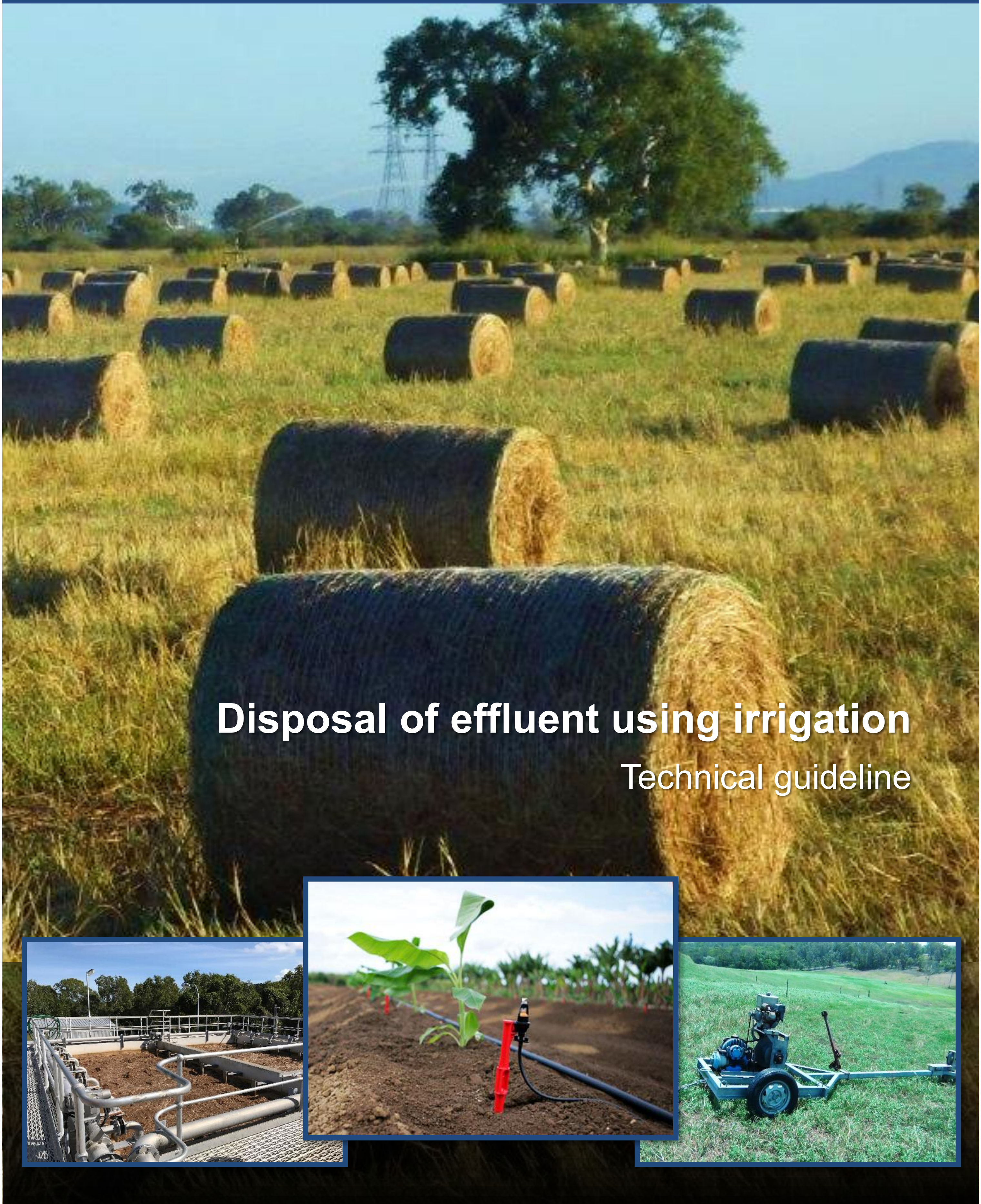

Disposal of effluent using irrigation

Technical guideline

Queensland Government

Prepared by Science & Technology, Environmental Monitoring and Assessment Sciences Division, Department of Environment and Science

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Contents

1. Introduction

Disposal of effluent to land is currently the preferred disposal option to manage wastewater in Queensland and is defined in this guideline as the application of treated wastewater to land such that it does not adversely impact (cause "environmental harm") on the environment now or into the future. The most common and recommended land disposal method of effluent is via irrigation. Where systems involving effluent disposal to land are viable, this can result in environmental, ecological and economic gains and reduce or prevent the need for direct release of wastewater to waters. As a result, the number of land disposal systems is likely to increase in the future, particularly given the fact that many waterways are under significant pressure from a range of anthropogenic activities. Furthermore, as a result of land disposal via irrigation, water and nutrients present in the effluent can be beneficially used. However, land disposal requires proper planning and management to reduce the risk of impact to surface waters and groundwater, protect human health and maintain soil sustainability. The main processes involved in land disposal systems that use irrigation are illustrated in Figure 1.

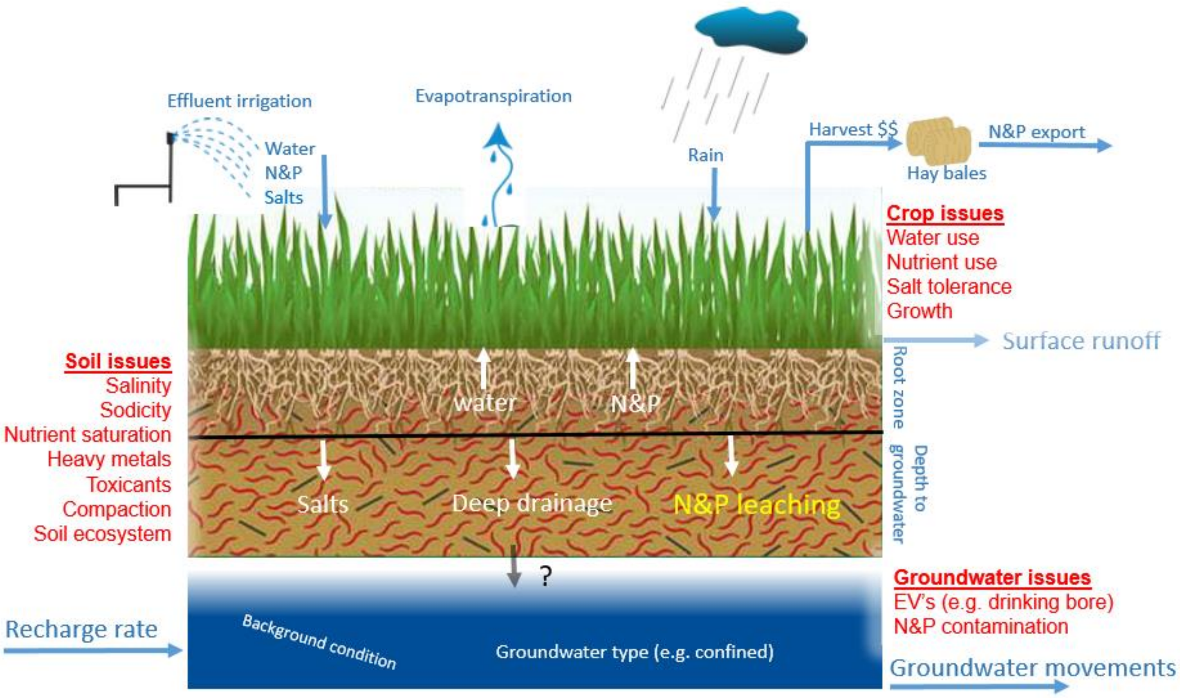

Figure 1. Effluent irrigation and environmental interaction conceptual model

In Queensland, one of the most common applications of land disposal is associated with sewage treatment plants, and to a lesser extent, with livestock, animal processing and other industries. These activities are called Environmentally Relevant Activities (ERA) and in Queensland require an environmental approval to operate. Applications for these approvals need to specifically consider proposed irrigation system design, operation and potential impacts on the environment. Once approved, the environmental approval will typically have conditions related to land disposal that require the operator to monitor and manage their irrigation systems to monitor and minimise environmental impacts.

Effluent irrigation systems require suitable land space, appropriate soil types and crop species, for it to be a viable. Furthermore, some effluent streams are more suitable for irrigation than others. For example, effluent high in nutrients (such as total nitrogen and total phosphorus) can be suitable for land disposal with a moderate level of wastewater treatment. Effluent streams high in salts and certain toxicants may be less suitable as they require a higher level of wastewater treatment that could be cost prohibitive. Nevertheless, the land disposal systems need to be designed and operated carefully to ensure that this practice is fit-for-purpose and does not cause detrimental impacts to the environment or to human health (see Figure 2).

This guideline is designed to assist operators and regulators in understanding the key considerations that must be evaluated when designing and managing effluent irrigation systems, with a particular focus on environmental and sustainability aspects. It includes a description of assessment and evaluation principles and criteria to be used. Another important aspect of effluent irrigation covered in this guideline is ongoing irrigation management, often outlined in an Irrigation Management Plan (IMP). This IMP includes important details about monitoring and management of the irrigation scheme and is used to ensure schemes are operated optimally and with minimal environmental harm.

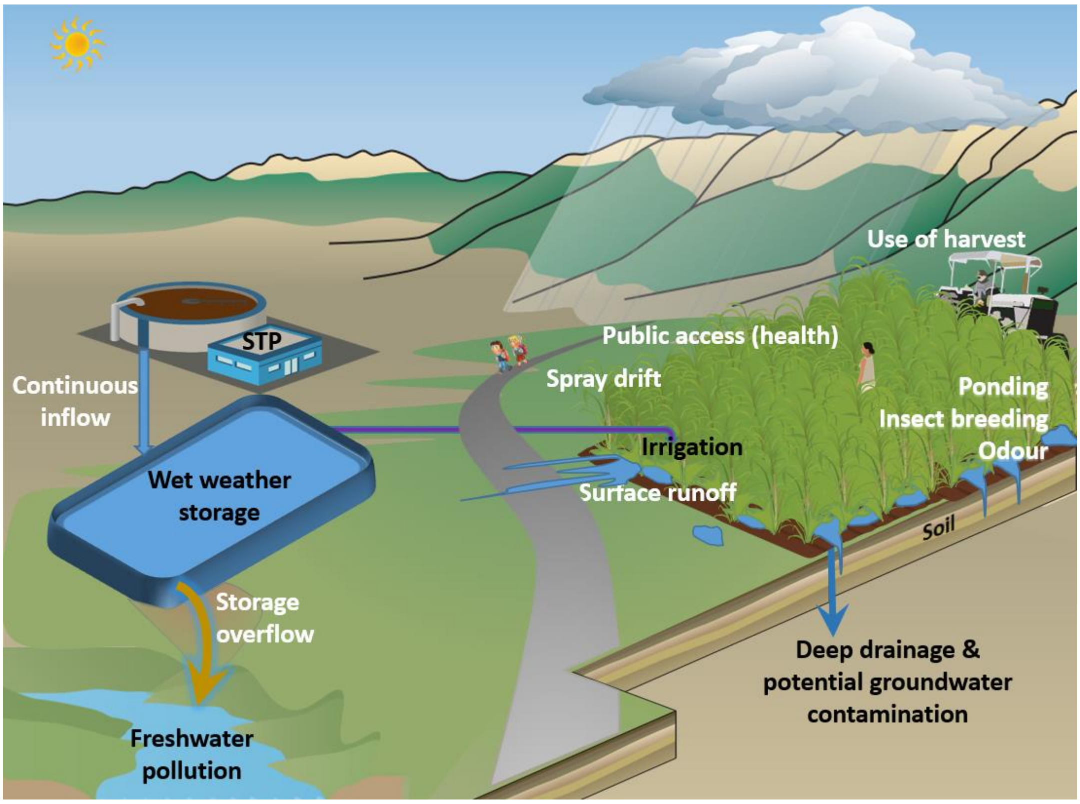

Figure 2. Schematic diagram showing mechanisms of potential impact on environmental values and human health from land disposal schemes using effluent irrigation

Poorly planned and managed effluent irrigation schemes can result in significant environmental degradation. Potential adverse environmental impacts include the following:

- Loss of soil ecosystems
- Increased soil salinity & sodicity
- Degradation of soil structure
- Desertification
- Accumulation of toxicants in the soil profile
- Environmental nuisance to neighbours from odours and insects
- Adverse impacts on waterways from runoff or overflows from storages
- Adverse impacts on groundwater from leaching of contaminants
- Public health issues as some effluent streams contain pathogens that pose significant health risks

Effluent disposal onto land can be carried out through various practices such as the use of infiltration trenches, evaporation basins and/or the use of the effluent for dust suppression and other beneficial reuse purposes. However, the most common and recommended effluent disposal practice is to irrigate and grow crops by applying suitably treated effluent. By irrigating crops with effluent, the water in the effluent is largely disposed of to the atmosphere via evapotranspiration and the nutrients and organic matter in the effluent act as fertiliser in the soil system. The nutrients are removed through being incorporated into plant biomass or crop yield. This guideline is largely focussed on sustainable effluent disposal/reuse practices via irrigation and the growing of crops.

It is important to note that effluent disposal via irrigation is technically different from normal agricultural irrigation practices. Agricultural irrigation is based on the crop water demand and generally involves the application of minimum requirements of water for optimum crop growth, whereas land disposal is based on using the maximum possible volumes of effluent. Generally, the amount of effluent available is of a fixed daily quantity, with a distinct flow pattern, and must be disposed of irrespective of the irrigation demand or weather conditions. In contrast, irrigation demand is a function of local climatic (rainfall and evaporation) conditions and the type of crop(s) grown.

In typical land disposal schemes that use effluent irrigation, the dry seasons supply is usually less than the irrigation demand, whereas the wet seasons supply usually exceeds the irrigation demand.

A number of factors can contribute to achieving sustainable effluent irrigation for land disposal. For example, appropriate site selection is critical and t the properties of the irrigation area(s) such as slope, shape, land use and soil type, the presence of shallow groundwater tables, the likelihood of flooding of the irrigation area(s) and related infrastructure, the presence of aquatic environments near irrigation areas, and the distance to public amenities or other sensitive receptors.

