DEVELOPMENT OF A SUSTAINABLE LAND TREATMENT SYSTEM FOR EROSION PRONE SLOPES

S.B. Hainsworth, K. Beecroft, H. Lowe and A. Broughton
CPG New Zealand Ltd, Palmerston North, New Zealand.

ABSTRACT

As municipal wastewater discharges to land become increasingly common, so does the pressure to utilise hill country. This country is often at risk of some degree of erosion. Land based wastewater treatment systems have tended to focus on the hydraulic properties but in hill country slope, geology and erosion must also be considered.

While many hydrological, nutrient and soil-landscape mapping models exist, few enable the assessment of irrigation on sloping land. This paper describes the process CPG recently developed to:

- Assess the suitability of an erodible hill country site for use in the land-based application and treatment of municipal wastewater under hardwood plantation forest;
- To identify Irrigation Management Units (IMUs); and
- To develop appropriate hydraulic loading rates for the IMUs.

A case study is presented which demonstrates how a land treatment system was identified as an option for an inland community with a small permanent population and an aged reticulation system.

The town has an existing discharge to a river in a phosphorus sensitive environment. The land treatment site is disadvantaged in that the topography is typically steep, creating access and erosion issues. For the life time of the land treatment system the owners will have an established hardwood plantation on the site. Notwithstanding the stabilising effect of the plantation forest, the addition of wastewater has the potential to exacerbate erosion on the site if not managed conservatively, with corresponding damage to infrastructure, reduction in treatment capacity and export of sediment and nutrients from the sites.

In the design process it was identified that a fit for purpose model was needed. The iterative process used to develop this model and the resultant IMUs for this proposed wastewater discharge is described.

KEYWORDS

Land Treatment, erodible hill country, New Zealand Land Use Capability Assessment, New Zealand Land Resource Inventory, Enhanced Land Management Units, Irrigation Management Units, hydraulic loading rates.

Deleted: E

1 INTRODUCTION

Land based application of wastewater onto hill country is becoming increasingly necessary in New Zealand. Many such application regimes are occurring under plantation forestry because of the trees ability to uptake nutrients applied by the wastewater and to stabilise the soil. With this trend towards wastewater application on hill country comes the associated risk of increased magnitudes of erosion, excessive interflow, overland flow, raised water tables and ponding. Few models exist that can take into

Deleted: the extra

Deleted:

account all these issues in a 3-dimensional context and many of the cases where this solution is required do not have substantial financial means to fund substantive technological solutions.

This paper addresses how to quickly and cost effectively evaluate the suitability of a hill country landscape for land based application of wastewater by considering the land in terms of a mosaic of interconnected individual components. Using the results of this process a system has then been devised to maximise irrigation potential on the site while minimising environmental impact.

The example used is erodible hill country in the East Coast of the North Island where municipal wastewater is proposed to be applied under plantation forest. A variety of landforms and soil types occur on the site.

2 DEVELOPMENT OF LAND TREATMENT PARAMETERS FOR MARGINAL LAND

In the selection of a land treatment site a number of factors are considered. For maximum renovation of applied wastewater a land treatment system would ideally be situated on flat land of extensive area. Soils which are deep and moderately to moderately well drained are well suited to land treatment of wastewater. In addition, it is desirable that a crop demanding high nutrient supply which can be removed from the site regularly is established to maximise water use and nutrient uptake.

It is seldom the case that sites facilitating the maximum renovation of wastewater are available. Cost of land and distance from a wastewater treatment plant (WWTP) can make the use of such land prohibitive for land treatment. Site constraints, climate and land owner requirements may limit the crop able to be established on the site. The use of more marginal land must be considered as the access to premium land diminishes.

This paper describes the process undertaken to develop a hydraulic regime for use on marginal land for a case study site.

3 CASE STUDY: PERMANENT TOWN OF 1,900 PEOPLE

The case study is concerned with a small inland community. The community's wastewater is reticulated to an existing WWTP and discharged to surface water; which is a phosphorus sensitive environment. The reticulation system is up to 80-100 years old in places and infiltration and ingress (I&I) of water to the sewer is a significant contributor to flows.

