OPTIMISATION OF WASTEWATER IRRIGATION

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ABSTRACT

Freshwater protection is an essential consideration in decision making on resource consent applications. This has been strengthened by the recent implementation of the National Policy Statement for Freshwater Management and National Environmental Standards for Freshwater. These documents require regional councils to give effect to Te Mana o te Wai and set requirements for certain activities, such as the discharge of nitrogen, that pose risks to freshwater and freshwater ecosystems. Wastewater discharges typically contain elevated levels of nitrogen which can be both difficult and expensive to remove. To provide higher levels of nitrogen removal from the wastewater prior to the water entering the receiving freshwater environment, discharges to land via irrigation as part of the treatment process are becoming increasingly common.

Understanding the water and nutrient balance for wastewater discharges to land provides key information which can assist in the design, consenting and management of wastewater treatment systems. Tools such as OverseerFM are currently widely used and accepted for assessments of nutrient leaching. OverseerFM, however, relies on a monthly timestep and is designed to model agricultural land use for farming rather than for wastewater treatment. This paper discusses an integrated water balance model developed by Pattle Delamore Partners (PDP) that can be used to assess the performance of land treatment systems.

The integrated model provides flexibility to include and estimate the complex interactions between multiple components in a system at a daily timestep. This provides information to optimise the system as a whole and understand where or when constraints may be present. The outputs identify management practices for an optimised system that can be used to achieve the best site-specific outcomes. This paper includes examples of how the model has been used to evaluate alternative irrigation options, optimise the land discharge relative to the soil moisture, and evaluate the relative nutrient leaching potential.

KEYWORDS

Soil moisture balance, OverseerFM, Wastewater, Irrigation optimisation, Land treatment, Nitrogen leaching, Modelling

PRESENTER PROFILE

Neeraj is an Environmental Engineer at Pattle Delamore Partners with 3.5 years of experience. Over this time, Neeraj has worked on multiple wastewater discharge projects and developed a good understanding of wastewater irrigation systems and modelling of wastewater discharges.

INTRODUCTION

The health and wellbeing of our water bodies are of high priority. With the implementation of the *National Policy Statement for Freshwater Management 2020* (NPS-FM), regional councils are required to give effect to Te Mana o te Wai. Requirements for certain activities, such as the discharge of nitrogen, are set out in the *National Environmental Standards for Freshwater 2020* (NES-F). These documents aim to protect and prevent further degradation of our freshwater environments.

Irrigation of wastewater to land is a common practice in New Zealand for both municipal and industrial wastewater. Irrigation to land typically provides significant environmental benefits over other discharge to land techniques and direct discharge to surface water.

Discharges following treatment at a wastewater treatment plant (WWTP) often contain elevated levels of nitrogen, which can be both difficult and expensive to remove. Elevated nitrogen concentrations can result in adverse effects on public health and aquatic life. The Drinking Water Standards (Ministry of Health, 2018) provide a maximum acceptable value (MAV) for nitrate-nitrogen, a highly mobile form of nitrogen which can be easily leached through soils into groundwater. The NPS-FM provides attribute states for nitrate-nitrogen for ecosystem health protection and sets national bottom lines.

Discharges of wastewater to land via irrigation following treatment in a WWTP can provide additional nitrogen removal prior to the water entering the receiving freshwater environment. This paper outlines a soil moisture balance (SMB) model developed by Pattle Delamore Partners (PDP). The tool is useful for assessing and optimising wastewater applications to land, including to maximise nitrogen removal. It can provide a better understanding of potential discharges to the receiving freshwater environment through drainage and/or overflow during extreme events.

The model was originally designed as a demand-based soil moisture model, focusing on determining clean water irrigation requirements. It was further developed to model wastewater irrigation, including modules for estimating nutrient leaching. The advantage of the model is that it works on a daily timestep and can incorporate various components of a wastewater treatment system, such as storage ponds, and wetlands to assess the full irrigation system. This provides the capability to evaluate and optimise a wastewater system's ability to achieve the desired environmental outcomes.

Flexibility to include any number of irrigation areas, each with its own soil and climate inputs is available. The soil moisture for each area is assessed at a daily timestep. The previous soil moisture content is used to establish priorities for the next timestep. Priorities can be set to a wide array of options. This includes the highest soil moisture deficit in an area or the number of days since the last irrigation. A daily resolution provides a fine level of detail for optimisation and can assist in reducing the total seasonal drainage to groundwater arising from the wastewater discharge.