The irrigation scheme design needs to consider the minimum size of land area and the minimum wet weather storage capacity required for sustainable effluent irrigation for the anticipated daily effluent volume for the particular location and activity. In urban areas, the availability of suitable land for effluent irrigation is one of the major constraints to adopting sustainable effluent irrigation. The use of appropriate wet weather storage is also necessary to store effluent when irrigation is not possible, such as on wet days or during wet soil conditions when there is a high likelihood of runoff of the effluent being irrigated. Constructing adequate wet weather storage facilities obviously becomes more challenging in high rainfall areas and this may add significant cost to effluent irrigation schemes, especially when considering the no or relatively small volume of effluent that is allowed to overflow for such schemes. Finally, best practice management and operation of effluent irrigation schemes is important as the irrigated effluent can contain high levels of nutrients (total nitrogen, total phosphorus), salts, toxicants, and pathogenic microorganisms which can adversely impact on the soil and the surrounding environment, if not managed appropriately.

Understanding effluent irrigation schemes and their potential impacts is complex as it involves considering dynamic and interrelated changes in water and nutrient balances, changes in soil properties, the fate of water, nutrients and salts and crop growth. The effect on the receiving environment is potentially long-term and difficult to assess through simple observations. Therefore, mathematical modelling is often required to predict how these complex systems will respond over time and can assist greatly with scheme design. A few simulation models, spread-sheets and calculation techniques are available to assist with effluent irrigation design. In Queensland, MEDLI® (Model for Effluent Disposal using Land Irrigation) is the preferred simulation model by the Queensland Department of Environment and Science for designing and assessing effluent irrigation systems. Further guidance on the application and assessment of MEDLI is presented in this guideline.

2. Irrigation system considerations for land disposal

In normal irrigation systems, water is artificially applied to crops and generally fills the soil moisture deficits in the root zone during the growing season. In many places irrigation water is scarce, and therefore, water conservation practices are implemented. In contrast to this type of irrigation, effluent irrigation is based on the concept that the amount of water available is of a fixed daily quantity or flow pattern, and must be disposed of irrespective of the needs of the plants or the weather conditions. Often effluent irrigation systems are designed to apply maximum amounts of effluent using limited land area.

By means of irrigation, water in the effluent is transported into the atmosphere through evapotranspiration. Factors that affect evapotranspiration include solar radiation, humidity, ambient temperature, wind (advection), crop type and percentage of soil covered by the crop. Evapotranspiration is an energy (solar) dependent phenomenon and the amount of solar energy available in each geographic location can be expressed in terms of potential evaporation (PE) and quantified in millimetres per day. As rainfall (RF) offsets PE, the available energy is the difference between PE and RF, which is known as net evaporation or the potential irrigation demand.

The land area required to dispose of a given volume of water is a function of irrigation demand. For example, a 10 kL/day (10 m^3/day) discharge requires 0.2 ha (2000 m^2) of land area with a 5 mm/day irrigation water requirements. The procedure for estimating irrigation water requirement is described in the Food and Agriculture Organisation (FAO publication 56). There is significant spatial and temporal variability in irrigation demand. This occurs primarily as a result of the variation in climate in the landscape.

Generally, irrigation is not possible during rainy days or when there are wet soil conditions in the irrigation area(s). Therefore, effluent produced during these times is usually stored in an onsite storage facility (wet weather storage). The designed storage volume should be sufficient to avoid overflows to natural streams or waterways. Therefore, the main task in designing an irrigation scheme is to determine the minimum size of the irrigation area and the minimum storage capacity needed for satisfactory disposal, given constraints related to the frequency of allowable overflows from wet weather storages. The following sub-sections expand upon these individual elements:

2.1 Irrigation land

Arable land with an appropriate slope is required for irrigation (<5% for surface irrigation and steeper or unevenly sloping lands require overhead irrigation systems such as sprinklers or drip irrigation). Most soil types (except coarse sand) with an infiltration rate of less than 30 mm/hour can be used for surface irrigation. If the infiltration rate is higher than 30 mm/hour, sprinkler or drip irrigation should be used. Establishment of a healthy crop is vital for a properly functioning effluent irrigation system, as a large proportion of the applied effluent needs to be taken up by the crop and released to atmosphere through the evapotranspiration process. The nutrients present in the irrigation water must also be taken up by the crop. Conveyance of treated effluent to the disposal site should be safe, pragmatic and cost effective. There are several key considerations when assessing a block of land for sustainable effluent irrigation including land use, soil type, depth to groundwater, flood prone land, allocated extent, access and public safety. These are discussed in more detail below.

2.1.1 Soil type

Consideration of soil texture, structure, hydraulic properties (ideally in-situ) and certain chemical properties is important in effluent disposal involving irrigation. Hydraulic conductivity and water holding capacity of soil dictate the irrigation frequency and application rates. Furthermore, nutrient retention ability, initial phosphorus content and the soils capacity for phosphorus adsorption are also important soil properties. Land with possible acid sulphate soil is not generally recommended for effluent irrigation schemes.

2.1.2 Groundwater table

Land with shallow groundwater tables are not recommended for effluent irrigation sites because capillary rise of soil moisture will supplement the crop water requirements and reduces irrigation demand. Also, the potential for groundwater impact is high in such cases. Generally, the groundwater level should not be within three metres of the surface at any time of the year for suitable effluent irrigation sites.

2.1.3 Flooding

Areas with frequent flooding should not be selected as effluent irrigation sites. All irrigation hardware and wet weather storage(s) should not be affected by floods. With careful design, flood plains can be used to set up an irrigation scheme. However, sites with average/flood recurrence intervals (A.R.I.) of less than five years are not recommended.

2.1.4 Allocation

The allocated land area should be sufficient to avoid over or under-watering of the crop. The required land area should be calculated based on the volume of effluent available for irrigation and the estimated irrigation demand at the location.

For example:

Area = Volume / Irrigation demand (height)

Available total annual volume of effluent is 50 ML (50,000 kL)

Annual irrigation demand is 500 mm (0.5 m)

Required Area = 50,000/0.5 = 100,000 square meters = 10 ha

If the effluent contains high concentrations of nutrients or organic matter, then the hydraulic loading should be restricted based on the loading rates for these individual constituents, irrespective of crop water requirements. For nutrient rich effluent, the allocated land area should be sufficient to meet recommended fertiliser application rates for the crop.

For example:

Area = TN loading (kg/year) / crop N fertiliser requirements (kg/ha/year)

Available total annual volume of effluent is 50 ML (50,000 kL)

Effluent has 100 mg/L of TN concentration (0.0001 kg/L)

Total TN loading = 50,000 X 1000 X 0.0001 = 5,000 kg/year

Crop N fertiliser requirements is 250 kg/ha/year

Required Area = 5000/250 = 20 ha

2.1.5 Accessibility and public safety

There must be reasonable buffer zones between the disposal site and any public amenities or neighbouring residential premises and the extent of the buffer zone will depend on the microbiological quality of the effluent being irrigated. Restricted access or fenced blocks should be used for disposing low quality effluent with respect to microbiology. Appropriate signage must be installed and viewable indicating effluent irrigation areas in such a case.

Irrigating food crops, public open spaces, playgrounds and golf courses require a high microbial quality for the irrigated effluent with respect to pathogenic microorganisms (using E coli as “microbiological indicators”) and toxic substances. Please refer to the Water Supply (Safety and Reliability) Act 2008, Schedules 3C, 3D and 3E of the Public Health Regulation 2018 and the 2005 Queensland Environmental Protection Agency’s (QEPA) Queensland Water Recycling Guidelines for further information.

2.2 Crop selection and management

An appropriate crop should be selected for the local climatic condition, soil type, land use and the nature of effluent being irrigated. For example, salt-tolerant crops should be chosen where the effluent contains high salt concentrations. The crop provides the vehicle for transporting water in the effluent into the atmosphere and also for the removal of nutrients. Different crops have different capacities for uptake of water and nutrients from the root zone. The crop’s ability to remove water (transpiration) is technically measured as the crop factor. Crop species with relatively high crop factors and nutrient uptake ability (e.g. Lucerne) are recommended for effluent irrigation schemes that are used for land disposal. Crop rotation will also enhance the sustainability of the land. Economic returns can also be gained by growing fodder, horticultural crops or perennial trees (agro-forestry), which can contribute to carbon fixing.

A healthy crop must be maintained to maximise the rate of evapotranspiration and nutrient uptake. In certain situations fertilisers, and pest and disease control may be required. Periodic removal of harvested biomass from the irrigation site is essential to remove nutrients and maintain the nutrient balance of the site.

2.3 Irrigation method and controls

2.2.1 Wet weather storage

There must be sufficient storage capacity in the wet weather storage facility to retain effluent when irrigation is not possible due to wet weather conditions or agronomic practices that prevent irrigation. As a general rule of thumb, approximately 20 days of effluent volume capacity is recommended as the storage capacity, except for schemes using fixed daily irrigation strategies (refer to Section 2.2.3) which require a minimum storage capacity of 3-4 days of effluent volume to deal with contingencies.

A Storage Management Plan is recommended to be implemented and should include an overflow management strategy, contingency plans for unexpected events and algae management and odour control strategies. Keeping treated effluent for a long period of time in a storage is not recommended as this can lead to severe degradation of the water quality and algal blooms including toxic algae. Losses by seepage through the base and side of any in-ground storage are to be kept to a minimum by use of appropriate engineering construction techniques, such as sealing the floor and embankment using clay or impermeable membrane liners.

2.2.2 Irrigation method

A number of irrigation methods are available and they are primarily categorised as flood, furrow, overhead sprinkler systems and surface/sub-surface drip systems. Selection of an appropriate irrigation method will depend on the cost, site topography, soil type, crop type, effluent quality, labour availability, power requirements and public health and environmental considerations. Ideally, there needs to be the capacity to apply small volumes of effluent evenly and frequently over large areas. Therefore, systems like sprinklers, trickle, or drip irrigation systems are more appropriate as these allow greater control of effluent application rates. Subsurface drip systems will avoid direct contact with humans and animals and are suitable for landscaped gardens or playgrounds. Drip systems will also avoid over-application and unintended environmental effects that can potentially occur with furrow or flood irrigation systems. Use of flood or furrow systems may require laser levelling of sites to achieve a reasonable degree of distribution efficiency. The infiltration rate of soil is an important consideration in the type of irrigation method used and the way it is operated. Effluent should be applied uniformly and at a rate less than the basic infiltration rate to avoid surface runoff or ponding.

2.2.3 Irrigation strategy/scheduling

Decisions about when to commence irrigation, the volumes to be applied and when to stop irrigating should be based on both soil and wet weather storage water-balances. Generally, in normal agricultural irrigation schemes, irrigation is triggered when the plant available water (PAW) deficit is around 50%. However, for land disposal systems, initiating irrigation at a lower level of soil moisture deficits (e.g. 10 mm) in the root zone is recommended. This will avoid any reductions in evapotranspiration due to a shortage of soil moisture that might cause crop water stress. Soil moisture depletion beyond 30 mm is not recommended, and schemes should be designed with adequate water storage to ensure that water is available during hot or dry periods. Termination of irrigation should occur at, or before, the field capacity of the soil is reached to avoid possible surface runoff and excessive deep drainage. If rainfall is expected, it is advisable to stop irrigating before the field capacity is reached (e.g. 2 to 3 mm deficit), thereby providing buffer capacity in the soil and reducing the potential for surface runoff of effluent. A fixed irrigation strategy, whereby a predetermined amount is applied at a regular interval (e.g. 2 mm/day) irrespective of rainfall patterns, can also be implemented if the conditions are favourable.

In wet regions or seasons, soils can remain at saturation or field capacity for extended periods, and the preferred soil moisture deficit trigger for irrigation may not be reached. In such situations, a small quantity (e.g. 1 or 2 mm/day) of water may be applied over the crop canopy using sprinklers or a spray system. The rationale for this practice is that small volumes of water will be intercepted by the canopy and evaporate directly back to atmosphere without reaching the soil. The nutrients left behind on the leaves will be absorbed by the plants to some extent.

2.2.4 Leaching requirements

Maintaining acceptable salt levels in irrigated soils is vital for crop growth. High salt concentrations in irrigated effluent can lead to increased soil salinity with possible adverse effects on plant growth. Therefore, estimated periodic leaching requirements should be considered as a part of irrigation activity to prevent possible soil salinity issues.

2.2.5 Erosion control

The possibility of soil erosion should be considered in terms of both stormwater runoff and effluent application rates. Appropriate soil conservation techniques should be implemented on the irrigation site when soils have a potential to erode.

2.4 Other considerations

The following considerations should also be used to assess the environmental risk from an effluent land disposal scheme.

2.4.1 Proximity to sensitive environmental receptors

The potential for environmental harm from land disposal will significantly increase where irrigation sites are located next to, or close to, sensitive environmental receptors, particularly aquatic environments such as creeks or rivers. Some aquatic environments, such as those found in wetlands or high-ecological value areas, are very sensitive to nutrients or other contaminants that are contained in effluent runoff or seepage. Other sensitive receptors could include drinking water bores, conservation areas or national parks. Accordingly, land disposal schemes should not be operated in close proximity to these locations.

2.4.2 Volume management

The amount of effluent to be disposed of can be reduced by reducing the wastewater input to the treatment facility. Onsite water management practices such as the use of water efficient devices, prevention of leaks and sewer infiltration/exfiltration and deployment of water-wise practices within the wastewater collection network (sewer) will reduce the amount of wastewater generated and required to be treated and disposed of. Onsite water recycling measures, such as use of effluent for toilet flushing, outdoor cleaning, dust suppression or any other recycling activities, will also reduce the volume requiring disposal. Please refer to the 2005 Queensland Environmental Protection Agency publication entitled Queensland Water Recycling Guidelines, 2018 Queensland Public Health Regulations, and Queensland Water Supply (Safety and Reliability) Act 2008 for the standards that apply to these various effluent reuse options. Transfer (by tanker) to a licensed wastewater disposal facility is also recommended when land disposal is not possible.