Deleted: ,

Faced with expensive upgrades to the WWTP to meet stringent treatment requirements for the continued discharge to water, and public resistance to water discharges, the examination of alternative discharge options was undertaken. Many available sites were considered for land treatment, however were excluded due to costs and their location. A further opportunity arose to apply the town's wastewater to steep hill country located close to the WWTP as a result of a joint venture between the District and Regional Council.

Deleted: The location and cost of optimal land

Deleted: initially precluded this option

Deleted: an opportunity

A desktop and detailed field investigation of the potential land treatment site identified a risk of erosion ranging from slight to severe over the entire site. Evidence of erosion on the site suggests that past erosion has occurred and it was deemed likely that under any management erosion would continue to

Deleted: detailed field and

occur in the future. However, if the site is to receive wastewater for land treatment the risk of erosion has important implications for the land treatment system including:

Deleted: ¶

- Damage to infrastructure;
- Reduction in treatment capacity through modification of the soil properties and damage to crop; and
- Off-site transport of sediment and nutrients.

In design of a land treatment system on the erosion prone slopes, the most important consideration was identified to be the minimisation of erosion. Since the application of wastewater to the site has the potential to exacerbate erosion, the movement of water received by the site needed to be modelled to account for impacts on adjacent landforms. There was also a need to predict the impact of increasing the site moisture status on erosion and the potential for nutrient loss from the site.

A number of models exist to describe parts of the proposed application However, no widely available fit for purpose models were identified that incorporated the site, climatic and wastewater flow elements of the land treatment system given the 3-dimensional nature of the hill country receiving environment. A process was developed to determine a suitable hydraulic regime for the site.

Deleted: ,

Deleted: h

Deleted: ,

Deleted:

4 MAPPING OF HILL COUNTRY LAND UNITS

4.1 LAND USE CAPABILITY ASSESSMENT

4.1.1 METHOD

Hill country land was field mapped at a paddock scale (1:5,000) using NZLRI and LUCA methods (Lynn *et. al.*, 2009) and using 0.5-2 m resolution topographic maps generated by LiDAR survey. This categorised the land not by landform, but by unique units of rock, soil, slope, present erosion and vegetation. The Land Use Capability (LUC) units attributed to the land units were correlated to the existing LUC Extended Legend for the area (Noble, 1979). Through reference to Noble (1979) and taking into consideration the nature of the specific NZLRI units and the past erosion that was evident, erosion potentials were assigned to each LUC unit. This involved predicting the type and severity of potential erosion.

Formatted: Font: Italic

Deleted: (

Deleted: or

4.1.2 RESULTS AND DISCUSSION

The NZLRI and LUC map are shown in Figure 1:

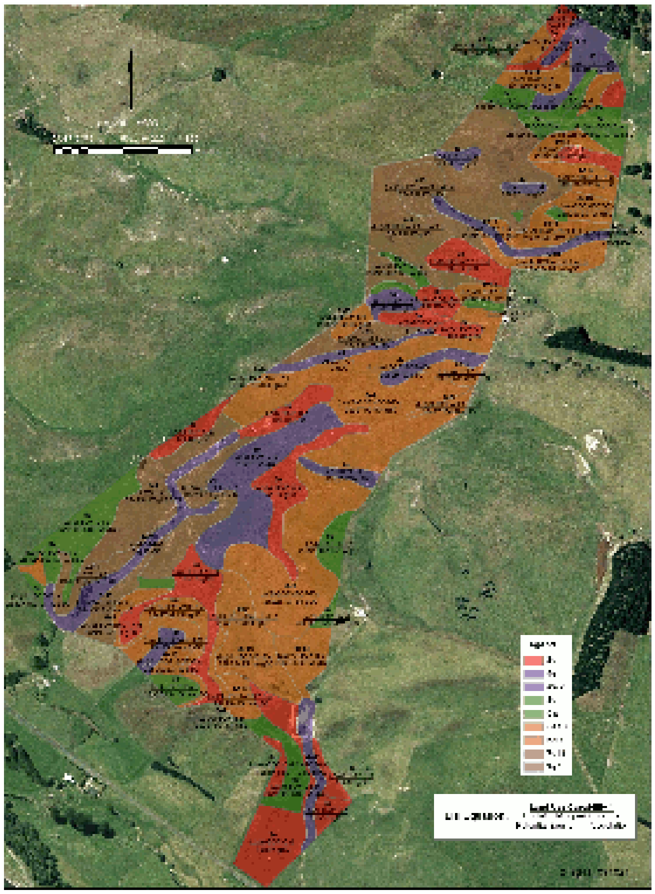

Figure 1. NZLRI and LUC map

Table 1 shows the resulting LUC units and their erosion potentials:

LUC	Landform, Parent Material, and/or Slopes	Potential Erosion
4w2	Perennial & ephemeral watercourses	0
3e	Argillite or siltstone, gently rolling (8-15°)	1Sh1R
4e	Argillite or siltstone, strongly rolling (16-20°)	2Sh2R1W
5e	Argillite or siltstone, strongly rolling to moderately steep (18-22°)	2Sh2R1Ss1G1W
6e13	Argillite, moderately steep to steep	2Sh2Ss2G1W
6e9	Siltstone, moderately steep to steep	2Ss2T1G1Sh
7e11	Argillite, very steep	3Ss3G3Sh3W
7e4	Siltstone, very steep	3Ss2Sh1T

Table 1. LUC units and associated erosion risks

As can be seen from the above map, the site contains a mixture of LUC units, ranging from LUC Class 3e to 7e. The Class 3 and 4 units have lower slopes, whereas the Class 6e and 7e units have slopes with steeper gradients. Rock types include alluvium, siltstone and argillite. Generally there is only the risk of slight to moderate sheet, rill or wind erosion on the rolling slopes. There is a risk of slight to moderate soil slip, tunnel gully and gully erosion on the moderately steep units and on the very steep country the risk of soil slip erosion becomes severe (along with the risk of gully, sheet and wind erosion on the 7e11 argillite country).

4.2 ADDITION OF CURVATURE TO LUC UNITS

4.2.1 METHOD

Drawing from the concepts of Barringer *et. al.* (2008) and Draft ASNZ 1547:2007, land curvature was then taken into account by attributing a curvature factor into the LUC units. The curvature factors were flat, planar, convergent and divergent. This meant that the hydrologic dynamics of the Enhanced LUC (ELUC) units became more defined and could thus be shown to be modified by the addition of more water to the slopes via the application of wastewater. ELUC units were then assigned amended erosion potentials.

Formatted: Font: Italic

4.2.2 RESULTS AND DISCUSSION

Divergent ridges and spurs are more exposed to wind and sun, disperse water and in the case of ridges do not receive water from any units above them. Water applied on these units via wastewater will tend to be lost through evapotranspiration, overland flow and interflow to units lower in the landscape. Consequently divergent ridges and spurs are unlikely to suffer from increased severity of erosion or a detrimental increase in water table leading to break out at the soil surface and/or ponding.

With the application of wastewater onto planar slopes, they are likely to be susceptible to increased interflow and the risk of overland flow if wastewater application rates combined with rainfall and inputs (from wastewater and rainfall) from ridges and spurs above exceed the hydraulic loading rates of the soil. This will lead to an increase in the incidence of sheet (surface) and rill (fluvial) erosion, as well as an increase in the severity of soil slip and earthflow erosion. The extent of the erosion increase is dependent on the factors such as rock type, slope length and slope gradient which were already taken account of in the original determination of the LUC units.

Comment [HTL1]: Long and somewhat complex sentence...please simplify

Convergent slopes are more at risk of increases in severity of fluvial erosion types, such as rill, tunnel gully and gully erosion. In the case of back hollows situated up the slope, there is a net output of water from the units through interflow, overland flow and erosion, whereas there is a net input into the footslopes and floodplains though interflow, overland flow and deposition, leading to higher water tables and the potential for breakout at the soil surface and ponding.

Comment [HTL2]: Long sentences and complex for this audience....can it be made more succinct

4.3 LAND MANAGEMENT UNITS

4.3.1 METHOD

ELUC units with similar characteristics were aggregated into Land Management Units (LMUs). This allowed patterns of more and less suitable land to be developed.