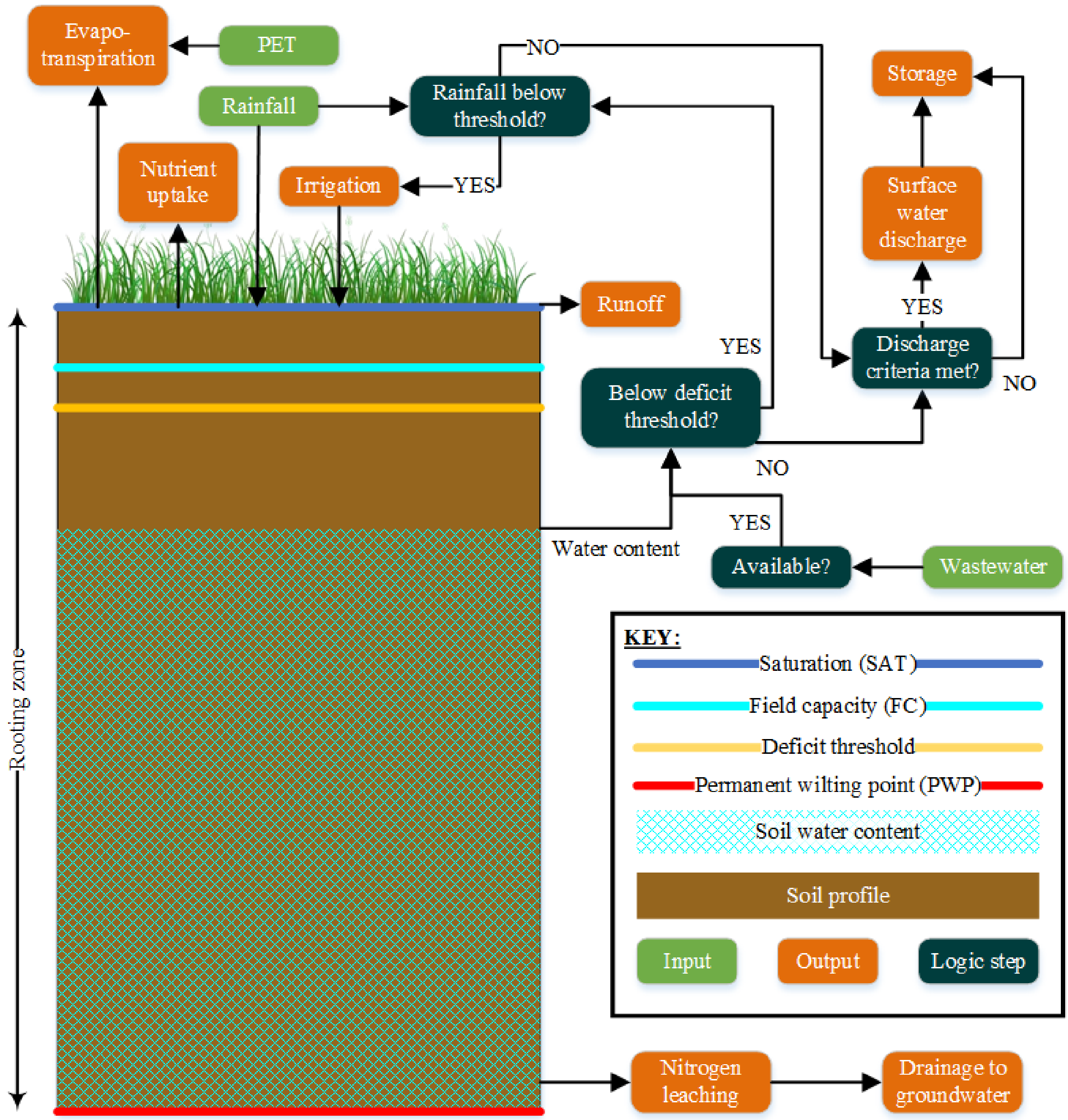
This paper describes the soil moisture balance component of the model, and then describes how the model can be used to estimate nutrient leaching. The model has the capabilities to be run in real-time to optimise wastewater management and minimise adverse effects.

SOIL MOISTURE BALANCE MODEL

CONCEPTUAL MODEL

The general principle of a soil moisture balance is to track the mass of water entering and leaving the soils over a fixed depth profile. The model can be extended to allow for nutrient leaching. **Error! Reference source not found.** illustrates the conceptual soil moisture balance model. The key components available in the model are described in detail below.

Figure 1: Soil water balance conceptual diagram



IRRIGATION

Different irrigation systems use different methods to apply water to the land treatment area. These include spray, drip, or border dyke irrigation. A spray irrigation system such as a centre-pivot system is commonly used to irrigate wastewater for larger scale discharges. In areas where the terrain is a limiting factor or spray irrigation may not be as effective (for example some forestry) or for smaller scale systems, drip irrigation may be specified.

Deficit irrigation is ideal to minimise nutrient leaching, but not always practical for wastewater discharges given the year-round nature of most wastewater generating activities and common limitations on storage. Deficit irrigation models set a maximum threshold for soil moisture levels below which irrigation can occur (often below field capacity). When the water level in the soil profile drops below the threshold, the depth required to reach the threshold is the soil moisture deficit. The maximum irrigation applied for the day can then be set as either the soil moisture deficit or a maximum irrigation rate as determined by the soil characteristics and specified irrigation system.