2.4.3 Wastewater treatment

High strength effluent (i.e. effluent with more than five times the ANZECC and ARMCANZ (2000) water quality trigger values for irrigation waters) typically require special consideration. The effluent can be converted into lower strength effluent streams by utilising certain wastewater treatment technologies. This is particularly important for nutrients, organic matter or pathogen reduction to meet certain disposal standards. Disposal of high-quality effluent onto land will reduce the potential for environmental and human health impacts.

2.4.4 Shandying (Dilution)

Mixing effluent with fresh water (shandying) can be used to reduce concentrations of various contaminants and thereby meeting water quality standards for irrigation. This is especially helpful if the effluent contains high concentrations of salts or if the effluent poses a sodicity hazard. Detailed chemical analysis can help in deciding the degree of dilution required. However, shandying will also increase the volume for disposal, and therefore, increase the land area required for irrigation.

2.4.5 Disinfection

Disinfection reduces the risk to human and animal health by reducing populations of pathogenic microorganisms in the effluent being irrigated. This is particularly important if the effluent disposal site is accessible to the public, such as with playgrounds, golf courses or landscaped gardens. However, if chlorine is used as a disinfectant, the free residual chlorine (FRC) and total chlorine residual (TCR) concentrations should be checked prior to irrigation, as high concentrations (above 5mg/L) of these chemicals can adversely affect some crops.

The recommended microbiological indicator count of the effluent will depend on the type of crop being irrigated (e.g. a fresh food crop destined for human consumption without any further processing requires more stringent microbiological requirements than a tree crop grown for timber) and the potential for infection in humans or animals (e.g. irrigating school playgrounds with effluent requires at least a "Class A" or "Class A+" recycled water). Further guidance on the different classes of recycled water and acceptable uses is available in the 2005 Queensland Environmental Protection Agency Queensland Water Recycling Guidelines, 2018 Queensland Public Health Regulations, and Queensland Water Supply and Reliability Act (2008).

2.4.6 Conveyance

Conveyance of effluent using pipes or channel systems to an appropriate location (e.g. local farmer) for irrigation will reduce the environmental risk.

2.4.7 Use by third party

Effluent can be transferred to commercial growers of pasture or horticulture, golf courses, landscaping or a range of other purposes, by way of a third-party beneficial reuse agreement. This should comply with the Water Quality Guidelines for Recycled Water Schemes. If the effluent is irrigated using standard agricultural irrigation methods with best management practices, the potential public health and environmental risks should be low. However, the responsibility for disposal of the effluent in an environmentally appropriate manner will then reside with the third party.

3. Assessing and licensing disposal of effluent to land

Licensing of Environmentally Relevant Activities (ERAs) that involve disposal of effluent to land will require some level of environmental assessment that will depend on the scale and potential risk of the irrigation scheme. This guideline provides a broad risk assessment framework tailored to the level of risk and site-specific factors. Small, low risk irrigation schemes should be assessed in a simple, streamlined manner requiring less information (see Appendix 1) to be supplied with the application. Higher risk schemes would generally need to be assessed through a mathematical modelling process to better ascertain potential environmental impacts.

A broad risk assessment framework is shown in Figure 3 and is discussed in more detail in this guideline. In order to design, implement and operate sustainable effluent irrigation for land disposal, this guideline should also be used in association with more specific guidance documents such as the 2005 Queensland Environmental Protection Agency's Queensland Water Recycling Guidelines.

3.1 Risk minimisation

Prior to undertaking any risk assessment of the land disposal system, it is important to ensure that all measures are first undertaken to avoid the need for land disposal, both in terms of the quantity and quality of the effluent. Alternative options include source reduction, reuse and treatment (also see Sections 2.4.2 to 2.4.7). However, in general, the level of treatment required for land disposal, such as for nutrient removal, will not be as high as for release to water. Nonetheless, some contaminants can impact significantly on land disposal systems, such as high levels of salt or toxicants. For most sewage treatment plants, the level of these contaminants are not usually a major concern. A further consideration is the level of microbial pathogens in the treated effluent, and in some cases will need to be treated further, for example to Class A. Once all practical measures have been taken to minimise the quantity and quality of the effluent, a good design of the irrigation system can significantly minimise environmental risks. Appropriate choice of irrigation land in terms of location and size is critical, and can avoid the need for detailed environmental assessment and can significantly reduce the ongoing environmental risk and need for rigorous monitoring and management. In some cases, where suitable irrigation land area is limited, it could avoid the need for expensive trucking of effluent for treatment off-site.

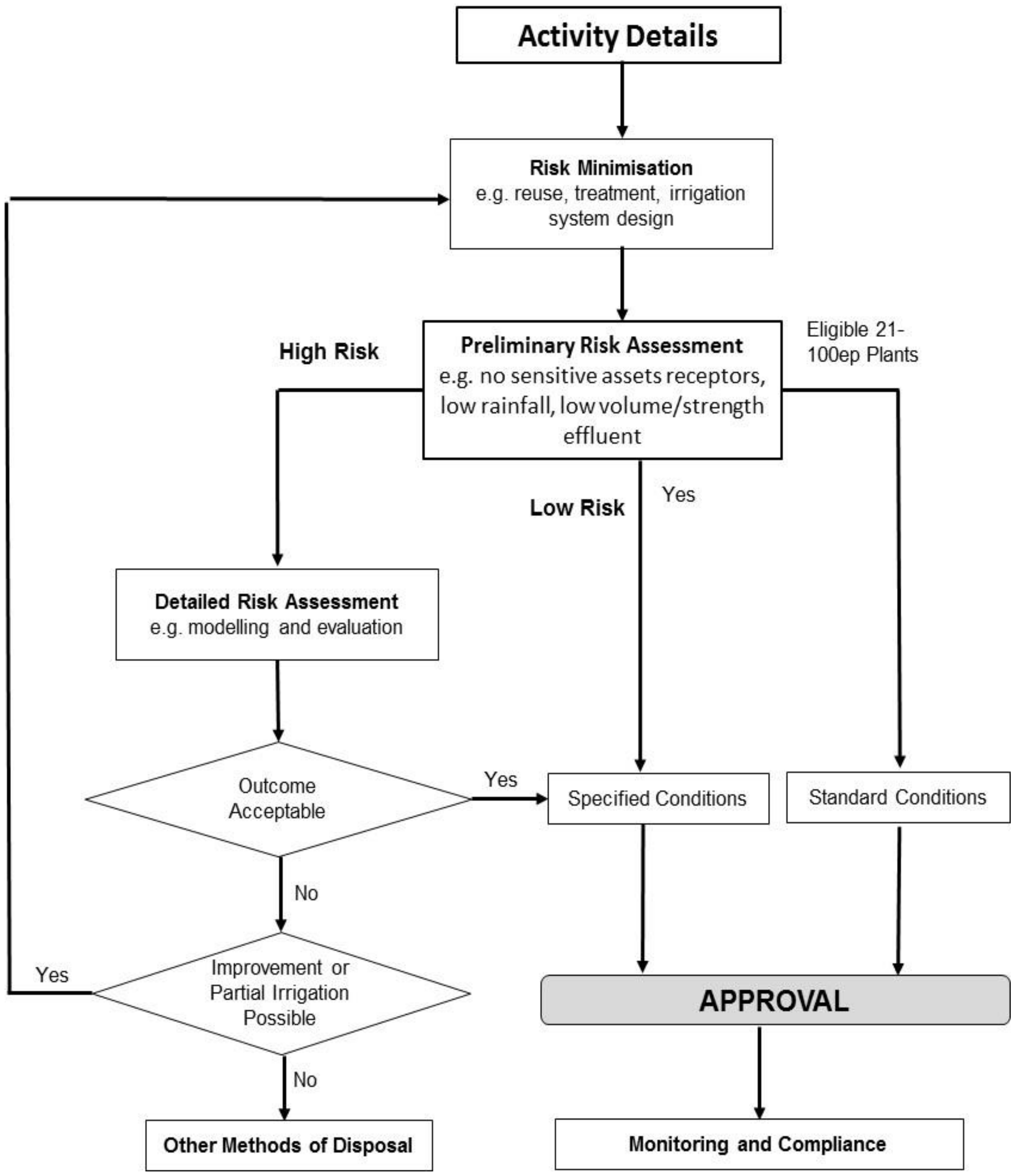

Figure 3. Process for assessing and licensing disposal to land using irrigation

3.2 Preliminary risk assessment

Preliminary risk assessment against the following criteria should be undertaken to determine the level of likely risk from the activity. If the activity is a sewage treatment plant (ERA 63) in the category of 21 to 100 equivalent persons, as well as meeting set eligibility criteria (see Eligibility criteria and standard conditions for sewage treatment works ERA 63) standard environmental authority conditions can be applied. For other activities, if the proposed land disposal system is found to be low risk, more detailed risk assessment involving modelling and evaluation of environmental impacts may not be required. This section outlines criteria that can be used to classify land disposal systems as low risk.

3.2.1 Proximity to environmental value and features

Where land disposal occurs in close proximity to any environmentally sensitive assets (i.e. regarded as matters of National or State environmental significance), areas of High Environmental Values (HEV), or shallow groundwater, they can be categorised as high-risk operations. Similarly, disposal activities near public amenities where there is potential for primary or secondary contact with humans or animals present a potential risk. The following distances can be used as guidance for reducing the risk associated with land disposal schemes involving effluent irrigation:

- Natural waterways >100 m;
- Residential facility or public amenities >50 m;
- Domestic water bore >250 m;
- Drinking water catchment & aquatic systems with HEV >250 m;
- Town water supply bore >1000 m;
- Groundwater bore used for potable water supply >250 m; and
- Groundwater table at a depth >3 m.

3.2.2 Local climate

Climate is an important consideration for land disposal schemes using irrigation. The volumes of effluent that can be irrigated is constrained by the evaporative and rainfall potential in a location. The difference between evaporation and rainfall is known as net evaporation and a reasonable net evaporation evenly distributed across the year is necessary to make the irrigation scheme sustainable. The opportunity for land disposal via irrigation is limited in high rainfall areas because of a lack of irrigation demand where the natural rainfall provides most of the crop water requirements. Conversely, in relatively dry locations, where average annual rainfall is less than 600 mm, land disposal can be categorised as low risk (see Appendix 2). In regions where annual average rainfall exceeds 600 mm, environmental impact assessments through mathematical modelling processes is typically required.

3.2.3 Effluent quantity

Managing large volumes of effluent for land disposal is potentially risky due to increased likelihood of offsite movement of contaminants in effluent such as nutrients. Therefore, attention is required to prevent overflow from wet weather storages, and to minimise irrigation surface runoff or irrigation induced deep drainage into groundwater. A scheme with less than 20 kL/day (100 EP) volume can be used as guidance to define a lower risk activity in terms of effluent quantity. Regardless of the quantity, the hydraulic pathway of deep drainage must not be used as a main mode of wastewater disposal. Further information on deep drainage from land disposal schemes is provided in Appendix 3.

3.2.4 Effluent quality

Effluent disposed onto land needs to be of a suitable quality. Certain effluent streams (e.g. treated sewage) contain ingredients useful for crop growth such as organic matter and nutrients. However, excessive quantities of nutrients or organic matter can be harmful to soil ecosystems. Effluent can also contain toxicants (e.g. heavy metals, hydrocarbons, and pesticides), PFAS, salts and pathogenic microorganisms that are potentially detrimental to soils or plant growth or pose a risk to the wider environment or public health. Therefore, to maintain land sustainability, toxicity to plants or soil organisms, public health impacts and environmental harm must be minimised.

Nutrients:

Although the term nutrients can be used to describe various requirements for plant growth, including nitrogen, phosphorus, potassium, magnesium, sulphur and calcium, only nitrogen and phosphorus are discussed here as nutrients of potential concern. Because the crops used in the disposal scheme act as a harvestable sink for nitrogen and phosphorus, it may not be necessary to remove or reduce these components prior to irrigation, provided that the loads and application rates are at a sustainable level and the soil does not become saturated with nitrogen or phosphorus over the long-term.

Soil and crops have a limited capacity to store or utilise nutrients, and if excessive amounts are applied, there will be a risk of plant toxicity or offsite movement, which can result in contamination of local surface waters or groundwater. If the annual loading rates are within the normal fertiliser requirements for crops and pastures, the potential risk should be low.

The following long-term averages of total nitrogen (TN) and total phosphorus (TP) concentrations can be used as guidance for the assessment of low risk:

- TN <30 mg/L as Nitrogen
- TP <7 mg/L as Phosphorus

Please note that these limits would typically correspond to maximum concentrations of TN and TP of 60 mg/L as N and 15 mg/L as P, respectively.

Salts:

Salts are present in all-natural waters at varying concentrations. The ionic components most typically associated with salinity are combinations of Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^- and SO_4^{2-}. Following irrigation, water is removed by evapotranspiration processes, but all the dissolved salts will remain in the soil. Unless the salts are leached from the root zone, accumulation of these salts will result in soil salinity, which can partially or entirely prevent crop growth. The following total dissolved salt (TDS) concentration (also expressed as electrical conductivity (EC)) can be used as guidance for lower risk:

- TDS <1000 mg/L (EC < 1600 µS/cm)

Sodicity:

Sodic soils develop when irrigated effluent contains relatively more sodium ions than calcium and magnesium ions, even though the total concentration of salts may not be very high. Sodicity has important implications for soil structure. Accumulation of high quantities of sodium ions in soil results in a breakdown of soil aggregates responsible for good soil structure. Depending on the type of soil, increases in sodicity can result in reduced soil permeability for the infiltration and movement of water and air.

Sodicity is generally measured as the sodium adsorption ratio (SAR), which is a mathematical relationship between the concentrations of Na^+ with Ca^{2+} and Mg^{2+} (expressed as milli-equivalents per Litre).

- A SAR value of less than 6 is considered low risk.

Please note that the permissible limits for TDS (as EC of the effluent) depends on the chosen crop species and SAR depends on the soil type (see ANZECC & ARMCANZ 2000).