4.3.2 RESULTS AND DISCUSSION

The LMU map is shown in Figure 2 below:

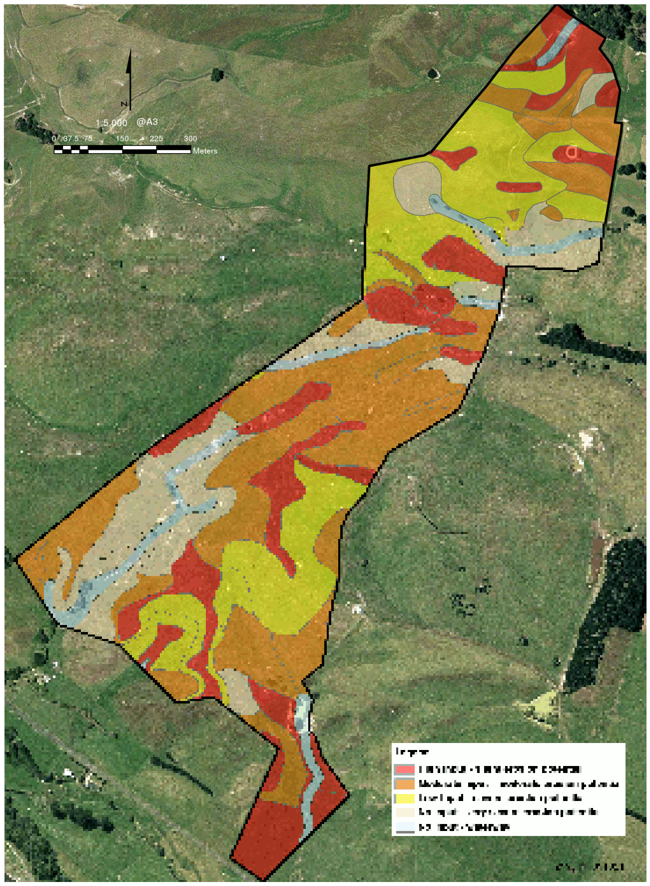

Figure 2. LMU map

Table 2 shows the resulting ELUC and LMU units:

LUC	Landform Description	Curvature	Potential Erosion Under Proposed Land Use	Enhanced Land Use Capability	Land Management Unit
3e	Argillite or siltstone, gently rolling (8-15°)	Planar	NA	NA	NA
		Divergent	1Sh1R	3e	High Input
		Convergent	1Sh1R	3e	High Input
4e	Argillite or siltstone, strongly rolling (16-20°)	Planar	2Sh2R	4e	High Input
		Divergent	1Sh1R	4e	High Input
		Convergent	1Sh1R	4e	High Input
4w2	Watercourses	Flat	5w	5w	No Input
5e	Argillite or siltstone, strongly rolling to mod steep (18-22°)	Planar	2Sh2R2Ss1G	5e	Moderate Input
		Divergent	2Sh2R1Ss	5e	Moderate Input
		Convergent	2Sh2R1Ss2G	5e	Moderate Input
6e13	Argillite, moderately steep to steep	Planar	NA	NA	NA
		Divergent	2Sh2Ss	6e13	Moderate Input
		Convergent	2Sh3Ss3G	6e13	Low Input
6e9	Siltstone, moderately steep to steep	Planar	NA	NA	NA
		Divergent	2Ss2Sh	6e9	Moderate Input
		Convergent	NA	NA	NA
New unit	Siltstone or argillite, moderately steep to steep	Planar	3Ss2T2Sh	7e	Low Input
		Convergent	2Sh3Ss3G	7e	Low Input
7e11	Argillite, very steep	Planar	NA	NA	NA
		Divergent	NA	NA	NA
		Convergent	NA	NA	NA
7e4	Siltstone, very steep	Planar	NA	NA	NA
		Divergent	3Ss2Sh	7e4	Low Input
		Convergent	NA	NA	NA
New unit	Siltstone or argillite, very steep	Planar	2Sh4Ss2G	8e	No Input
		Convergent	4Ss3Sh3T	8e	No Input