As part of reconsenting or upgrades to a system, modelling the status quo and comparing it to new systems or alternative management practices can provide valuable information to optimise improvements. An existing scenario can be modelled using recorded application depths and other data, where available, to set the existing baseline for comparison.

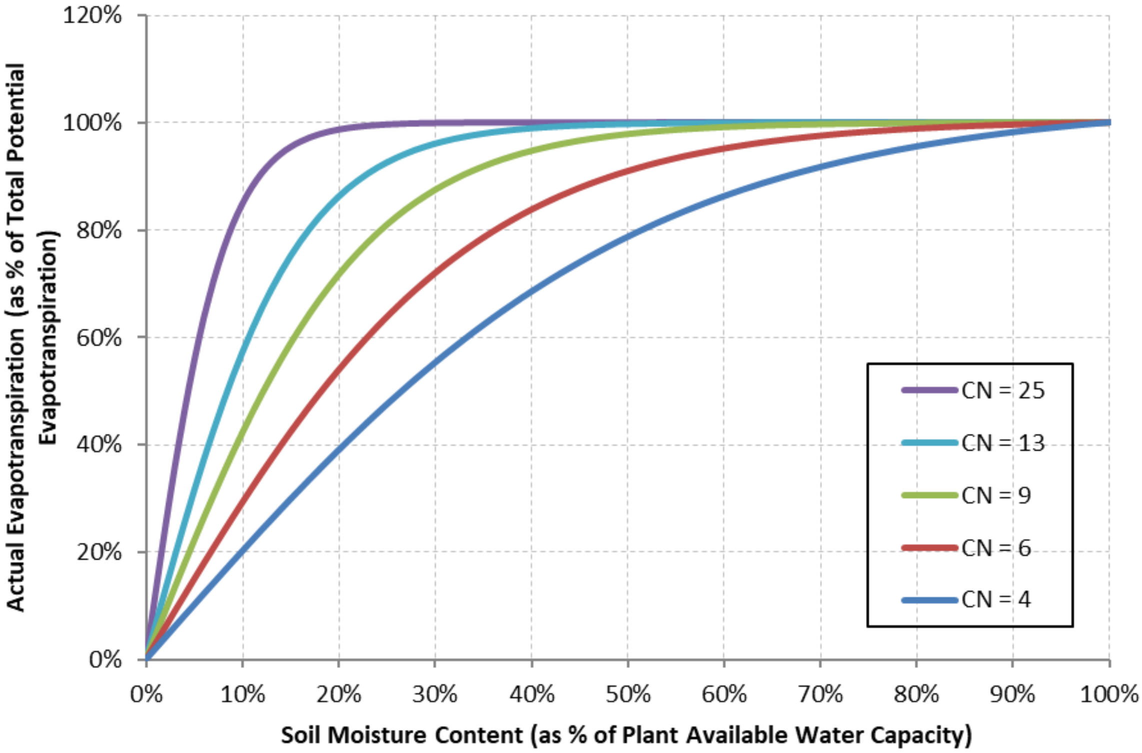
Assessing the soil moisture balance for each irrigable area using a daily time step, the model can select which area to irrigate based on the prioritisation of demand parameters. The demand parameters can include soil moisture deficit, time since last application (after any minimum rest periods), and/or a specific irrigation sequence. By optimising the application of wastewater available based on the required prioritisation, the drainage and consequent leaching of nutrients can be better managed.

CLIMATE

EVAPOTRANSPIRATION

Evapotranspiration (ET) is a key mechanism for non-draining moisture loss from the soil profile. The amount of ET losses from the soil is a function of the soil moisture content. The model assumes that actual ET from the soil is given by the relationship with potential evapotranspiration (PET) shown in Figure 2. As the soil becomes drier, water is more difficult for plants to draw from the soil. The curves shown in Figure 2 are based on a mathematical approximation of experimental data (Denmead & Shaw, 1962). The approximation does not account for variances with soil type. The curve numbers allow for adjustment of the relationship for various climates.