Pathogenic Microorganisms:

Most effluent streams, especially treated sewage, are likely to contain pathogenic microorganisms. The concentrations of these pathogenic microorganisms, and the magnitude of risk to human or animal health, are dependent on the treatment processes used. The presence of pathogenic microorganisms does not preclude land disposal provided suitable precautions are in place. Adverse health and environmental impacts can be minimised by careful management of the irrigation activity to avoid exposure of the public and operators to the effluent and associated aerosols. This can include restricted access to the irrigated area or using an irrigation method that avoids the formation of aerosols, or irrigation at certain times of the day, for example at night. Crop selection is also important and can include plants that will not be directly consumed by people or stock, or which will be processed prior to consumption in order to minimise the potential for exposure via ingestion.

Pathogenicity for effluent being used for recycled water is usually based on Escherichia coli (E. coli) as a microbiological indicator and the following E. coli counts can be used as guidance for the assessment of different risk levels:

- Class A = 10 colony forming units (cfu)/100 mL (median) does not require restricted access;
- Class B = 100 cfu/100 mL (median) where sprinklers are employed and there is restricted access for pasture or stock fodder irrigation; and
- Class C = 1000 cfu/100 mL (median) where sprinklers are employed and there is restricted or controlled access for non-consumable crops.

Organic matter:

Organic matter in effluent can contribute to soil fertility if applied at an appropriate rate. However, continued overloading with organic matter can physically clog soil pores, favour anaerobic soil microbes and lead to slimy bacterial scum coating the soil, blocking pores and closing up cracks, along with the generation of odours due to anaerobic decomposition. These changes could limit the sustainability of the soil. An application rate up to 1500 kg/ha/month of organic matter can be considered as acceptable for many soil types.

pH:

pH affects the availability of nutrients and other elements to plants. If the effluent's pH is between 5 and 8.5, the risk to soil and plants is low. If the effluent is very acidic (pH less than 5), or very alkaline (pH greater than 8.5), it may need to be neutralised before irrigation.

Chemical toxicants:

Effluent may contain potentially undesirable chemical contaminants, including some metals and chlorinated organic compounds that may have an adverse effect on soil and plants, if above certain concentrations. Some inorganic elements are toxic to biological organisms at certain concentrations and the bioavailability and toxicity of these contaminants may be increased if the soil is acidic. Therefore, it is important to ensure that there are acceptable concentrations of metals and metalloids in irrigation effluent which avoid long term contamination of the site. Table 4.2.10 of ANZECC & ARMCANZ (2000) provides trigger values for concentrations of metals and metalloids in irrigation waters.

Trace concentrations of insecticides, herbicides or other pesticides may be found in effluent from municipal sewage treatment plants, or they can be present in effluent as a consequence of other industrial or agricultural inputs to sewer. These hydrocarbon contaminants can also have adverse effects on soil ecosystem, wildlife and crops. Table 4.2.12 of ANZECC & ARMCANZ (2000) provides interim trigger values for concentrations of some herbicides in irrigation waters. Overall, the risk is low if the total concentration of these organic compounds in the effluent is less than 0.001 mg/L. Chlorine is frequently used to disinfect effluent, and residual chlorine can be present in effluent streams destined for land disposal. Total chlorine levels in excess of 1 mg/L may affect some sensitive horticultural crops, nursery plants and cut flowers. For other crops, it is likely that levels up to 5 mg/L total chlorine would be acceptable.

Constituents loads:

For certain water quality indicators such as nutrients, it is useful to consider loads rather than concentrations to assess impacts associated with land releases. For example, use of total nitrogen loads applied to the land as kg/ha/year is a much more sensible measurement than the use of concentrations as mg/L, unless there is an issue with toxicity. Generally, in standard agricultural practices, fertilisers are applied on a kg/ha basis. If the loading rates are within the recommended fertiliser applications rates for the crop species, the potential environmental risk is low. Loads can be easily calculated as concentration times volume. For example, if applied effluent volume is 10 ML/ha/year with 30 mg/L of TN, the TN loading rate is 300 kg/ha/year.

3.3 Detailed risk assessment

Detailed assessment of land disposal schemes should be carried out based on the potential risk to the environment and public health. The main risk of effluent being disposed to land is the adverse environmental impact due to contaminants in the effluent stream. The impact of these contaminants in the receiving environment and surroundings should be evaluated. The main receiving environment is the soil system and there are a range of potential adverse environmental impact and health hazards in relation to the environmental values of the land, soil ecosystems and sustainability. Contaminants can accumulate in the soil profile over time and create irreversible damage to the soil system. The potential for offsite movement of polluted water (as surface runoff and or discharge to groundwater) needs to be carefully assessed to minimise or prevent pollution of receiving waters. The risk to human and animal health due to microbial contamination should also be carefully evaluated with respect to specified guidelines.

The mass balance of water and the constituents in the various stages of the irrigation process should be estimated to gauge the potential risk. This should include the fate of nutrients and salts in the irrigation area to detect possible offsite movement and plant toxicity. The long-term impacts in the soil environment must be assessed in relation to, to land sustainability, soil ecosystems and potential land contamination. Generally, these long-term influences involve complex processes and mathematical modelling and simulation is required to predict the potential impacts.

3.3.1 Modelling and simulation

In cases where modelling of an irrigation scheme's performance is required, this can be carried out using various mathematical models. The modelling outputs should provide complete details of water balance, fate of nutrients and salts and the performance of the crop. It will be necessary for the applicant or designer proposing to undertake land disposal to provide information describing the credibility of the model used. In Queensland, the Queensland Department of Environment and Science’s preferred model for the design and development of land disposal schemes is MEDLI (Model for Effluent Discharge through Land Irrigation), which is discussed in more detail in the following section.

3.4 MEDLI modelling

MEDLI has been designed to simulate the operation of land disposal scheme over a ‘long’ period, typically many decades. The model’s basis is a ‘physical system’ comprising of a field of crop or pasture, which is irrigated with water supplied from a tank or pond that provides buffer storage (wet weather storage) to hold incoming effluent at times when irrigation is not possible. MEDLI simulates the material balance in the storage systems, in the soil systems and the crop growth. The model provides estimates for the fate of applied effluent, nutrients, salts and pathogenic microorganisms, and their potential impact on the receiving environment (see Figure 4).

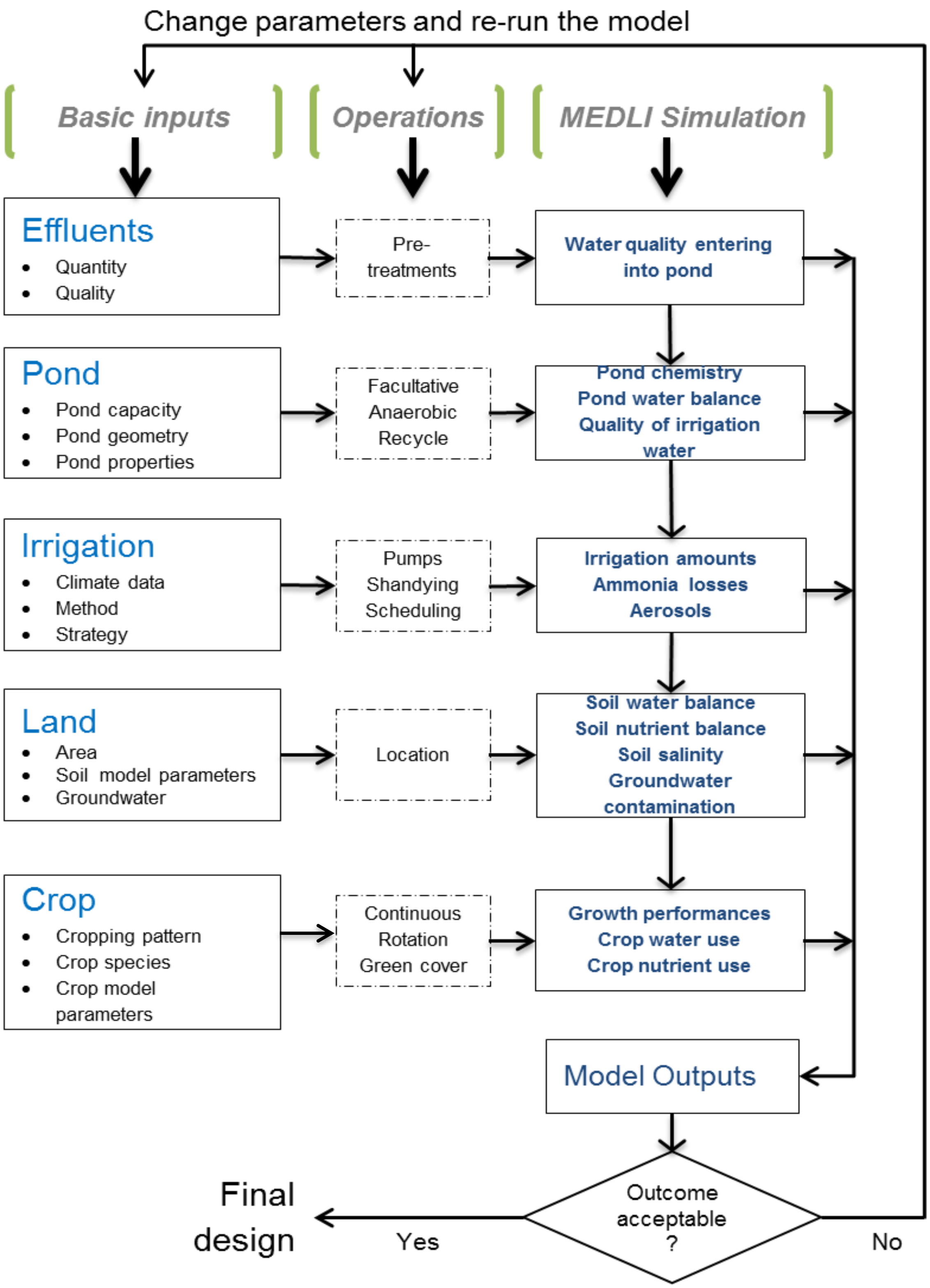

Figure 4. Flowchart of the MEDLI modelling process

The accuracy of the modelled estimates is reliant on the use of appropriate input data. A summary of the major model inputs is provided below along with information on model setup and major outputs. For more information on MEDLI, please refer to Help with effluent disposal using land irrigation.

3.4.1 MEDLI setup

Prior to modelling, it is necessary to formulate a ‘tentative’ scheme design so that the model can be provided with the relevant input data for an initial run. In effect, this means making rough estimates or ‘educated guesses’ for some parameters, including the size of the proposed irrigation area and the capacity of the wet weather storage. Once the user has run the model with a given data-set comprising scheme design details (such as pond dimensions, irrigated land area) and operating parameters (such as irrigation method and strategy), the outputs can be reviewed to check whether they meet the user’s expectations or specific criteria with respect to storage overflow behaviour, overland runoff, deep drainage, leaching of nutrients, crop yields, etc. If the predictions are not satisfactory, one or more of the parameter values can be changed and the model can be run again. This process can be repeated as often as desired, in an attempt to find an acceptable combination of scheme design and operating strategy. This is an iterative process.

The Multi-run option available in MEDLI v2 allows a scenario to be run with many permutations. It is possible to define a range of irrigation areas and pond sizes with specified increments and then the runs will be performed for all the possible combinations of irrigation areas and the pond volumes. It is also possible to define expected costings, which include fixed cost, cost per unit area and cost per unit volume of pond. Using the simulated results, an optimum combination of land area and storage volume can be selected to achieve acceptable outcomes.

3.4.2 Major model inputs

MEDLI requires a range of input data. Table 1 describes the major input data categories that is required along with more detailed examples of the input data.

Table 1. Description of major inputs data required to run MEDLI

Primary inputs	**Description**	**Input data & example**
Effluent quantity and flow patterns	The effluent volume allocated for irrigation per day is required. Other effluent reuse allocations other than irrigation should also be considered when estimating the amount of effluent allocated for irrigation disposal.	Quantity of effluent for sewage treatment plants is estimated using the measure of the wastewater generated by each equivalent person (EP). The flow pattern over the year is estimated using the expected occupancy rate in terms of EP, i.e. the number of staff, residents and visitors on a daily, weekly, monthly or seasonal basis.
Effluent quality	Effluent quality is represented in averages as the measured or predicted concentrations based on treatment plant specifications.	The measures for total nitrogen (TN), total phosphorus (TP), total dissolved solids (TDS), total solids (TS), total volatile solids (TVS), fractions of nitrogen as Organic Nitrogen, Ammonia Nitrogen and Nitrate Nitrogen and pathogen counts, are necessary as input data for MEDLI simulation.
Historical climate data	Site-specific climate data (daily basis) for the past 50 to 100 years is recommended. Historical climate data (p51 format) can be downloaded from Long Paddock Silo website at www.longpaddock.qld.gov.au	The climatic data required for MEDLI simulation are rainfall, Class A pan evaporation, maximum and minimum temperature and solar radiation.
Allocated land area for irrigation	The required area can be estimated based on the potential irrigation demand and the available daily effluent volume. The irrigation demand is a function of potential evaporation (Class A Pan reading) and rainfall in a location. The net evaporation, which is the difference between evaporation and rainfall, is an indication of irrigation demand.	Effluent volume of 100 m^3/day with a 4 mm/day net evaporation requires 2.5 ha of area i.e.100/0.004/10000. For effluent with high concentrations of nutrient, the hydraulic loading should be restricted to match crop’s fertiliser requirements, irrespective of irrigation demand.

Primary inputs	Description	Input data & example
Irrigation method	The method of irrigation needs to be defined.	Includes; sprinkler, centre pivot, flood, lateral move, travelling sprinklers etc.
Irrigation strategy	Conditions for irrigation initiation and termination can be based on soil moisture depletion, plant available water contents or fixed irrigation.	For example, initiate at 10 mm soil moisture depletion and terminate at field capacity. Another example includes a fixed daily of 2mm application.
Wet weather storage capacity	The number of ponds (or tanks) for storage and their volumetric capacities are required. In MEDLI the irrigation water is extracted from the last pond in a series.	The specific details required include: pond capacity, depth at outlet, side slope, length to breath ratio, rainfall and evaporation area, leakage and evaporation coefficient.
Soil parameters	The soil properties of the irrigation land are essential. MEDLI comes with model parameters for some standard soil types and users can use or modify these values to match local soil type. For large scale irrigation schemes, the use of site specific soil characteristics is recommended.	Includes the number of distinct soil layers (up to 4) and the layer thickness, hydraulic properties, bulk density, initial nitrogen and phosphorus content, runoff and soil evaporation parameters.
Crop parameters	Details of the cropping system and the crop species are required together with the crop model parameters for the particular species.	Parameters required include: maximum crop factor, root depth, radiation use efficiency, threshold for growth responses, nitrogen concentration limits for shoot growth, maximum yield, harvest triggers and salt tolerance details.
Pathogens	The details about pathogens in the effluent is required to simulate the health risk to humans.	Information required includes: organism units (counts), aerosol characteristics, sprinkler details and weather characteristics.
Groundwater	MEDLI has an elementary groundwater module and its use is optional.	Parameters required include: distance between irrigation area and property boundary in direction of groundwater flow and characteristics of the aquifer.