Table 2. ELUC units, associated erosion risks and LMUs

Table 2 shows that on rolling slopes (Classes 3e and 4e), the impact of curvature and proposed use of the land has minimal impact. These units are "high input" LMUs. However, as the slope of the LUC units increased, so does the impact on erosion. On the planar parts of the Class 5e land units, the risk of soil slip erosion increased from slight to moderate. On the convergent Class 5e units the risk of gully erosion increased to moderate. On the planar and convergent Class 6e9 LUC units, the risk of erosion increased to the extent that the ELUC units had to be reclassified as Class 7e units, making these units "low input" LMUs. Most elements of the Class 7e units had to be reclassified as Class 8e units because of their very severe soil slip erosion risk under the proposed land use, making these units "no input" LMUs.

Deleted: id

4.4 IRRIGATION MANAGEMENT UNITS

4.4.1 METHOD

IMUs were developed from LMUs. Irrigable areas of regular shapes and sizes were identified. Units suitable for use as separately manageable irrigation cells were delineated. The edges of the cells were smoothed to allow for irrigation lines to practically be installed. Care was taken not "take" from the more suitable rather than from the less suitable areas when smoothing, to ensure no areas ended up irrigated beyond the capacity of the landscape.

4.4.2 RESULTS

The IMU map is shown in Figure 3 below:

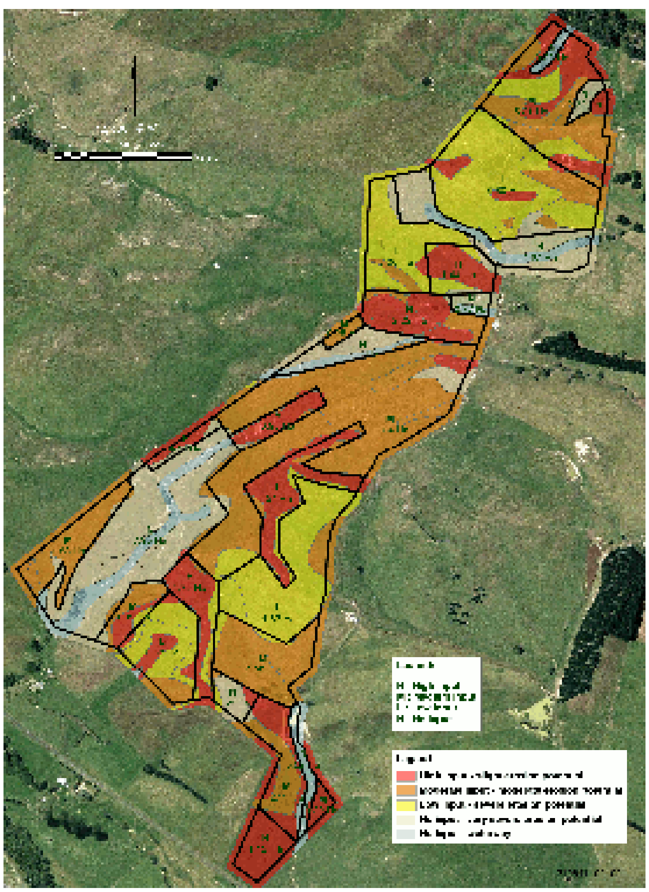

Figure 3. IMU map

The smoothed, regular sized irrigation units are evident on this map, with the "high input", "moderate input", "low input" and "no input" areas clearly identified.

4.5 DETERMINATION OF HYDRAULIC LOADING RATES

4.5.1 METHOD

Typically in design of a land treatment regime the soil hydraulic characteristics of the site are used to develop a sustainable rate of application which will avoid excessive drainage or run-off of the applied wastewater. Additional consideration of the impacts of slope, curvature and erosion potential were considered in the development of a hydraulic regime for the site. From this, the ability of the site to receive, retain and renovate the wastewater was incorporated into a water balance for the site in order to determine an appropriate hydraulic regime. Figure 4 shows a stepwise process for the development of a hydraulic regime.

