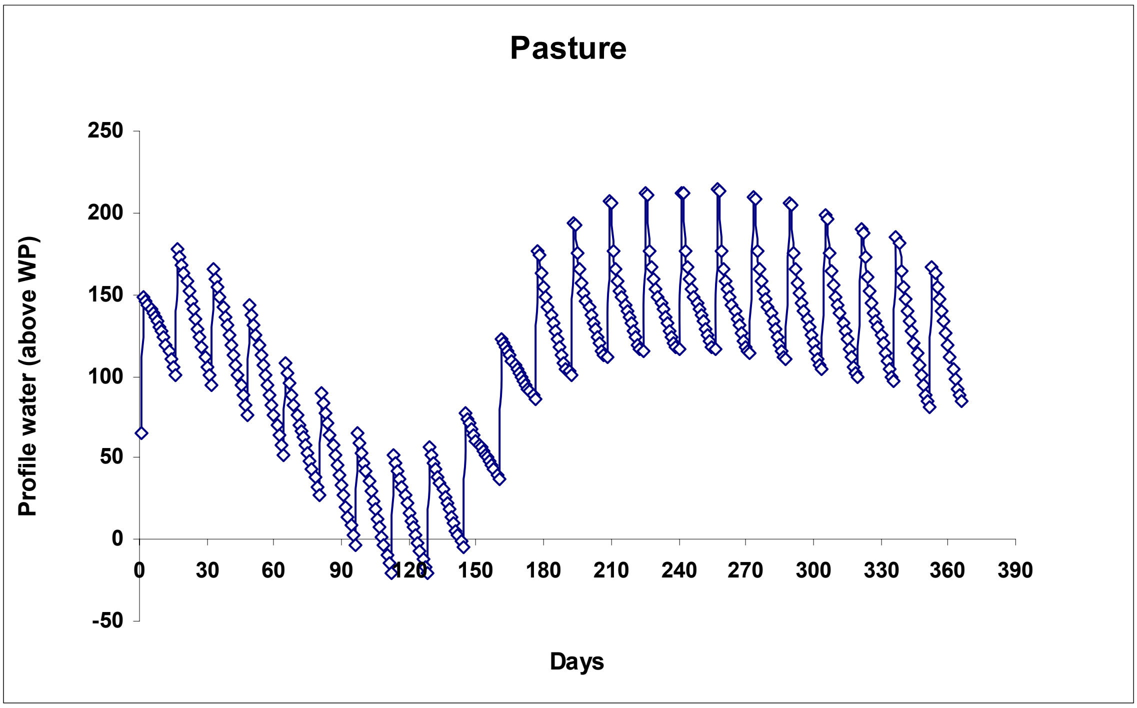
As discussed previously, the way the agro-engineering aspects of the Land-FILTER system is driven at different locations, depends on the specific goals of the wastewater manager. If the aim of FILTER management is to maximise the treated drainage water discharged from a limited land area, a high hydraulic loading of effluent for water-logging tolerant crops would be preferred. The irrigation/drainage scheduling could also be adjusted to cater for changes in seasonal effluent supply and climatic conditions in different months of the year. If the effluent supply increases during wet winter months, a shorter cycle could be adopted to increase treated water removal in the subsurface drains, provided that the pollutant removal is adequate under the higher hydraulic loading.

2.4.2. Step 10. Develop FILTER system operation procedures and monitoring requirements

A typical operation of the Land-FILTER system requires adoption of a 14-day rotation system of applying the wastewater sequentially to different FILTER plots. This requires at least 7 plots, each receiving 2-days of wastewater application on a 14-day cycle. As some of the FILTER plots need to be taken out of this cycle periodically for crop agronomic operations such as planting, harvest etc., a shorter filter cycle will need to be adopted in such periods

The method for developing a site-specific Land-FILTER farm operational manual is described in a report prepared for the Griffith City Council for managing their FILTER site (Jayawardane et al. 2002b). A daily water balance was used to predict soil profile water storage for specific cropping, based on effluent application rates, potential evapo-transpiration rates, crop factors and subsurface drainage rates, Figure 12. The predicted dry soil periods could be used for planning the harvest of the crops and the land preparation for establishment of new annual or perennial crops, in the different irrigation blocks. The success of the FILTER systems depends on efficient cropping, irrigation, drainage and site management and monitoring procedures, which can be listed in the Farm Operational Plan for the site.