3.4.3 Model outputs

The model estimates a mass balance of water and nutrients in the pond system and in the soil system on a daily basis and reports based on annual averages. The pond water balance indicates the adequacy of allocated land area and the storage volume to prevent overflows. The soil water balance quantifies the amount of water that moves through the various hydrological pathways of the irrigation process. The estimated nutrient balance indicates the fate of major nutrients applied through irrigation. These predictions help assess the likely environmental impacts. It is expected that most of the water and nutrients applied through irrigation will be consumed by the crop or stored in the soil profile. If a considerable amount of applied water or nutrients move out of the designated irrigation area, which includes the root zone, there will be a risk of contamination of the surrounding environment, such as water or land outside the designated irrigation area. In such case, the scheme may require redesigning.

3.5 Evaluation criteria

Any environmental impact assessment of a land disposal scheme that is to be performed to support a development approval, or for the purpose of assessing compliance with an existing approval, should be based on certain evaluation criteria. The effluent will go through various phases and processes from the facility outlet to the final disposal pathway of evapotranspiration from a cropping field and major changes can occur. Mass balances of materials, which include water, nutrients, salts and pathogens, in the various stages of the irrigation process is required to assess the fate of applied effluent and its constituents. Furthermore, long-term and cumulative impacts of applied materials (contaminants) in the receiving environment need to be quantified and assessed. This section describes the evaluation criteria that should be used for detailed risk assessment.

3.5.1 Storage water balance

One of the major evaluation criteria is the potential overflows from wet weather storages. Generally, overflows from storages are not allowed, except during major rainfall events, and the storage capacity should be sufficient to prevent overflows. Therefore, undertaking a water balance for the storage is essential and the following components need to be estimated to assess the adequacy of storage capacity:

- Total inflow volume into the storage;
- The quantity of effluent used for irrigation;
- Seepage losses from the wet weather storage;
- Total overflows and frequency of overflow from the wet weather storage;
- Direct evaporation losses from the wet weather storage; and
- Direct precipitation into the wet weather storage

The total inflow into a storage is made up of the effluent inflow and rainfall inputs. The main output from storage is the irrigation used with some losses through evaporation and seepage. The preferred condition is that all inputs into the storage tank should be used for irrigation, except direct evaporative losses. However, when the storage is full, excess water will leave the storage as overflows. The ratio of inflow to the storage and the amount used for irrigation is calculated as the reuse efficiency. As a part of a proposal for land disposal, the Regulatory Authority in Queensland prefers to see 100% reuse efficiency, which means there are no overflows from the storage. However, if MEDLI has been used for designing the scheme, 95 percent reuse efficiency is normally accepted considering uncertainties in the MEDLI model parameters and practicalities of operation.

For wet regions, such as in North Queensland, and in areas with highly variable rainfall distributions, it is difficult to dispose of 100 percent of wastewater through irrigation. Often wet soil conditions prevent irrigation and prolonged rainfall will result in wet weather storage overflows. In this situation, a portion of effluent can be disposed of through land irrigation and the remainder should be disposed of via other means such as transportation off-site.

3.5.2 Soil water balance

The soil water balance helps determine the fate of disposed effluent to land. Irrigation and rainfall are the major water inputs, and soil evaporation, crop transpiration, surface/sub-surface runoff and deep drainage are water outputs from the soil system. Surface ponding and waterlogging are also a part of the soil water system. The estimation of these different components is necessary for detailed environmental impact assessment.

Inputs to soil:

- **Rainfall:** Depending on the amount and distribution, natural rainfall provides the crop with either part or all of its water requirements. However, the amount of rain falling on an irrigation area can vary considerably, spatially as well as temporally. In many places in Queensland, irrigation is required to successfully grow crops as the rain is inadequate to provide crop water requirements.
- **Irrigation:** This is the amount of water that is artificially applied to the irrigation area. The irrigation inputs should not exceed the irrigation demand and the leaching requirements of the site.

Outputs from soil:

- **Crop transpiration:** This is the amount of water transported to the atmosphere through the plant leaves (via the stomata).
- **Soil evaporation:** This is the amount of water that will be directly evaporated from the soil surface in a cropping field. This occurs from the soil patches not covered by the crop canopy.
- **Evapotranspiration:** Evapotranspiration is the sum of soil evaporation and plant transpiration from an irrigation area. Evapotranspiration is the designated disposal pathway for irrigated effluent and is generally estimated using the potential evaporation in the location and a crop factor.
- **Surface runoff:** Also known as overland flow, surface runoff is the amount of water that flows off the site due to excess rainfall or irrigation. Irrigation induced surface runoff is not permitted as it can potentially pollute natural streams.
- **Surface ponding and waterlogging:** Surface ponding is generally not permitted as it can cause insect

breeding and waterlogging conditions that could adversely influence crop performance.

- **Deep drainage:** Also known as deep percolation, deep drainage is a hydrologic pathway where water moves downward beyond the root zone, potentially reaching groundwater. A reasonable amount of deep drainage is essential to washout salts from the root zone and often occurs naturally. However, excessive and contaminated deep drainage could potentially pollute the groundwater (Appendix 3).

3.5.3 Fate of nutrients

Nutrient dynamics in the wet weather storage: Depending on the kind of infrastructure used, the quantity and the composition of nutrients may change within the wet weather storage system. Some ponds will function as a part of the wastewater treatment process, which can include chemical and biological transformations within the wet weather storage, particularly among the nitrogenous compounds. These changes will affect the nutrient concentrations in the effluent used for irrigation.

Nutrients balance in the soils system: The fate of major nutrients being applied to the soil needs to be evaluated. If the concentration of nutrients in the irrigation water are high, even a moderate hydraulic application rate can cause nutrient loads to exceed crop fertiliser requirements and the soil's storage capacity. The surplus nutrients will eventually move offsite and potentially contaminate surface water or groundwater. Very high loads of nutrients can also cause toxicity to plants.

General evaluation criteria for nitrogen and phosphorus management:

- The nutrient loading rate should not exceed the rate of crop uptake and the soil storage capacity;
- Nitrogen and phosphorus concentrations present in deep drainage should not cause contamination to natural waters;
- Nutrient toxicity to crop should be avoided;
- The rate of increase in phosphorus content of the irrigated soil profile needs to be monitored and should not reach the relative saturation level for adsorbed phosphorus within 25 years of the commencement of the irrigation scheme;
- Applied nutrients should not move offsite as a consequence of surface or sub-surface runoff; and
- Harvested biomass should be removed offsite as a means of exporting nutrients from the site.

3.5.4 Salinity

The total quantities of salt added to soil through irrigation and the accumulation of salts in the soil profile over time should be estimated and evaluated against the acceptable levels for the particular type of crop that is irrigated. Soil salinity issues due to irrigation of effluent should be prevented. Where a potential for salinity issues to occur, it should be specifically monitored and managed.

3.5.5 Soil structural stability

The main influence on soil structure is the proportion of sodium in the effluent, which is measured as the Sodium Adsorption Ratio (SAR) and the Electrical Conductivity (EC) of the irrigated water. Section 4.2.4 of ANZECC & ARMCANZ (2000) provides guidance on the process of assessing structural stability of soils in irrigated lands.

Note that the SAR of domestic sewage is typically quite low (around 4) and within a range that makes it unlikely to be a problem with irrigation. However, routine checks should be made to confirm this. Municipal sewage, which includes 'trade waste', may be somewhat different, especially if a contributing industry uses large amounts of salts or salt forming materials, such as acids and alkalis.

3.5.6 Organic matter in irrigation water

Excessive amounts of organic matter in effluent could cause adverse environmental impacts to the soil. The amount of organic matter in treated sewage is normally not an issue for land disposal schemes as typical organic matter (as represented by the 5 day Biochemical Oxygen Demand) loading rates are well below the acceptable limits. Organic matter can however significantly impact on waterways and this needs to be considered if there is a potential risk from runoff.

3.5.7 Microbial contaminants

Microbial contaminants or pathogenic organisms found in treated effluent can cause adverse health impacts to humans and animals. However, the occurrence, concentration and type of pathogenic microorganism can vary substantially depending on the source of the effluent. The health risk associated from pathogenic microorganism will vary depending on the pathogenic microorganism load (count) and the form of contact between the pathogen and its host. The acceptable levels of pathogenic microorganisms (using E Coli as a "microbiological indicator") for different irrigation uses are available within the 2005 Queensland Environmental Protection Agency's Queensland Water Recycling Guidelines. As per the recommendations from Queensland Health Department, at least Class A (E. coli <10 cfu/100 mL, median) recycled water must be used for public areas with uncontrolled access.

3.6 MEDLI limitations and other considerations

MEDLI predicts water and nutrient balances on a daily basis for an effluent irrigation scheme. However, the current version has limited ability to predict groundwater impacts, soil salinity issues and pathogen risks. The impact of sodicity on soil's structural stability is not considered in MEDLI and this assessment needs to be undertaken separately by suitably qualified persons. The limitations and additional considerations for the current version of MEDLI, i.e. Version 2.0, are discussed below.

3.6.1 Large scheme with multiple paddocks/cropping systems

Generally large land disposal schemes use multiple paddocks with mixed crops. The current MEDLI version has no ability to model multiple paddocks for effluent supplied from a common wet weather storage facility. Modelling these complex systems requires special attention in setting up the model parameters and expert advice (see Appendix 3 for more information).

3.6.2 Multiple irrigation methods and strategies

The current MEDLI version can handle only one irrigation method and one irrigation strategy for each modelling run. However, in the real world, multiple irrigation methods (e.g. sprinklers and flood) and different irrigation strategies (e.g. fixed irrigation or irrigation based on soil moisture deficit) are often utilised depending on the operators or agronomic needs. Therefore, in some cases, the use of representative model inputs in MEDLI is required for more accurate predictions by generating area-weighted model parameters.

3.6.3 High seasonal rainfall areas

Queensland has a large variability in rainfall over time and sometimes the use of annual average rainfall values for irrigation design is not appropriate. For example, North Queensland has typically very high rainfall during the December to February period and this is followed by no rain or minor rain for the rest of the year. This results in no irrigation demand during the wet period and high irrigation demand for the rest of the year. This unique rainfall distribution causes some difficulties in designing dedicated land disposal systems. The MEDLI predicted water balances, as annual averages, have limited value for designing land disposal schemes in such cases. Achieving zero overflows are often not possible as the cost of increased wet weather storage capacity would be too high. Therefore, MEDLI predictions for high seasonal rainfall areas need to be used cautiously.

3.6.4 Soil salinity and sodicity

MEDLI predicts the effect of soil salinity in irrigation schemes using a steady-state model with no salinity feedback on crop growth or subsequent water and nutrient use. The model predictions simply warn when salinity may be present to a degree that potentially invalidates MEDLI's assumptions, and therefore reliability of predictions. Under variable climate conditions with high saline effluent, irrigation assessment may require the use other salinity models such as SALF2 to predict the sustainability of the land disposal scheme.

Sodicity is one of the major risks in land disposal schemes and the adverse impact of sodicity on soils structural stability needs to be assessed outside of MEDLI. The information on sodicity assessment is given in ANZECC 2000 (Section 4.2.4 Irrigation salinity and sodicity).

3.6.5 Groundwater impact assessment

The groundwater module in MEDLI involves a simple model that predicts the fate of contaminants (in this case nitrate) leaching down into an underlying aquifer. It predicts maximum likely concentrations at the property boundary after different time intervals. The inputs required for the model are difficult to estimate and MEDLI does not consider the impact that could occur between bottom of the root zone and the top of the aquifer and its attenuation effects. Therefore, the predictions are not suitable for assessing the groundwater quality beneath the irrigation site. However, it is acknowledged that MEDLI's predicted deep drainage and the concentration of contaminants in the deep drainage will help indicate the risk of groundwater contamination. If the predicted nitrogen leaching is more than 5 kg/ha/year, further specialised groundwater assessment would be required (see Appendix 4).

3.6.6 Changing crops

Generally MEDLI modelling is performed using a single crop or a fixed rotation in the irrigation scheme. However, in the real world, monoculture is not a good agronomic practice and often periodical change in crops or rotation is practiced to achieve land sustainability and economic viability. Therefore, the use of a representative crop, or the rotation for MEDLI modelling, is important as the change to a completely different crop in the irrigation scheme can have significant impact on model predictions.

3.6.7 Schemes with supplementary fertiliser

Certain effluent irrigation schemes (e.g. golf courses) can have supplementary fertiliser applications to keep the pastures green and healthy. MEDLI modelling does not factor in supplement fertiliser inputs and the model predicted nutrient balance will be invalid for such cases. Therefore, extra attention is necessary for effluent irrigation schemes with supplementary fertiliser applications and soil monitoring and groundwater quality may provide required information for environmental impact assessments.

4. Post approval monitoring and management

Once approved and operating, the effluent irrigation scheme needs to be managed using best management practices and monitored to achieve optimal environmental outcomes. The operators need to have a good understanding of the compliance requirements that are stipulated under their Environmental Authority. Typically, operators of land disposal systems are required to develop and undertake an Irrigation Management Plan (IMP) as part of their approval conditions. This is discussed in more detail below.