Figure 2: Evapotranspiration soil moisture content adjusted by a curve number



RAINFALL AND RUNOFF

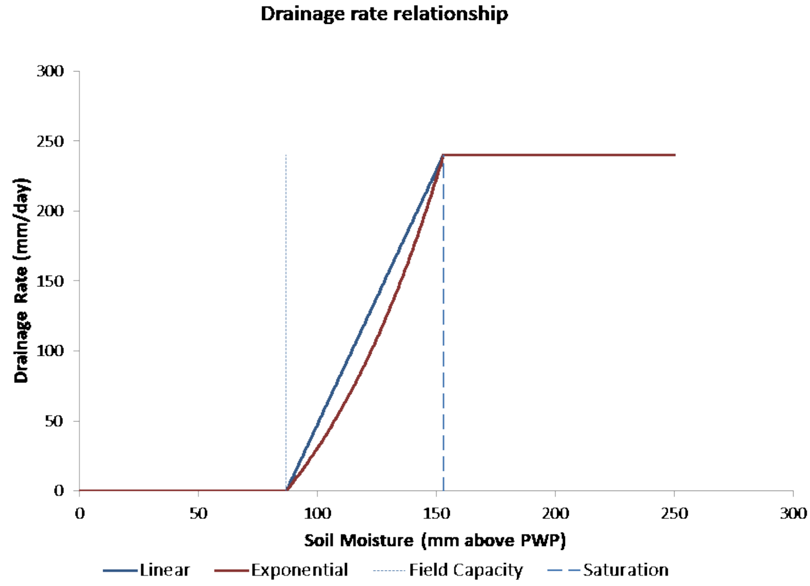
Rainfall is the key factor for producing drainage through the soil profile for deficit irrigation. The rainfall series selected is site specific and chosen to best represent the modelling period. The most ideal record would be a complete long-term dataset from a rainfall gauge near to the irrigation site. This is often not the case and judgement is required to produce a reasonable estimate of the rainfall at the site.

Wastewater is typically irrigated on flat or gently sloped areas. Therefore, rainfall losses due to overland flow runoff are generally minimal. This assumption is hydraulically conservative provided that the application rates are low enough not to cause runoff during irrigation. Runoff coefficients can be used if the irrigation site includes areas where runoff generation can be expected. The model reduces the rainfall applied to the area by a calculated proportion to estimate the runoff losses.

DRAINAGE

Drainage occurs when the soil water content exceeds field capacity. The model assumes drainage continues at an increasing rate as the water content approaches saturation. At this point, water from the soil profile is assumed to drain at the saturated drainage rate, which can be measured in-situ for different soils. The model assumes the drainage rate relationship is either linear or exponential. An example of the drainage rate relationship is provided in Figure 3.

Figure 3: Example of linear and exponential drainage rate relationships



INTERACTION WITH SYSTEM COMPONENTS

During larger rainfall events, if the soil water content is above the deficit threshold, the ability for the soil to receive additional wastewater without resulting in drainage is limited. For WWTP's servicing larger catchments (for example municipal wastewater), inflow and infiltration during these larger events also tend to increase the flows through the WWTP and increase the volume to be irrigated.

Possible options for excess wastewater above the daily irrigable volume are storage or an alternate disposal such as discharge to a nearby waterbody, where appropriate. In practice, a combination of the two is often implemented and designed based on site restrictions and the characteristics of any receiving water body. A design event can be used as a threshold for when excess volumes may be discharged outside of the irrigation system. Non-deficit irrigation may be a preferable option to other discharge methods.

The two key variables when designing a new wastewater disposal system are the land available for irrigation and any storage volume available. For reconsenting existing systems these parameters may not always be easy to accommodate without investigating alternative areas for discharging. Optimising the full system in an integrated manner can identify where the most effective adjustments could be made.

NUTRIENT ASSUMPTIONS

The key nutrient typically modelled is nitrogen. Nitrogen is commonly the main nutrient of concern for leaching associated with wastewater discharges. Excess nitrogen entering the environment can have adverse effects on the receiving environment and may pose a risk to human health.

The nitrogen cycle has been conservatively simplified in the model. The complex transformation processes such as nitrification, denitrification, and mineralisation have not been included in the model at this point in time. It has been reasonable to assume for the wastewater discharges modelled to date that all applied nitrogen is readily available for conversion into nitrate that can be lost to groundwater via leaching during a drainage event. Plant uptake is the only mechanism for nitrogen removal in the model. All nitrogen which is not taken up by plants is assumed to leach during drainage events. This results in a conservative estimate of leaching output.

While the modelled nitrogen entering the receiving environment is conservatively estimated in the current model, meaning the nitrogen leached may be over-estimated compared to models that allow for more complex processes, the model is able to provide a useful comparison of potential leaching between different irrigation systems and management approaches. A demonstration of an assessment between two irrigation systems is provided in the case study below.

COMPARISON AGAINST OVERSEERFM

OverseerFM is a widely used and accepted software package for consenting and modelling the impact of farm management on the flow of nutrients. The core model has been developed around informing strategic farming decisions with a focus on agricultural production.

OverseerFM provides capability for modelling the nutrient cycle, working on a monthly timestep. The nutrient component of OverseerFM incorporates the nitrogen cycle and natural processes such as nitrification and denitrification. The nitrogen leached is calculated at a monthly timestep and based on the monthly drainage.