Figure 12. Changes in soil profile water storage above wilting point under a perennial pasture, starting from 1st November at the Griffith site



Advice may need to be provided in the Farm Operational Manual to the farm operators on maintaining detailed written notes on an annual, seasonal and day-to-day basis, and on environmental sampling and monitoring, public health protection, reporting etc. It is also necessary to provide detailed procedures on site security, public access, visitor safety and staff health and safety issues.

The monitoring design should list the pollutants. For each pollutant, the frequency and method of sampling and analysis must be recommended. The monitoring system should be designed to:

- Track wastewater and pollutant concentrations/loadings of effluent applied
- Discharge of treated wastewater and pollutant concentrations
- Record of operational and environmental performance
- Specify how the monitoring can be used to adjust operation of the site
- Ensure EPA or wastewater managemenr agency regulations are met
- Provide a data compilation system that allows the manager to keep up-to-date with the operational and environmental data

- Highlight events and conditions that signal the need to review management and monitoring protocol

In common with other land-based wastewater use and treatment systems, the FILTER system operates within a dynamic natural system, in which the crops, soils and climate interact. A very precise prediction of the FILTER performance or environmental effects is not possible, even where a very detailed design process is employed based on extensive field trials. Many of the assumptions used in the design may need to be refined using the data collected during actual operation. With careful management in the early stages, such refinement can be made with minimal adverse effects on the system performance or the environment. Planning of ongoing monitoring is required to achieve this, and the results must be reviewed regularly to see if the system is functioning properly and if its management and operations can be improved.

2.4.3. Step 11. Analyse potential environmental effects

As with other systems of land application of wastewaters, the FILTER system will need to operate within the EPA or wastewater regulatory agency guidelines on environmental effects. The potential effects on air, land, groundwater, human health, ecosystem, economic, social and cultural effects needs to be considered. The detailed procedures to be used are extensively described in land treatment manuals (NSW EPA 1995, USEPA 1981, NZLTC 2000).

Comprehensive field investigations need to be carried out to evaluate the potential environmental effects.

2.4.4. Step 12. Conduct further field investigations

This step involves carrying out additional field studies to deal with site specific problems and issues. For instance, if the site has a salinised soil, the rate of salt removal in the subsurface drainage and the management of the saline drainage water could be an important issue to downstream uses. More detailed soil and hydrological investigations will then be needed to quantify the extent of site salinisation and to develop acceptable soil amelioration and salt discharge strategies (Jayawardane and Blackwell 2002).

2.4.5. Step 13. Prepare cost and return estimates

This step estimates the capital and operating costs of FILTER systems and other treatment options (Jayawardane and Blackwell 2006). This will allow a calculation of relative benefits of different FILTER operational options, and its potential combination with other treatment techniques at specific sites.

A Land-FILTER economic assessment model is available for calculation of the land application site economics in China, using a spreadsheet (Cheng et al. 2003).

2.5. Stage E – Design finalisation, installation and operation

2.5.1. Step 14. Finalise design and obtain resources

Steps 9 to 13 evaluate the alternative FILTER designs and sites, and results in the recommendation of the preferred option. Any additional site information obtained can then be used to finalise the design of the detailed engineering aspects of the irrigation and sub-surface drainage collection.

Design information from stage D on the irrigation blocks and the anticipated flow rates through each block to the underlying subsurface drainage system can be used to design the final layout of the subsurface drainage design components, such as the depth and spacing of drains, drain pipe sizes and drain installation gradients. The design data from all the blocks are integrated to design the drainage collector pipes, sumps, pumps and associated structures, which can be illustrated in design engineering layout drawings.