4.1 Irrigation management plan

An IMP needs to identify all potential risks associated with the land disposal scheme. The IMP needs to contain the following elements, as a minimum:

- estimating correct irrigation requirements based on local climatic condition;
- buffer zones and security management for the protection of sensitive receptors and public safety;
- irrigation infrastructure details and their maintenance program;
- soil property and soil monitoring information;
- irrigation rates and frequency to optimise for evapotranspiration;
- nutrient loading rate and management for the build-up of salts and toxicants in the soil;
- crop selection and management;
- soil amelioration to compensate for poor effluent (e.g. high SAR);
- a wet weather storage management plan, and
- monitoring of the local receiving environment, including surface and groundwater, where required.

Many of these elements will be decided as part of the approval process. The monitoring elements of the IMP are discussed further in Section 4 2.

4.2 Irrigation scheme monitoring

Monitoring allows operators of land disposal schemes to keep track of potential impacts so that they can adjust their management practices to prevent environmental harm or potential health risks. Furthermore, monitoring records will assist in demonstrating the due diligence.

Monitoring programs should be developed to ensure adverse impact to all public health, agricultural resources and environmental values is minimal. Monitoring should provide sufficient data to assess and manage the relative risk to each of these. The extent of monitoring should reflect the degree of risk. Where the risk has been evaluated as being low, monitoring can often be restricted to the quality and quantity of the irrigation water and the soil and crop properties within the irrigation areas.

Table 1 provides a list of recommended standard indicators and monitoring schedules. Nonetheless, depending on the perceived risks, site specific monitoring plans may be required.

Soil moisture measurements are recommended for irrigation scheduling purposes. Periodic soil testing is required to evaluate soil nutrients, salinity, structural damage and potential build-up of contamination. Visual observations of the crop, including monitoring for pests and diseases, and if necessary, plant tissue analysis, are also recommended.

Where the risk to environmental values has been evaluated as being high, approval conditions may require a receiving environment monitoring program (REMP) to monitor groundwater, and in some cases, surface water.

Groundwater need only be monitored if it is within 10 metres of the ground surface and/or if the existing groundwater quality is at risk from the land disposal scheme. Groundwater sampling should occur at the irrigation site before crop planting (in order to obtain a baseline condition for the aquifer), when the crop is mature and quarterly/yearly thereafter. Where the groundwater depth is shallow or where the soil have highly permeable, monthly monitoring may be appropriate. Hydraulic gradients should be considered when establishing groundwater monitoring boreholes.

Table 1 Recommended monitoring regime for land disposal schemes.

		Indicator	Frequency	Monitoring Point
Low and High-Risk Schemes - Routine Monitoring	Irrigation management	Rainfall (mm)	Daily	Local gauge
		Inflow to storage (m^3)		Pump house
		Wet Weather Storage Overflows (m^3 and mm)		Wet weather storage
		Irrigation Volume (m^3, mm and time intervals)	During Irrigation	
		Irrigation initiated (soil moisture mm)		Irrigation field
		Irrigation termination (soil moisture mm)		
	Irrigation water quality	$EC_{(1:5)}$ (µS/cm), pH, Turbidity TN, TP, SAR, Free and Total Chlorine (mg/L) E. coli (cfu/100 ml) Odours	Weekly	Pre-irrigation storage
	Soil quality	TN, TP, $EC_{(SE)}$ and Exchangeable Sodium Percentage (ESP)	Annually	Irrigation field
	Crop condition	Cover (%), Visual observations	Monthly	
High Risk Schemes	Surface water REMP	$EC_{(1:5)}$, pH TN, TP, TDS (mg/L) Chlorophyll a (ug/mg/L) E. coli (cfu/100 ml)	Quarterly	Upstream MP & Downstream MP
	Groundwater REMP	Level, $EC_{(1:5)}$, pH, TN, TP Depth to groundwater level	Quarterly	Up-gradient MP & Down-gradient MP

Surface waters, such as upstream and downstream of the effluent irrigation site, could be monitored prior to the commencement of the irrigation to obtain a baseline condition for the waterway. Monitoring could also occur following storms and during high flow events. Thereafter, depending on the frequency of effluent discharge and the strength of the effluent, a sampling program should be developed to determine and manage any potential impacts, or in accordance with approval requirements for the activity. Monitoring of surface water is typically only required when the land disposal scheme has been identified as being high risk in terms of receiving waters.

An Algal Management Plan is often needed for uncovered effluent storages. There is a high probability that algal blooms will occur periodically in uncovered effluent storages. These algal blooms may include toxic algae and monitoring may be needed to determine the types and concentrations of various types of algae which could propagate in these storages. Consideration should be given to management to reduce the potential for algal blooms, such as artificial de-stratification, aeration devices, submersible mixers, covering lagoons, additions of algaecides, use of floating constructed wetlands, additions of micronutrients to stimulate the growth of diatoms etc.

4.3 Compliance

The EAs associated with land disposal conditions typically include discharge limits, allocated resources and operating conditions, as well as monitoring, recording, reporting and compliance review requirements. Often site-specific EA conditions have been determined on a case-by-case basis, based on the potential environmental risk of the particular land disposal scheme. For example, a small, low risk activity can often have a daily fixed irrigation limit regardless of irrigation demand with no effluent quality limits. Generally, operators are required to produce an annual environmental management report to enable assessment of the performance of the land disposal scheme. The requirements of this report will depend on the size and the potential environmental risk of the effluent irrigation scheme. To check potential breaches of EA conditions, the regulator often carries out compliance checks (see Compliance Checklist in Appendix 5).

Appendix 1: Information request list for disposing effluent to land

1. **Effluent source** (Industrial, Agro-Industry, Domestic etc.)
    a. Type of treatment applied – include description of treatment type, piping diagram and design details such as size/volumes etc.
    b. Quantity - include quantitative description of average and maximum wastewater flows and explain how these were determined. Could include dry versus wet times and pattern of production over time
    c. Quality (key contaminants of concern) – describe and quantify the concentrations of key contaminants including total nitrogen, total phosphorous, pH, electrical conductivity/total dissolved salts and sodium/SAR. Include average and maximum concentrations
    d. Quality (other contaminants) – provide hazard assessment of other contaminant including heavy metals, pharmaceuticals, toxins, pathogens if applicable

2. **Location of effluent discharge (irrigation scheme)**
    a. Latitude, longitude and elevation
    b. Maps showing the property and surrounds, including the following details for both the property and adjacent areas:
        i. Property boundaries and proposed irrigation area(s), any wet weather storage and overflow discharge point(s)
        ii. Current land use including vegetation (and vegetation of the proposed effluent irrigation area)
        iii. Infrastructure such as buildings, roads, people access, bores supplying potable water, bores for non-potable use, dams etc.
        iv. Topography including drainage lines, water courses, springs, soaks etc.
        v. Any adjacent environmental values or sensitive/high ecological values in the vicinity of the scheme.

3. **Historic climate data for area used for designing the scheme.** Where available, review the most locally relevant climate data. Otherwise, obtain and assess the Silo "DataDrill" (https://legacy.longpaddock.qld.gov.au/silo/datadrill/index.php) data.

4. **Flooding history for area -** Check frequency of inundation (ARI) in the area and assess if this is a potential risk.

5. **Soil characteristics of effluent irrigation area(s) – Based on site investigation and available data, provide the following;**
    a. Soil profile description including texture, structure, impermeable layers and any evidence of rising water table
    b. Hydraulic properties
        i. Moisture content at field capacity, permanent wilting point, saturation, and
        ii. Saturated hydraulic conductivity
    c. Chemical properties
        i. Nitrogen content, especially organic nitrogen,
        ii. Phosphorus content,
        iii. Phosphorus sorption capacity,
        iv. Exchangeable sodium percentage, and
        v. Background concentration of any contaminants mentioned in Item 1 above

6. **Proposed vegetation for effluent irrigation area(s)**
    a. Species of plant cover, and
    b. Management of plant biomass (cut and cart, cut only)

7. **Groundwater**
    a. Levels over time – any risk of groundwater or temporary perched water tables impacting on operation of effluent irrigation area, and
    b. Background Water Quality (nitrogen, phosphorus, salinity and concentrations of any contaminants) mentioned in Item 1 above

8. **Irrigation area management**
    a. Irrigation regime proposed (how irrigation is triggered and applied),
    b. Irrigation method and infrastructure required, and
    c. Management of aerosols if above-ground irrigation is proposed

9. **Wet weather storage management**
    a. Type and volume,
    b. How any overflows will be managed,
    c. Algae management, and
    d. contingency plans

10. **Predicted environmental impacts of the proposed land disposal scheme**
    a. Model(s) used – where MEDLI is not used, a justification for the validity and calibration for the model is required,
    b. Input data used – provide all raw files. If MEDLI V2 is used, provide scenario file (*.med)
    c. Meta Data Details/Quality Assurance of data used (measured by qualified personnel, model defaults, expert estimates etc.), and
    d. Details of outputs and interpretation. If MEDL V2 is used, provide output file (*.medr)

Where bio-physical models need to be used to assess the suitability of land disposal of wastewater, the following information should be provided to proponents:

The preferred model is MEDLI. This model assesses the hydraulic load applied to the irrigation areas, the fate of nitrogen, phosphorus and salts, and the required wet weather storage volume. The assessment must include, but not be limited to the following:

- The required size of the irrigation area/s;
- The required wet weather storage volume/s and frequency of overtopping events;
- Irrigation rates;
- Soil water balance;
- Soil nutrients balance;
- The protection of groundwater;
- Crop performances.

The assessment should be carried out for the proposed and future effluent irrigation rates. Any predicted overflows to the environment from any storage need to be justified in terms of environmental impact (impact assessment). This justification may include details on:

1. How irrigation rates are to be undertaken and scheduled to ensure that they do not result in an exceedance of water holding capacity of the soil or the uptake capacity of the crop, which may as a consequence result in water logging, surface runoff or excessive deep drainage. How this is to be managed through the use of rain gauges, soil moisture meters or other measures;
2. The salinity of the applied wastewater, and the capacity of the vegetation and soils in the irrigation area/s to assimilate these salts on a sustainable basis;
3. Method/s of effluent application (surface or sub-surface irrigation);
4. How irrigation is triggered and applied;

5. Potential for human exposure to irrigated effluent and aerosols;
6. Potential for aerosols and drift to be generated and move to off-site locations;
7. How the irrigation system is to be operated and maintained in a safe and sustainable manner;
8. Details of buffer zones between irrigation area and sensitive assets.

Appendix 2: Long-term annual rainfall

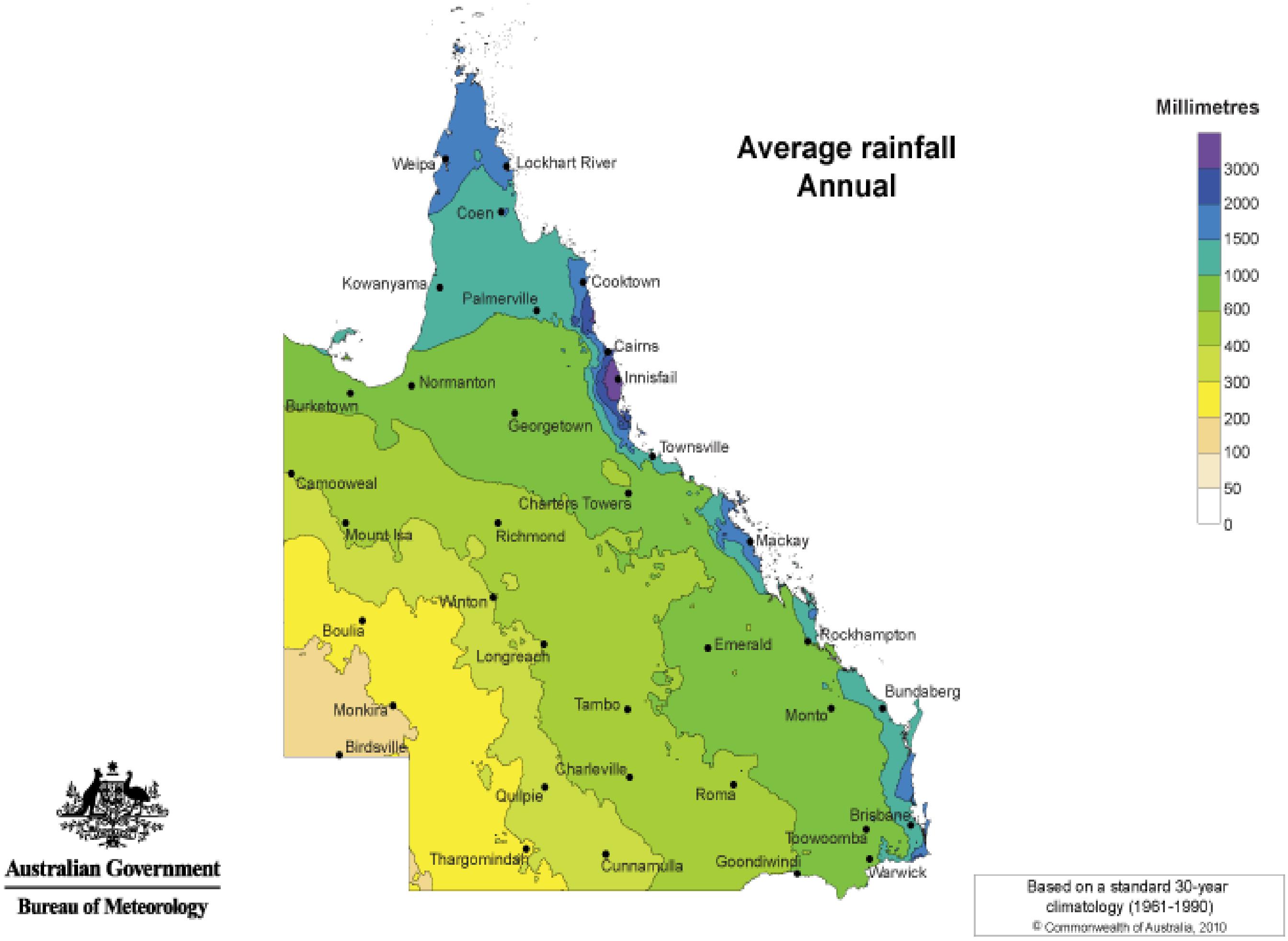

Figure A1. Long-term average rainfall regimes in Queensland

Appendix 3: Schemes with multiple paddocks

Schemes with multiple paddocks connected to one pond system are not yet able to be explicitly modelled by the current version of MEDLI (V2.1). In the meanwhile, the multiple-paddock scheme may be roughly approximated using one or more methods as follows:

- Simplify the irrigation areas into one “average” area based on the area-weighted average irrigation demand. This involves determining the irrigation demand for each paddock for its given soil type, vegetation, and irrigation regime, then calculating the area-weighted average irrigation demand, formulating a single paddock with this irrigation demand, and running the scenario using the Multirun option to determine the optimal wet-weather storage pond volume and irrigation area to use.