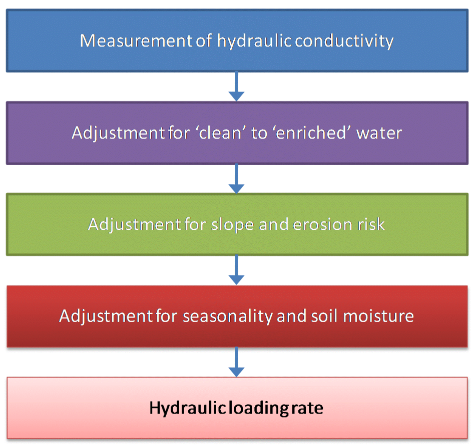

Figure 4. Development of the hydraulic regime

The IMUs divide the site into areas labelled as no, low, moderate or high input, indicating the relative capacity of the area to receive varying amounts of effluent. The hilly topography of the site encourages the downslope movement of water thereby creating an increased risk of overland flow, interflow, erosion and break out/surface ponding of water on lower slopes and floodplains. Consequently a reduction in the hydraulic loading rate calculated for a flat site is required.

By viewing the aggregation of ELUCs as a whole, interrelated wastewater application limits were set with a view to avoiding the risk of erosion on any units and the risk of breakout or ponding on the footslopes and floodplains. Because these adverse environmental effects are both controlled by movement of water through/over the root zone and the deep vadose zone, by conservatively controlling wastewater inputs to minimise the risk of erosion, control was also exerted over the risk of surface break-out and ponding.

Deleted: all units being

The hydraulic loading was reduced according to each IMU, whereby the application depth for High Input > Moderate Input > Low Input areas.

Water accumulation may occur in the soil due to the effects of the climatic regime and soil properties. When the soil moisture content is close to field capacity additional water will result in drainage or run-off; with runoff being more likely than deep percolation due to the slope, underlying soil and geological properties. This movement of water is related to the available water holding capacity (AWHC) of the soil. The hydraulic loading should account for the potential for rain to have occurred in the period preceding irrigation and to allow for rain to occur during or immediately following irrigation. This may occur at any time of year; however the effects are larger in winter due to the corresponding lower evapotranspiration which is the main mechanism for removal of water from soil on the site. In order to account for the seasonality of the land treatment system the hydraulic loading was modified in accordance with the soil moisture content as determined by the water balance.

A daily water balance was used by CPG to optimise the application of the wastewater under conditions which provide for minimal storage requirements, cater for peak seasonal loading, utilise a minimal land area and provide for simple robust system management. In addition the water balance considers the system requirements under wet year conditions to ensure adequate provision is made for storage and land area.

In preparation of the water balance concept, a range of key input parameters were considered. These include:

- Wastewater flows to the WWTP;
- Rainfall to the site and to the WWTP ponds;
- Potential evapotranspiration under the proposed crop;
- Canopy interception;
- Rainfall runoff;
- Available land area and application depths; and
- AWHC and soil water storage capacity.

Figure 5 shows the input and output parameters of the water balance:

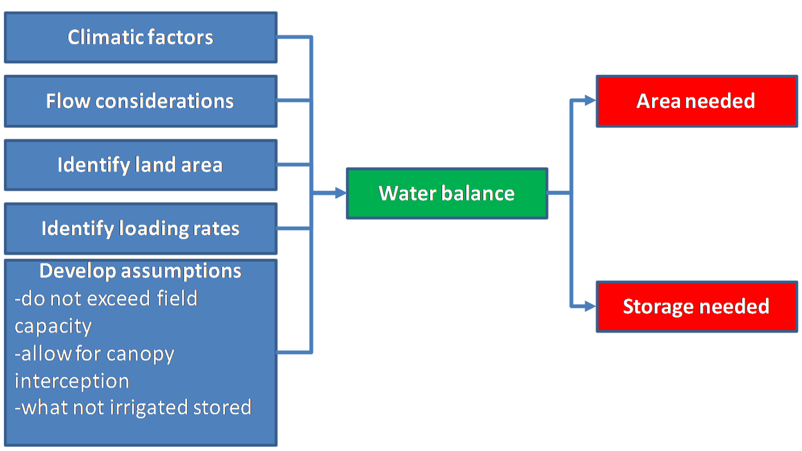

Figure 5. Schematic of water balance concept.