A NIWA 30-year average climate model is used where the climate information (rainfall, average temperature, and annual PET) is selected based on the site location and is gridded at a 500 m scale. The monthly rainfall figures are not available to the user nor is there an ability to enter or edit blocks manually.

Irrigation applications are entered monthly as either: a fixed return period and fixed depth; or as a soil moisture strategy with triggers and application depths based on the soil moisture deficit. OverseerFM supports seven irrigation systems: fixed pivot, spray lines, border dyke, controlled flood, micro irrigation, travelling, and solid set. The type of irrigator has an impact on losses to the atmosphere or drainage. The selected irrigator also has set defaults for application depth and irrigation start/stop triggers. The soil moisture strategy is based on how much water is required by plants rather than a required volume to be discharged, as is required for wastewater discharges. There is no ability in OverseerFM to model volumes in excess of the soil capacity going to storage or an alternative disposal system.

Irrigating pasture typically increases dry matter (DM) production and so allows more animals to graze the same area of pasture or greater production of grass/silage (cut and carry). Commonly, the discharge of wastewater is coupled with cut and carry operations. OverseerFM estimates pasture DM production based on the metabolisable energy (ME) requirements of grazing (or cut and carry fed) animals on a farm less the ME supplied as crops and/or supplements. This is determined by animal management and production information that the user enters.

As OverseerFM is designed to assess agricultural production, parameters such as storage volume and required area for wastewater irrigation are not provided for. There are assumptions associated with the OverseerFM model to ensure ease of use. The PDP model is not considered to be a replacement for OverseerFM, rather it is complementary and provides an additional level of detail focused on the discharge of wastewater. The optimised irrigation results from the PDP model can be used for comparison with OverseerFM and to develop OverseerFM inputs to provide additional assessment of the nutrient cycle and transformation.

EXAMPLE CASE STUDY

The following case study involves the discharge of treated meat processing wastewater to land. The study presented here is to assess the transition from existing travelling irrigators to centre pivots. The site includes five main irrigation blocks and contains a diverse range of underlying soil types. Figure 4 shows the soil types, and Figure 5 shows the existing and proposed irrigation layouts. It is noted that Ruat_7a.1 is restricted by clay horizon which limits the rooting depth, and therefore, the profile available water capacity.

Figure 4: Case-Study Soil Map

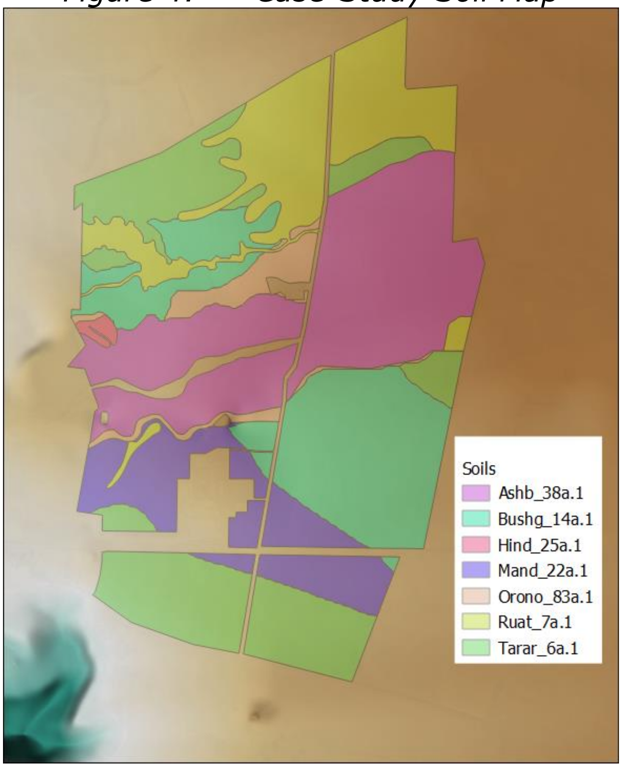
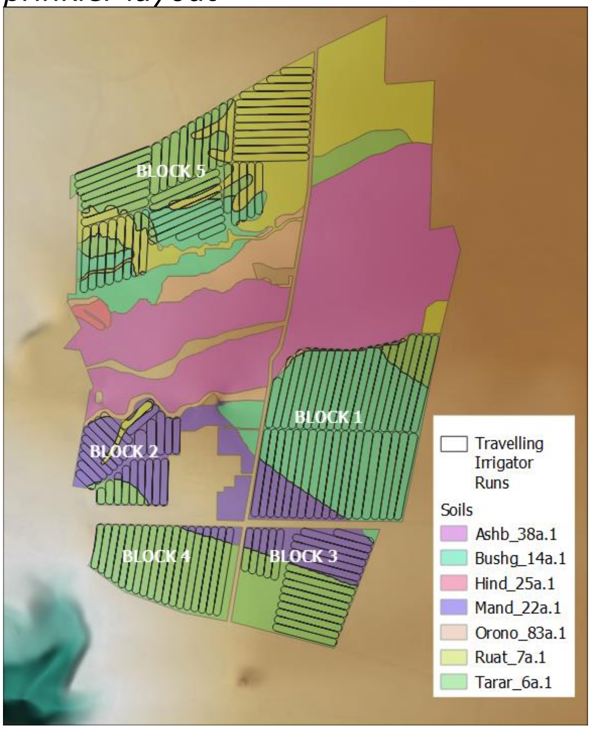
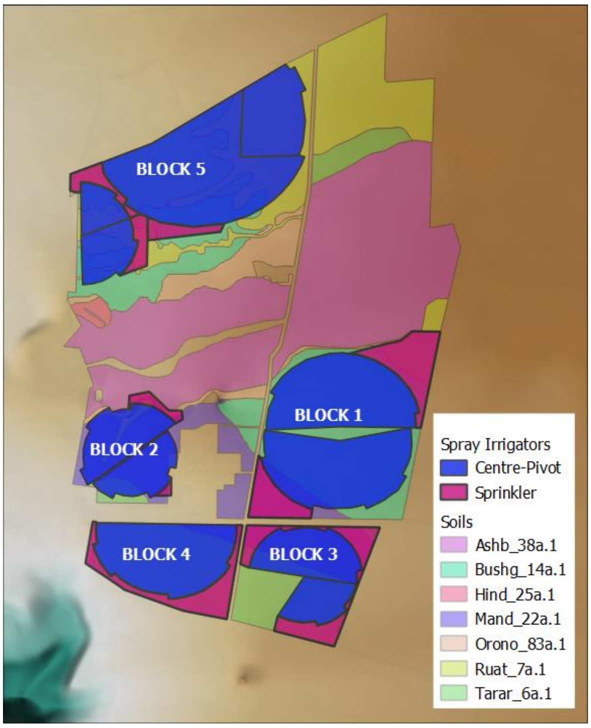