- Split the scheme into separate schemes for modelling by MEDLI. This again involves determining the irrigation demand for each paddock for its given soil type, vegetation, and irrigation regime. The ratio of paddock area x paddock irrigation demand across all paddocks is used to split the wet-weather storage pond volume and inflow volume. Each separate scenario is then run to optimise pond volume and irrigation area for the given inflow volume.

- Subtract the irrigation demand of the higher priority paddocks from the inflow volume. This produces a simple scheme consisting of the low priority paddock, and the remaining inflow to optimise the wet-weather storage pond volume and the irrigation area of the low priority paddock.

- Use a spreadsheet for performing the pond daily water balance. This involves saving the daily irrigation data (per unit area) from each paddock (when determining the irrigation demand) into columns in a spreadsheet. This data represents the potential irrigation. The total storage pond daily water balance for each pond size and irrigation area is then calculated outside of MEDLI using the spreadsheet, with any daily irrigation from each paddock being subtracted from the pond water volume where possible.

Appendix 4: Considerations related to 'deep drainage' associated with MEDLI modelling and environmental impact assessment (FAQs)

Deep drainage is the water that moves below the root zone of plants and is no longer available for crop transpiration. It is measured in units of depth (mm) to allow mass balance comparison with rainfall (mm) and irrigation (mm).

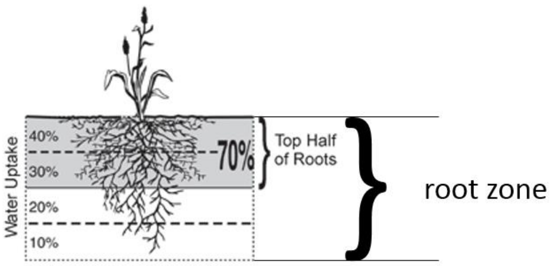

Figure A2. The part of the soil that is populated by roots of plants to absorb water and nutrients, e.g. pastures up to 1 m, trees more than 5 m.

Deep drainage occurs when the soil water content in the root zone exceeds Field Capacity (FC) or the Upper Storage Limit (USL). The difference between the field Saturation Water Content and Field Capacity is the Drainable Porosity (DP) that supplies the water that moves below the root zone. A schematic of the time trend in soil water content from Saturation to FC is shown in Figure A3. Deep drainage can also occur when surface water ponding occurs on the soil surface and the soil profile over the root zone has wet to saturation moisture content. Infiltration under these circumstances reflects the saturated hydraulic conductivity of the hydraulically active soil profile. This type of deep drainage tends to be rare in well managed irrigation areas.

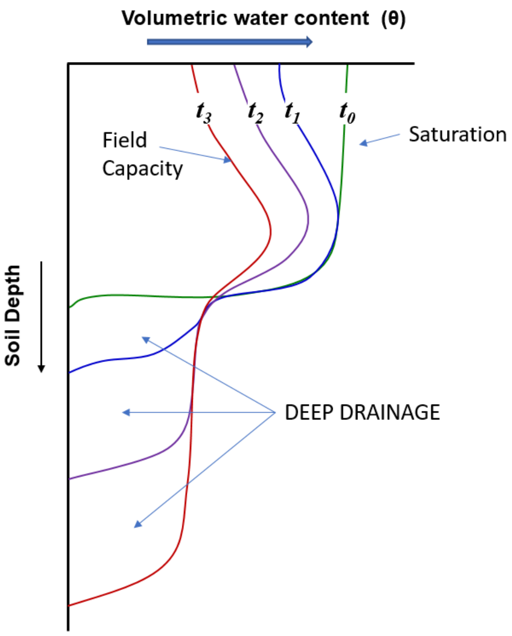

Figure A3. Time trend of the soil water content in a permeable soil draining from soil saturation (at t_0) to field capacity over time (at t_3)

Both rain and irrigation can cause deep drainage. Deep drainage is vital for the soils health as it removes salt from the root zone that accumulates at each irrigation. In low rainfall irrigation areas, extra irrigation in excess of the soil water deficit is required to create deep drainage and hence manage root zone salinity. In most Queensland irrigation areas, especially in north and eastern parts, rainfall on a pre-wet soil is sufficient to raise the soil water content above field capacity multiple times per year, and hence create deep drainage. The higher the annual rainfall, the larger the fraction of its infiltration that is repartitioned into deep drainage.

Natural deep drainage: Rainfall can cause deep drainage during extended rainfall events and generally no environmental harm is caused, unless the catchment is vulnerable to dryland salinity. This deep drainage contributes to groundwater recharge. A MEDLI scenario with no irrigation can estimate the natural deep drainage in a location.

Irrigation induced deep drainage (IIDD): Excessive irrigation loading into the soil (more than irrigation demand) will result in deep drainage, in addition to that that which occurs from rainfall infiltrating into a soil profile being irrigated with effluent.

The downside of deep drainage is that it can leach nitrate (NO_3) and possibly phosphate (PO_4) along with the dissolved inorganic salts into groundwater. However, the soil solution nitrate concentration (mg/L) in soil that has been irrigated with effluent tends to be lower than in traditional irrigated soils where the crop fertilizer requirement is applied in one or two large loads (kg/ha). Hence, the opportunity for high NO_3 leaching in effluent irrigated paddocks could be infrequent. The other advantage of Australian soils is that they usually have a high capacity to store P in the soil profile. This fixing ability is quantified by the P adsorption isotherm recommended for MEDLI runs, although a qualitative assessment can be made from the plant available P and the P buffering capacity. Generally, it takes many decades of effluent irrigation before the P fixing ability of the root zone is exhausted, although exceptions can occur with high strength effluent and/or sandy soils.

Another downside of deep drainage is that it can cause a rise in the regional water table and if this comes within 2 m of the soil surface, capillary rise can cause surface salting, which is a major problem in many of the world's irrigation areas. This problem should not occur in the small irrigation areas associated with sewage land disposal (e.g. < 2 ha) but should be considered as possible for larger irrigation areas.

If substantial nitrate and pathogen leaching occurs under an effluent irrigation area and the drainages reaches the water table, the subsequent down gradient concentration will be affected by:

- the hydraulic gradient of the groundwater;
- the permeability of the aquifer, its effective porosity;
- the solute dispersion characteristics of the aquifer; and
- the dissolved organic carbon (DOC) concentration that will allow denitrification to occur, since most aquifers are anoxic or anaerobic.

Measuring all these hydro solute parameters is both difficult and expensive and unlikely to be warranted unless a clear contamination risk is assessed. The alternative is using an analytical groundwater model and/or groundwater monitoring to alert the irrigators of adverse consequences to groundwater.

The hydrological pathway of deep drainage should not be used as a method of wastewater disposal unless otherwise authorised. The contaminated deep drainage can adversely impact the environmental values of groundwater and surface water that is connected.

Therefore, the potential risk of groundwater contamination should be assessed for land disposal systems. The groundwater contamination risk is mainly dependent on the amount of deep drainage, quality of the deep drainage water, type of aquifers, depth to groundwater, background groundwater quality, environmental values, rate of recharge, presence of groundwater dependent ecosystems and potential for human uses of this groundwater, such as for potable water supply, irrigation etc.

Obviously, natural deep drainage amounts will be enhanced due to irrigation and <u>there is no fixed allowable deep drainage amount for land disposal schemes</u>. The allowable amount of deep drainage will depend on the risk assessment, irrigation management and leaching practice, and accordingly is site specific.

MEDLI modelling can be used to predict natural deep drainage and irrigation induced deep drainage (IIDD). If the modelling results indicate that the IIDD is excessive (e.g. greater than 200 mm/year, or more than 25% of natural deep drainage), it is recommended that an assessment of the risk to groundwater quality and potentially connected surface water(s) be assessed, where this cannot be reduced through alternative management or irrigation design.

Environmental risk assessment

Acceptable IIDD rates (mm/year) should be decided based on a risk assessment, with the allowable amount of deep drainage being site specific. The following should be considered for an Environmental Risk Assessment:

- Deep drainage must not adversely impact on the environmental values of groundwater
- Deep drainage must not significantly change the background condition of groundwater with respect to quality and quantity (levels).

Assessment Criteria:

- Irrigation demand,
- Quantity of effluent irrigated,
- Amount, frequency and method of effluent application (e.g. fixed, soil moisture deficit based),
- Method of effluent irrigation (i.e. sub-surface, above-ground sprinkler, flood),
- Quality of irrigated effluent (typically, microbiological quality (in terms of “indicator organisms (E. coli)), nutrient concentrations (TN,TP), total dissolved salts (TDS in mg/L or EC as uS/cm),
- Soil type(s) as reflected in Drainable Porosity (mm/m) in the crop root zone and the saturated hydraulic conductivity,
- Type of aquifer (e.g. confined/unconfined),
- Depth to groundwater (e.g. minimum depth due to seasonal meteorological conditions). The risk of contaminant movement is low if the thickness of this layer is more than 10 meters,
- Horizontal Proximity to abstraction bores,
- Horizontal Proximity and connection to surface waters,
- Groundwater flow direction and velocity,
- Presence of groundwater-dependent ecosystems,
- Background groundwater quality and characteristics, and
- Climate (especially high rainfall areas on the coastal uplands).

Often ongoing monitoring and assessment is necessary to confirm potential/predicted impacts as initial cost-effective modelling identifies the likelihood of risk rather than exact temporal/spatial concentrations.

Appendix 5: Compliance checklist associated with sustainable land disposal schemes

This is a protocol recommended for undertaking compliance inspections of land disposal schemes:

- Review the current Environment Authority (EA) and related data with regards to land disposal requirements covering effluent quality and quantity and relevant receiving environment monitoring (REMP), monitoring related to soil, crops, groundwater and surface water, nutrient export and associated reports.
- Use Queensland Globe or other spatial software to view the existing site, noting the location and status of the wet weather storage(s), effluent irrigation area(s) and any indications of unsustainable irrigation practices, such as evidence of overflows, leaks from the wet weather storage(s), runoff from effluent irrigation areas, preferential flow paths, status (health) of vegetation being irrigated etc.
- Check the location of the irrigation area(s) as specified in the EA, topography, as well as the size of the irrigation area, any specified buffer zones, signage, controlled or uncontrolled access and any environmentally sensitive assets surrounding or nearby the designated irrigation area(s).
- Check the typical daily allowable irrigation flow data required to be monitored and recorded by the operator with that specified in the EA.
- Check the allowable irrigational water quality limits, typically required to be monitored and recorded by the operator, specified in the EA and compare to measurements of the irrigated water. These should be obtained prior to any on-site inspection and analysed for compliance with limits (and frequency requirements) specified in the current EA.
- Check that the analysis of irrigated water has been undertaken (typically by N.A.T.A registered laboratories) for the indicators and frequency specified in the current EA.
- Check that the analysis and frequency of other indicators undertaken by the operator are in accordance with that specified in the EA.
- Request copies of N.A.T.A. Laboratory reports for indicators specified in the EA to check they agree with data typically summarised in spreadsheets.
- Review data provided in the N.A.T.A. Laboratory reports to see if values comply with levels, ranges specified in the EA.
- Check that samples of effluent have been collected in accordance with Departments latest Water Quality Sampling Manual.
- If necessary, check all “Chain of Custody” forms have been completed correctly.
- Check the integrity of the wet weather storage(s) (for example leaks from sides of the wet weather storage), location of the wet weather storage, correct volume, any unlawful seepage (for example at the base of the wet weather storage), signs of previous or existing overflow(s), status of any spillway(s), presence of algal blooms (toxic or non-toxic), colour of stored water, density of algae, species of algae, nuisance aquatic plants, odours, any controlled access infrastructure, signage, if possible check wet weather storage dimensions, description of any destratification infrastructure, status of any level detector, whether open or enclosed as specified in the EA, whether there have been any unlawful or reported wet weather overflow(s) and number of such incidences.
- Check for any groundwater extraction bores located near the irrigation site.
- Check for any watercourses located near the irrigation site and any signs of eutrophication or impacted aquatic ecosystem in these watercourses.
- Check for potential groundwater depth at the irrigation site.
- Check the integrity of any irrigation pumping infrastructure and any colour coding of irrigation piping (e.g. lilac).
- Record the type of irrigation infrastructure and methodology adopted for effluent irrigation by the operator (e.g. aboveground spray irrigation, flood, subsurface irrigation). Get the operator to demonstrate irrigation practice during the site visit and verify the uniform distribution across allocated land area.
- Obtain a description of the irrigation scheduling and management system, if applicable.
- Obtain a description of soil moisture measurements used in irrigation, if applicable.

- Check irrigation area(s) for any evidence of soil erosion, surface runoff off-site, surface ponding, water logging, flooding, soil moisture, soil cracking, soil saturation, salt crusting etc.
- Land use – description of irrigated pasture/crop/vegetation (if specified in EA - crop “health”, crop coverage, crop appearance, diseased crop, crop pests, any observed crop abnormalities, crop canopy density, noxious weeds, evidence of harvesting if applicable, unlawful grazing (e.g. cattle)).

Definitions and abbreviations

Adsorption: Adhesion of molecules or ions onto the surface of particles, including exchangeable cations and anions on soil particles.

Aeration: A process by which air is circulated and mixed creating new air/liquid interfaces to promote the transfer of oxygen across the interface.

Aerosol: A colloid of fine solid particles or liquid droplets, in air or another gas.

Anaerobic pond: A pond where microorganisms break down biodegradable material in the absence of oxygen and other forms of oxygen such as nitrates.