For the minimisation of erosion risk the water balance model utilised in this project uses a deficit application approach, whereby no drainage is allowed following an individual irrigation event. The water balance determines whether sufficient land area is available and gives the necessary storage volumes required to enable wastewater application to be withheld. In this case a trigger stopping irrigation when soil moisture was 5 mm below field capacity was used.

4.5.2 RESULTS

The resultant loading rates for IMUs are shown in Table 3:

Irrigation Management Unit	1	2	3
Unit description	High Input	Moderate Input	Low input
Total land area (ha):	15.6	18.0	24.6
Effective land area (ha):	10.5	25.0	25.0
Soil depth (mm)	300	300	300
Soil AWHC (mm/100 mm)	20	17	14
Soil AWHC (for soil depth) (mm)	60	51	42
Maximum application (mm/day)	6	4	2

Table 3. The Loading Rates For Irrigation Management Units

Taking into account soil depth and available water holding capacity, maximum wastewater application rates ranging from 2 to 6 mm were determined for different irrigation management units. A 5 mm soil moisture buffer was employed to prevent wastewater being applied to soils which had reached field capacity.

Formatted: Space After: 0 pt

The results of the initial water balance analysis indicated that at the calculated rates of application onto the nominated land area available, the storage pond associated with the WWTP would be unable to be emptied annually. This resulted in an ever increasing storage requirement each year. The only way to empty the pond was through the application of wastewater to soils where field capacity would be exceeded, or alternatively use a larger land area.

A fundamental design consideration was to ensure that field capacity was not exceeded on the moderate and low input areas, and as a result this necessitated increasing the land area. The water balance was used to determine the minimum additional area needed.

5 CONCLUSIONS

This paper outlines how the NZLRI and the LUCA process was enhanced through the additional consideration of the impact of land curvature on erosion risk (in terms of the cumulative effects of water in the landscape and exposure to wind). The impact of the plantation forest proposed for the case study site on a variety of erosion types and land types was also taken into consideration in the determination of erosion risk. IMUs were subsequently developed which identified land areas of shapes and sizes that were practical for irrigation as well as being categorised based on their extent of erosion risk and therefore suitability for irrigation. Suitable hydraulic loading rates were allocated to each of the IMUs which maximised the amount of wastewater applied to the site while ensuring that wastewater application rates did not exceed the capability of each ELUC unit leading to excessive interflow, raising of the water table, surface ponding, or erosion.

REFERENCES

ASNZ 1547:2007. 'Draft Guidelines For On-Site Domestic Wastewater Management'. Standards New Zealand, Wellington, 194p.

Barringer, J.R.F., Hewitt, A.E., Lynn, I.H., Schmidt, J. (2008). 'National Mapping of Landform Elements in Support of S-Map, A New Zealand Soil Database'. *Advances in Digital Terrain Analysis*. Springer, Berlin, Heidelberg, pp 443-458.

Kingma, J.T. 1962. 'Sheet 11 – Dannevirke'. *Geological Map of New Zealand, 1:250,000.* New Zealand Geological Survey. Department of Scientific and Industrial Research, Wellington.

Kingma, J.T. 1971. 'Geology of Te Aute Subdivision'. *NZGS Bulletin* 70, New Zealand Geological Survey. Department of Scientific and Industrial Research, Wellington.

Lynn, I.H., Manderson, A.K., Page, M.J., Harmsworth, G.R., Eyles, G.O., Douglas, G.B., Mackay, A.D., Newsome, P.J.F. 2009. 'Land Use Capability Survey Handbook – A New Zealand Handbook For The Classification of Land'. 3rd Edn. Hamilton, AgResearch; Lincoln, Landcare Research; Lower Hutt, GNS Science. 163p

Noble, K.E. 1979. 'New Zealand Land Resource Inventory Southern Hawkes Bay – Wairarapa Region'. *Land Use Capability Extended Legend*. 1st Edn with limited revision, 1988. National Water and Soil Conservation Authority, Wellington, New Zealand.