Figure 5: Existing travelling irrigator runs and proposed centre-pivots with sprinkler layout





For this study, the two irrigation layouts were compared using the same input wastewater flow series for a year with sufficient data. The wastewater flows were recorded over the entire year and applied using the existing travelling irrigators. An optimised irrigation scenario using centre-pivots and sprinklers was then modelled and compared for the same study year.

Figures 6-8 compare the modelled irrigation applied, modelled drainage, and modelled nitrogen leaching over the model year, respectively. Figure 6 shows the average of the total irrigation applied over each of the blocks is greater in the centre-pivot scenario. The travelling irrigators can be seen to underutilise two of the sub-blocks in Block 5 (5b and 5d). These areas have a clay horizon limiting their soil water capacity. With the higher application rates of the travelling irrigator, these areas were not well draining and therefore not preferred. With the centre-pivot scenario, the irrigation is applied more evenly over all the areas available for that scenario. This results in the average of the total irrigation applied over the site being greater even though the same wastewater volume was applied. The modelled drainage and nitrogen leached however, are lower.

As all the blocks were utilised effectively using a centre-pivot with soil moisture optimised irrigation, the average application depth over many areas increased. Assessing the drainage and consequent leaching, the centre-pivot irrigation system has been optimised to irrigate with the objective of reducing the drainage. The areas with the highest soil moisture deficit were prioritised to ensure that the wastewater was applied based on the water holding capacity of the soil types.

Figure 6: Irrigation applied over a single year. The dashed lines represent the average irrigation over all blocks.