2.5.2. Step 15. Install the FILTER system

Land-FILTER systems

The installation procedures of the Land-FILTER system will vary according to the site features. In general, it involves several steps as outlined below:

1) Initial land surface preparation, such as land clearing and surface slope grading according to the type of irrigation practiced.
2) Installation and commissioning of main drainage sump and pump
3) Installation of discharge pipework to remove treated water from the site
4) Installation of collector mains and submains.

5) Installation of horizontal drain laterals at required depth, spacing and grade. Use of a gravel envelop around the drain pipe, if required. Connection of the drain laterals to the collector submains.
6) Where soil porosity is inadequate, loosening of the soil above the drains is required by deep ripping and cultivation. This may be combined with addition of chemical ameliorants to increase soil stability.
7) Installation of sumps and valves in the drainage system to control the sub-surface drainage.
8) Construction of a bund around the FILTER plots with sufficient height to safely retain all wastewater applications and peak rainfall.
9) Installation of the irrigation channels to apply the wastewater to the FILTER plots, and associated irrigation control structures.
10) Installation of structures to measure the irrigation and drainage volumes, and devices to sample these waters for chemical analysis.

In the Catchment-FILTER system, the installation of a vertical drainage system can precede or follow the field instalment of the surface irrigation system.

2.5.3. Step 16. Operate and monitor the FILTER system

The designers of the FILTER system in consultation with the FILTER operators, need to finalise the FILTER farm operations and monitoring handbook, which details all the information required by the farm operators. Initially the farm operator needs to strictly follow the instructions in the farm operator handbook. As the farm operator gains field experience in running the FILTER system, the operator can initiate modifications to facilitate ease of operation and to increase the efficiency of the system.

3. Summary

These guidelines are intended to provide a broad understanding of a complex design process, in a step-by-step manner.

Steps 1 to 16 will guide those responsible for wastewater reuse and treatment sequentially through the issues and decisions involved in designing, installing and operating FILTER systems, potentially in combination with other complimentary treatment systems. At the end of each step, a check needs to be made that the milestones listed in Table 1 are met.

Local knowledge and experience from FILTER test sites and other land applications systems will be useful in complementing the use of these guidelines at specific sites.

The outcomes of this sequential process will be

- A fully sustainable FILTER system operating successfully to provide the required pollutant reduction below EPA or wastewater regulatory agency limits, maintaining adequate flow rates and protecting the environment, and ensuring public health and safety.
- An informed community and stakeholders
- Documentation of design process
- Documentation of engineering drawing for use in tender process
- A site management and monitoring plan to meet the requirements of the regulatory authorities and to ensure the long-term sustainability of the land application site.

4. References

Asano, T. and Roberts, P.V. 1980. Proceedings Symposium on Reuse for Groundwater Recharge, September 1979, Kellogg West Center, California State Polytechnic University, Pomona, California.

Aulenbach, D.B. and Clesceri, N.L. 1979. Monitoring for Land Application of Wastewater. Fresh Water Institute, Lake George, Troy, New York. Report 79-3, 34 pp.

Aulenbach, D.B., Clesceri N.L. and Tofflemire, J.I. 1975. Water renovation by discharge into deep natural sand filters. *Proceedings of the 2nd National Conference on Complete Water Reuse.* Fresh Water Institute, Lake George, Troy, New York. Report 74-20.

Baillod, C.R., Waters, R.G., Iskandar, I.K. and Uiga, A. 1977. Preliminary evaluation of 88 years rapid infiltration of raw municipal sewage at Cabinet, Michigan. In *Land as a Waste Management Alternative*. R.C. Loehr, Ed. Ann Arbor Science, Ann Arbor, Michigan, Chapter 26, pp. 489-510.

Bouwer H.R. and Schilfgaarde. 1962. Simplified prediction method for the fall of the watertable in drained land. Paper presented at the ASAE Winter Meeting, Chicago Illinois, December 1962.

Bouwer, H.R., Lance, J.C. and Riggs. M.S. 1974. High rate land treatment. II. Water quality and economic aspects of the Flushing Meadows Project. *J. Water Pollut. Control Fed.* 46, B45-859.