Aquifer: Groundwater-bearing formations that are sufficiently permeable to transmit and yield water in useable quantities.

Arable land: Land capable of producing crops; suitable for farming; suited to the plough and for tillage.

Beneficial use agreement: A waste can be approved as a resource if the department considers that it has a beneficial use other than disposal.

Buffer zones: Areas created to enhance the protection of a specific conservation area, often peripheral to it.

Bulk density: Also known as dry bulk density, is the weight of dry soil (Msolids) divided by the total soil volume. The total soil volume is the combined volume of solids and pores which may contain air and water.

Cation exchange capacity (CEC): The capacity of the soil to hold and exchange cations. It is usually expressed as centimoles of positive charge per kilo of soil (cmol (+)/kg).

Chemical oxygen demand (COD): The oxygen equivalent of the organic matter in wastewater that can be oxidised by using a strong chemical oxidising agent in an acidic medium.

Controlled public access: The limitation of public access to sites to minimise the likelihood of direct physical contact with effluent.

Crop Factor (Kc): The proportion of potential evapotranspiration (PET) actually transpired by the crop (Etcrop). (Etcrop = Kc x PET). PET = Class A Pan reading x Pan Coefficient.

Crop rotation: The practice of growing a series of dissimilar/different types of crops in the same area in sequential seasons.

Crop's fertiliser requirements: The amount of fertilizer required to supplement the total quantity of nutrients removed by the crop from the soil or substrate. In order to achieve optimum yields, each crop should have at its disposal the pre- determined amount of nutrients. These conform the basis of all fertilizer recommendations.

Deep drainage: The amount of water that 'leaks' below the root zone of plants

Deficit (irrigation) scheduling: Scheduling irrigation used to ensure that a soil moisture deficit remains after each irrigation event (see also irrigation scheduling).

Denitrification: The biological process by which nitrate is converted to nitrogen and other gaseous end products.

Desertification: A type of land degradation typically losing its plant available water as well as vegetation and wildlife. It is caused by a variety of factors, such as human activity, salinization, through climate change and through the overexploitation of soil. Desertification is a significant global ecological and environmental problem.

Disinfection: Process of reducing the concentration of disease-causing (pathogenic) organisms.

Effluent: The outflow from sewage during purification or liquid industrial waste.

Effluent irrigation system: Irrigation systems that use effluent. Irrigation of effluent is not synonymous with land disposal of wastewater but is the key method used for sustainable land disposal of effluent in Queensland.

Electrical conductivity: A measure of the conduction of electricity through water or a water extract and used to determine the soluble salts content in the effluent. Electrical conductivity measurements are used in routinely in many industrial and environmental applications as a fast, inexpensive and reliable way of measuring the ionic content in a solution.

Electrical conductivity saturation extract (EC_{se}): A method for estimating the electrical conductivity of the saturated soil-paste extract (EC,) from measurement of the electrical conductivity of the saturated soil-paste for purposes of soil salinity appraisal.

Environmental harm: Environmental harm is any adverse effect, or potential adverse effect (whether temporary or permanent and of whatever magnitude, duration or frequency) on an environmental value, and includes environmental nuisance and human health.

Environmental sensitive asset: Sensitive receptor under any relevant environmental protection policies.

Eutrophication: Enrichment of waters with nutrients, primarily phosphorus, causing abundant aquatic plant growth.

Evapotranspiration (ET): The sum of evaporation and plant transpiration from the land to the atmosphere. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception, and waterbodies. Transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapour through stomata in its leaves. Evapotranspiration is an important part of the water cycle and the desired discharge endpoint (end of pipe) of the effluent disposed onto the land.

Exchangeable cations: Positive ions such as calcium, magnesium, potassium, sodium, hydrogen, aluminium and manganese, which interchange between soil solutions and clay or organic complexes in soil.

Exchangeable sodium percentage (ESP): The relative proportion of sodium ions to other exchangeable cations in soil expressed as a percentage. ESP is the method used to determine the sodicity of a soil (i.e. ESP >5 is considered to be a sodic soil).

Exfiltration: Refers to a loss of water from a drainage system as the result of percolation or absorption into the surrounding soil.

Faecal coliforms: A fecal coliform (British: faecal coliform) is a facultatively anaerobic, rod-shaped, gram-negative, non-sporulating bacterium. Coliform bacteria generally originate in the intestines of warm-blooded animals.

Field capacity: The amount of water held in soil when it has been allowed to drain (24hrs) under normal gravity.

Flood irrigation: An irrigation method that applies water or wastewater to directly flow onto the land area by means of earthen canals or gated pipe distributors. This procedure generally allows the water or wastewater to flood soils and percolate through the soil. The distribution efficiency is relatively low depending on the slope and length of the irrigation plot.

Freeboard: Spare capacity of the pond to accommodate any unexpected increase in containment requirements.

Furrow irrigation: An irrigation method that applies water or wastewater by furrows or small ditches that lead from the supply ditch.

Groundwater: Water located beneath the surface in soil pore spaces and in the fractures of rock formations.

High Environmental Values (HEV): The biological integrity of an aquatic ecosystem that is effectively unmodified or highly valued.

Hydraulic conductivity: Hydraulic conductivity, symbolically represented as K, is a property of soils that describes the ease with which a fluid (usually water) can move through pore spaces or fractures. It depends on the permeability of the material, the degree of saturation, and on the density and viscosity of the fluid. Saturated hydraulic conductivity, Ksat, describes water movement through saturated media.

Infiltration: The process by which water on the ground surface enters the soil.

Infiltration rate: The rate at which water can enter the soil surface. If the precipitation or irrigation rate exceeds the infiltration rate, runoff will usually occur. The rate of infiltration can be measured using an infiltrometer.

Irrigation demand: The amount of crop water use (consumptive use) in addition to the rainfall to grow a successful crop.

Irrigation scheduling: The monitoring of soil moisture deficits either by direct measurement (e.g. neutron probe) or indirectly by soil moisture budgeting to determine the frequency and quantity of irrigation water required. Normally used to ensure that only enough water is applied to meet plant water requirements and leaching salts from the root zone.

Land disposal system: The process of effluent disposal onto land, most commonly in Queensland via irrigation.

Leaching: The downward movement of a material in solution through soil.

Leaching fraction: Irrigation water applied in excess of the soil water holding capacity in order to leach salts to below the plant root zone. The fraction is usually smaller in higher rainfall areas and larger for higher strength effluent.

Micronutrients: Chemical elements such as boron, copper, zinc, iron, manganese, molybdenum and chlorine that are necessary in only extremely small amounts for plant growth.

Net evaporation: The difference between evaporation and rainfall on a location during a specified time period.

Nitrification: Transformation of inorganic ammonium (NH_4^+) into nitrate (NO_3^-). In treatment processes, conversion of organic nitrogen to ammoniacal nitrogen is preceding or occurring simultaneously with nitrification. Transformation of organic nitrogen in soil is referred to as mineralisation.

Nutrient: Nutrients (mainly nitrogen and phosphorus) are essential for plant health. Optimal yields can only be produced when all these nutrients are in proper supply. If one or more nutrients are lacking in the soil, crop growth/ yields will be reduced.

Overflows: The amount of effluent that spills from the wet weather storage when the storage capacity is full.

Pan evaporation: Evaporation is the change of water from its liquid (or solid) phase to its vapour phase. Supply of energy; solar radiation and advection are two main factors influencing evaporation for the earth's surface. A standard evaporation pan called a Class A pan is used a basis to estimate evaporation from open space.

Pathogen: An organism capable of eliciting disease symptoms in another organism.

Periodical leaching: Washing off the soil profile to remove salts (mainly Na) from the root zone.

Permanent wilting point: The point at which water in the soil is held at pressures sufficiently high that plants can no longer extract water.

Phosphorus adsorption capacity: The ability of a soil material to sorb phosphorus compounds onto soil particles thereby rendering the phosphorus unavailable to plants and immobilising it within the soil itself. Soil has a limited capacity to sorb phosphorus. When the maximum phosphorus sorption capacity of a soil is reached, phosphorus ions will move with water down the profile. This process starts to partially occur, well before the full sorption capacity is reached.

Phosphorus sorption: The process by which phosphorus binds with hydrous oxides of iron and aluminium in the soil, thereby becoming unavailable for plant uptake.

Plant available water: The amount of water held in the entire soil profile between field capacity and permanent wilting point within the root depths.

Potential evaporation: (ET_0): Sometimes referred to as reference ET, is a representation of the environmental demand for evapotranspiration and represents the evapotranspiration rate of a short green crop (grass), completely shading the ground, of uniform height and with adequate water status in the soil profile. It reflects the energy available to evaporate water, and of the wind available to transport the water vapour from the ground up into the lower atmosphere.

Potential irrigation demand: The maximum amount of water that can be artificially applied into the crop to meet evapotranspiration and leaching requirements in addition to the natural rainfall. Expressed in mm per specified time period (e.g. mm/day).

Reclaimed water: Wastewater that has been recovered for further use after appropriate treatment.

Recurrence intervals: Also known as return period (sometimes repeat interval), is an estimate of the likelihood of a flood event or a river discharge flow to occur. It is a statistical measurement typically based on historic data denoting the average recurrence interval over an extended period of time, and is usually used for risk analysis.

Relative crop yield: Crop yield expressed as a fraction of maximum (unstressed) yield where unstressed yield = 1.

Regulatory Authority: The regulatory authority in Queensland for the management of Environmentally Relevant Activities that involve land disposal is the Queensland Government, through the Department of Environment of Science.

Reuse efficiency: The fraction of water used for irrigation compared to the total water inputs into the wet weather storage.

Root zone: That part of the soil that is invaded by roots of plants to absorb water and nutrients.

Salinisation: The accumulation of water-soluble salts in soil to a level harmful to plant growth.

Saturated hydraulic conductivity: The flow of water through soil per unit of energy gradient. This is an important measure of the drainage capacity of the soil.

Shandying: Blending or shandying are the terms used to describe the mixing of water sources to a predetermined standard. Water sources may include mains, dam, rain, bore or recycled.

Sodic soil: A soil containing sufficient exchangeable sodium to adversely affect soil stability, plant growth and land use. Such a soil would typically contain a horizon in which the amount of exchangeable sodium percentage (ESP) would be five or more. Sodic soils generally have severe surface crusting, low infiltration and hydraulic conductivity, hard and dense subsoil, and are highly susceptible to gully and tunnel erosion.

Sodium adsorption ratio (SAR): The ratio of the concentration (in milli-equivalents per litre) measurement of sodium ions in soil or water relative to calcium and magnesium ion concentrations, calculated using milli-equivalents per Litre using a specific formulae.

Soil ecosystems: Soils ecosystems are composed of both living and non-living matter with a multitude of interaction between them. Soils play an important role in all natural ecological cycles of carbon, nitrogen, oxygen, water, and nutrient and provide media for plant growth. Soil also provide benefits through ecosystem services, waste decomposition and water filtration system.

Soil electrical conductivity (EC): A measurement of salinity that correlates with soil properties that affect crop productivity, including soil texture, cation exchange capacity (CEC), drainage conditions, organic matter level, and subsoil characteristics

Soil erosion: The displacement of the upper layer of soil, one form of soil degradation. The agents of soil erosion are water and wind, each contributing a significant amount of soil loss each year.

Soil fertility: The capacity of the soil to provide an adequate supply of nutrients in proper balance for the growth of specified plants, when growth factors such as light, moisture and temperature are favourable.

Soil moisture: Soil moisture is the amount of water contained in the soil.

Soil salinity: Salt content of soil.

Soil structure: The arrangement of the solid parts of the soil and of the pore space located between them. It is determined by how individual soil granules clump, bind together, and aggregate, resulting in the arrangement of soil pores between them. Soil structure has a major influence on water and air movement, biological activity, root growth and seedling emergence.

Soil water deficit (SWD): The amount of water needed to bring the soil moisture content back to field capacity or the upper drained limit. Field capacity (SWD=0) is the amount of water the soil can hold against gravity.

Sorption strength: The sorption strength of a soil is a measure of how strongly P is sorbed to the soil. It depends on the mineralogy and surface characteristics of the soil.

Spray irrigation: A method of applying water or effluent by means of spraying over the canopy.

Stormwater runoff: Runoff resulting from rainfall.

Surface irrigation system: An irrigation system using bays, borders or furrows. This typically excludes spray, drip and sub-surface irrigation methods.

Suspended solids (non-filtrable residue): The solids in suspension in wastewater that are removable by laboratory filtering, usually by a filter of nominal pore size of about 1.2 micrometres.

Tailwater: Wastewater runoff leaving the down-slope end of an effluent irrigation area.

Third party: The receiver of effluent from the primary producer.

Total dissolved salts (TDS): Combined concentration of dissolved mineral salts in effluent.

Total nitrogen (TN): Combined concentration of organic nitrogen, ammonia, nitrite and nitrate, expressed as m/L as Nitrogen.

Total organic carbon (TOC): The total organic carbon content of wastewater.

Total phosphorus (TP): The parameter total phosphorus (TP) defines the sum of all phosphorus compounds that occur in various forms.

Trickle (drip) irrigation: A method of irrigation where pressurised water or wastewaters are discharged through micro-emitters. Application rates are small, because the water is applied daily and water loss through evaporation is small. The method is suitable for row-crops and permanent horticultural plantings.

Uncontrolled public access: Public access to sites so that direct physical contact with effluent is possible.

Water holding capacity: Soil water is made up of plant available and plant unavailable water. Plant available water is the water in the soil profile between the full point and permanent wilting point (when the plant can no longer be revived by irrigation or rainfall). The soils ability to hold this water is known as water holding capacity and varies with soil texture, structure and organic matter content. For example, black clay soils have around 2 ML/ha of water holding capacity within one meter depth.

Water table: The surface of the saturated zone in an unconfined aquifer.

Waterlogging: The accumulation of excessive moisture in the soil within the zone or depth desirable for favourable root development of plants. Saturation of soil with water and the replacement of most or all of the soil air with water.

Wet weather storage: A facility for storing effluent generated when the use of effluent for irrigation is not possible due to wet weather, agronomic practices and unexpected incidents such as break down of irrigation hardware.