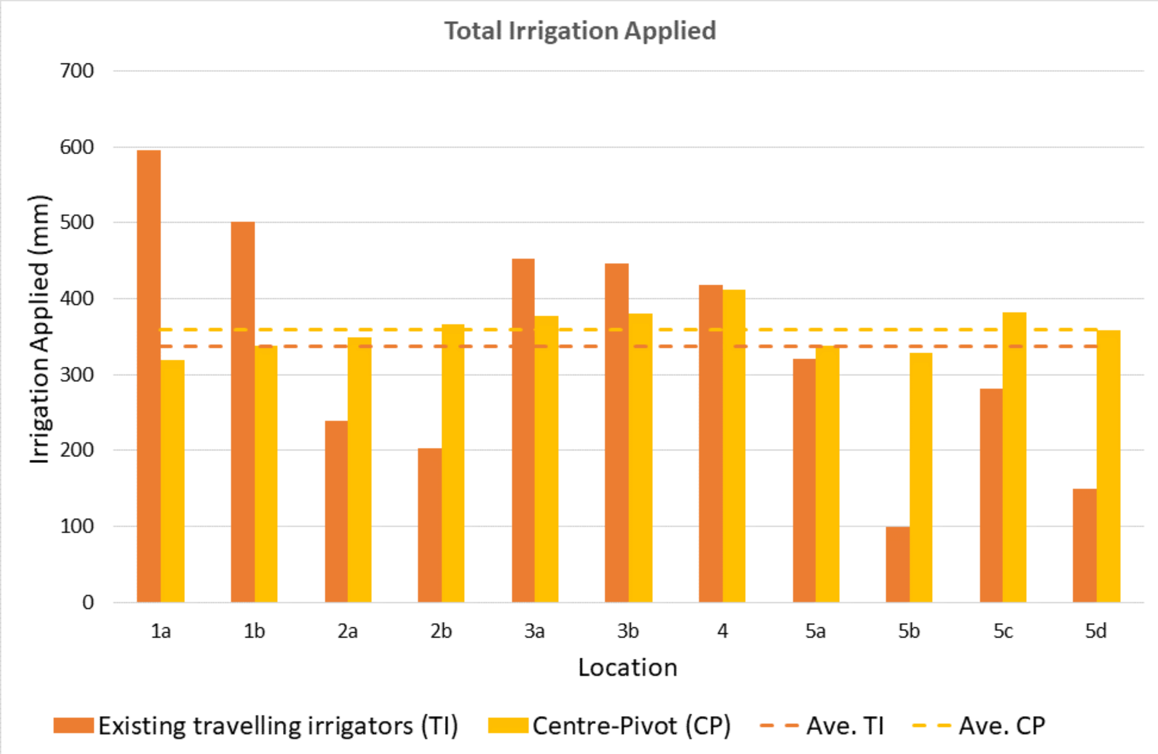


Figure 7: Modelled drainage for each block. The dashed lines represent the average drainage over all blocks.

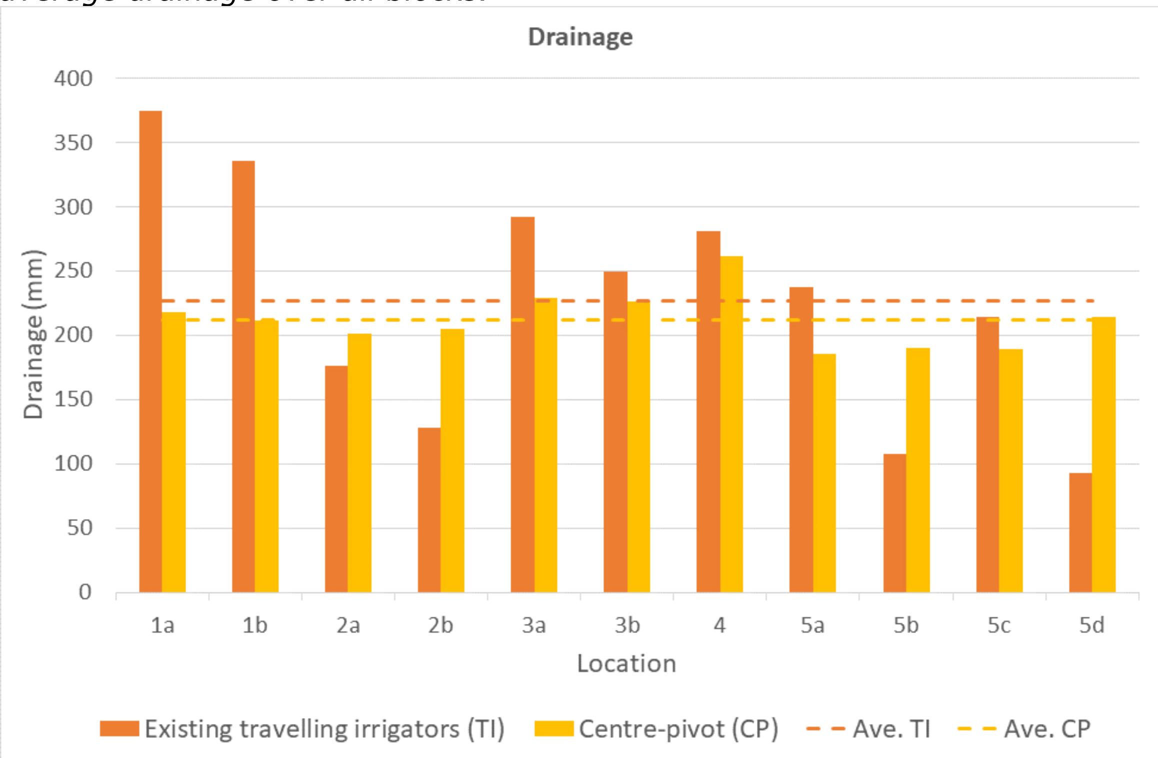
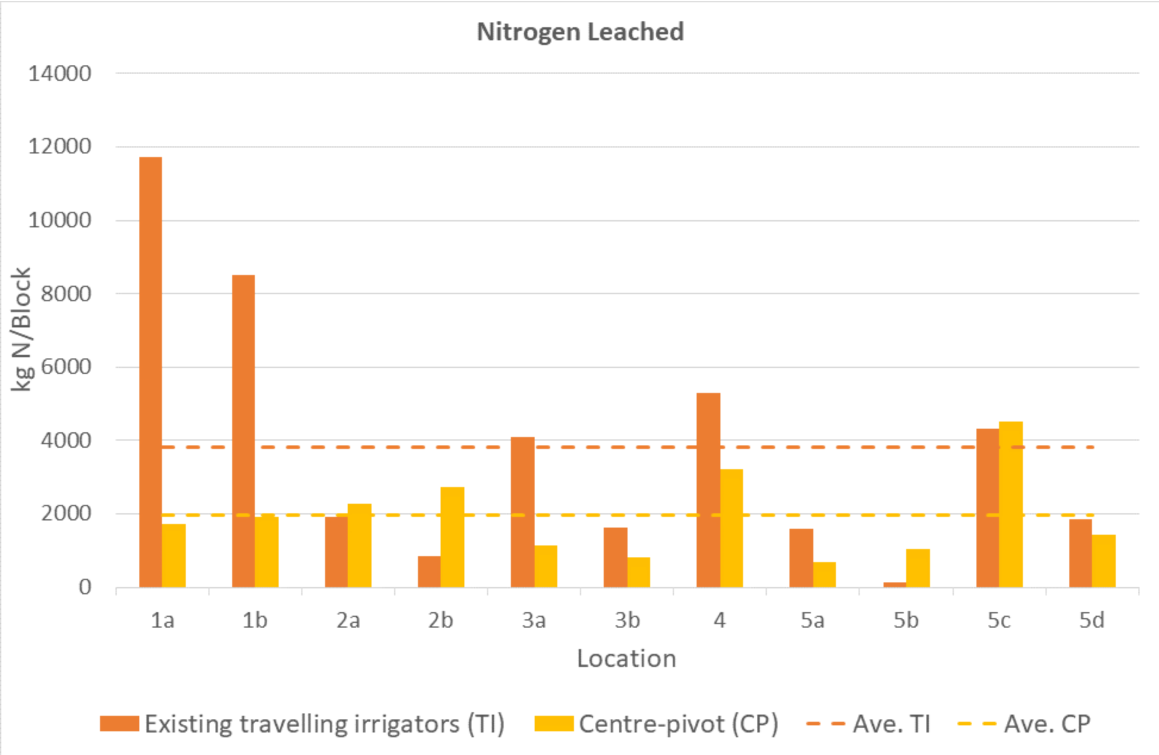