Cheng, X., Robinson, D., Blackwell, J., Liu, Q., Gao, Z. and Jayawardane, N.S. 2003. Financial evaluation of the FILTER system at Wuqing in North China Plains. CSIRO, Land and Water client report to ACIAR project LWR1/96/190 in January 2003.

Gao, Z., Biswas, T. K., Yuxiang, S., Cheng, X., Fu, M., Li, D., Yao, H ., Jayawardane, N. S., Cook F. J. and Blackwell, J. 2000. Planning, installation and operation of the FILTER trial in Wuqing, China. CSIRO, Land and Water client report to ACIAR project LWR1/96/190.

Gao Z., Jayawardane, N.S., Biswas, T. and Cheng, X. 2002. Dynamic programming models to minimise the land FILTER area required for wastewater treatment, while maintaining phosphorus balance or allowing for soil phosphorus saturation in a specified time period. CSIRO, Land and Water client report to ACIAR project LWR1/96/190.

Iskandar, J.K. 1978. The effect of wastewater reuse in cold regions on land treatment systems. *J. Environ. Qual.* 7, 361-368.

Iskander, J.K. 1981. Modeling Wastewater Renovation. U.S. Army Cold Regions Research and Engineering Laboratory. John Wiley and Sons.

Iskandar, J.K., Sletten, R.S., Leggett, D.C. and Jenkins, T.F. 1976. Wastewater Renovation by a Prototype Slow Infiltration Land Treatment System. CRREL Report 76-19, 44 pp.

Iskandar, J.K., Murrmann, R.P. and Leggett, D.C. 1977. Evaluation of Existing Systems for Land Treatment of Wastewater at Manteca, California and Quincy, Washington. CRREL Report 77-24, 34 pp.

Jayawardane, N.S. 1995. Wastewater treatment and reuse through irrigation, with special reference to the Murray Darling Basin and adjacent coastal areas. CSIRO, Div. Water Resources, Griffith NSW, Divisional Report 95.1.

Jayawardane, N.S., Blackwell, J. Cook, F.J. Nicoll, G. and Wallett, D.J. 1997a. The research project on land treatment of effluent from the Griffith City Council sewage work - Report 7. Final report on pollutant removal by the FILTER system, during the period from November 1994 to November 1996 for GCC, DLWC and DPIE. CSIRO, Division of Water Resources - Consultancy Report No. 97-40.

Jayawardane, N.S., Cook, F.J., Ticehurst, J., Blackwell, J., Nicoll, G. and Wallett, D.J. 1997b. The research project on land treatment of effluent from the Griffith City Council sewage work - Report 8. Final report on the hydraulic properties of the FILTER system, during the period from November 1994 to November 1996. Report for GCC, DLWC and DPIE. CSIRO, Division of Water Resources - Consultancy Report No. 97-42.

Jayawardane, N.S., Biswas, T.K., Blackwell, J. and Cook, F.J. 2001. Management of salinity and sodicity in a land FILTER system, for treating saline wastewater on a saline-sodic soil. *Aust. J Soil Res.* 39,

Jayawardane, N.S., Biswas, T. K. Blackwell, J. and Cook, F.J. 2002a. The research project on land treatment of effluent from the Griffith City Council sewage work - Report 10. Final report on pollutant removal and hydraulic flows in the pilot commercial scale FILTER system, during the period from June 1998 to June 2001 – Report 10. CSIRO, Division of Land and Water - Consultancy Report to GCC and ACIAR.

Jayawardane, N.S., Blackwell, J. and Christen, E.W. 2002b. Farm Operation Manual for Griffith FILTER site – Report 12. CSIRO, Division of Land and Water - CSIRO, Land and Water Consultancy report prepared for GCC.

Jayawardane, N.S. and Blackwell, J. 2002. Prediction of annual salt discharge from the GCC FILTER site during the reclamation stage – Report 13. CSIRO, Land and Water - Consultancy report prepared for GCC.