Figure 8: Modelled nitrogen leaching for each block. The dashed lines represent the average nitrogen leaching over all blocks.



FORECASTING AND REALTIME MODULE

Capabilities in future versions of the model, which are currently in development, include forecasting and the inclusion of real time modelling. Additional nitrogen processes are also being considered.

The forecasting module estimates future conditions based on rainfall predictions. As the key driver for drainage events is rainfall exceeding the field capacity of soil, forecasting wet weather events, and limiting the application of irrigation prior, can provide additional strategies for managing potential leaching into the freshwater environment.

The real time modelling can occur in conjunction with site monitoring equipment such as soil moisture meters and lysimeters. The model can be run with updates to the dataset and frequently be calibrated and reviewed against the in-situ modelling.

CONCLUSIONS

The protection of our freshwater environment is at the forefront of our engineering decisions. The discharge of treated wastewater from a wastewater treatment plant is often high in nutrients, with nitrogen being of particular concern for leaching through soils. Nitrogen is often difficult and expensive to remove, so discharge of wastewater to land via irrigation is often used as part of the treatment process to increase nitrogen removal.

As the discharge is part of the treatment process, it is important to understand the soil moisture balance and, as with any environmental engineering design, to optimise the system to achieve the best environmental results.

This paper has outlined a soil moisture model developed by PDP. The particular model described has been designed specifically for modelling and assessing the discharge of treated wastewater to land. The model can be used to optimise a wastewater irrigation system and provide valuable information on irrigation management. A case study has been presented which assessed the difference between two irrigation methods, an existing travelling irrigator and an optimised centre-pivot system. The modelled results showed better utilisation of the irrigable areas available and a reduction in modelled drainage and leaching.

The model has capacity to include forecasting modules in future developments as well as real-time modelling to assist in monitoring and adherence to consent conditions. Further nitrogen processes will be included as required. Overall, the model is a useful tool to aid in the understanding of the potential impacts from wastewater irrigation. It is versatile in its capabilities and can be used for the design and management of new systems as well as assessing and comparing upgrades to existing systems.

ACKNOWLEDGEMENTS

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