Jayawardane, N.S. and Blackwell, J. 2006. Guidelines for commercial adoption of the land FILTER technology for domestic wastewater reuse and treatment in Australia. CSIRO, Land and Water client report to ACIAR project LWR/2002/113.

Jayawardane, N.S., Gao, Z., Blackwell, J., Christen, E.W., Khan, S., Cheng, X., Cook, F., Biswas, T., Zhang, J and Meng. M. 2006. The potential use of FILTER technology for treatment and reuse of wastewater in China. 19th ICID Congress, Beijing, China. September 14, 2005. In the proceedings of a workshop on “Agricultural water management in China”. Eds: I.R. Willett and Zhanyi Gao. ACIAR proceedings No. 123, 142-152.

Jenkins, T.F. and Martel, C.J.. 1979. Pilot commercial scale scale study of overland flow land treatment in cold climates. *Proc. Water Technol.* 11, 207-214.

Jenkins, T.F., and Martel, C.J., Gaskin, D.A., Fish, D.J. and McKim, H.L. 1978. Performance of overland flow land treatment in cold climates. In State of Knowledge in Land Treatment of Wastewater, Proceedings International Symposium, Hanover, New Hampshire, August, 1978, Vol 2, pp. 61-70.

Khan, S., Zhaoqing, L., Rana, T., Jayawardane, N.S. and Blackwell, J. 2006 Hydrogeological Assessment of Shanxi FILTER Demonstration Site. CSIRO, Land and Water client report to ACIAR project LWR/2002/113

Li Shikui. 1993. Agroclimatic Resources and Agricultural Distribution Patterns. In "Climate and Agriculture in China", Eds: Cheng Chunshu, Feng Xiuzao, Gao Liangzhi and Shen Guoquan. China Meteorological Press. pp30-52.

Martel, C.J., Jenkins, T.F. and Palazzo, A.J. 1980. Wastewater treatment in cold regions by overland flow. U.S. Army Cold Regions Research and Engineering Laboratory. CRREL Report 80-7, Hanover, New Hampshire.

Melbourne Water. Undated. Wastewater treatment. Information booklet published by Melbourne Water Cooperation (Released in 1997).

NSW EPA 1995. Utilisation of treated sewage effluent by irrigation. February 1995. NSW Environment Protection Authority Publication No. 95/20. Pp. 92.

NZLTC 2000. New Zealand guidelines for utilizing sewage effluent on land. Part 2: Issues for design and management. (Edited by L.J.Whitehouse, H. Wang and M. Tomer). Joint publication of the New Zealand Land Treatment Collective and Forest Research, Rotorua, New Zealand.

Pescod, M.D. 1992. Wastewater treatment and use in agriculture. FAO irrigation and drainage paper 47.

Robb, C and Barkle, G. 2000. New Zealand guidelines for utilizing sewage effluent on land. Part 1: The design process. (Edited by L.J.Whitehouse, H. Wang and M. Tomer). Joint publication of the New Zealand Land Treatment Collective and Forest Research, Rotorua, New Zealand.

Satterwhite, M.B., Stewart, G.L., Condike, B.J. and Vlach, E. 1976. Rapid Infiltration of Primary Sewage Effluent at Fort Devens, Massachusetts. CRREL Report 76-48. 48 pp.

Smedema, L.K. and Rycroft, D.W. (1988). Land drainage planning and design of agricultural drainage systems. B.T. Batsford Ltd. London.

US EPA. 1981. Process Design Manual for Land Treatment of Municipal Wastewater. October 1981, U.S. EPA, U.S. Army Corps of Engineers, U.S. Dept. Of interior and U.S. Dept. of Agriculture.

Yang, J., Tan, Y., Jayawardane, N.S., Biswas, T. and Lu, C 2002. Nitrogen-2D model for simulation of nitrogen dynamic in FILTER systems. CSIRO, Land and Water client report to ACIAR.project LWR1/96/190.

Youngs, E.G. 1985. A simple drainage equation for predicting watertable drawdowns. *J. Agric. Engng. Res.* 31, 21-328.