Facelift for cheese plant – Puhoi soil hydraulic experience

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ABSTRACT

The Puhoi Valley Cheese Company (PVCC) has been applying high strength cheese processing effluent to steep clayey soils north of Auckland for over 10 years. The system has not always performed well. Pressure to expand the plant and Auckland Regional Council (ARC) requirements to reduce nutrient loads prior to consent review/renewal have required PVCC to significantly improve effluent quality, and alter application management.

To cater for plant expansion, reduce water usage and improve the quality of wastewater being applied to land, PVCC has invested in a reverse osmosis wastewater treatment plant (ROWTP). This has accompanied a revision and upgrade of their land application of wastewater to a surrounding 7 ha pine plantation.

This paper reviews the impact that land treatment of effluent has had on the site, and the likely improvements that the change in effluent will bring to the land treatment system. It summarises work undertaken to characterise the land application area in order to establish a more appropriate management criteria.

Specific work undertaken examining saturated and near saturated hydraulic conductivities, as well as soil moisture measurements, proved to be exceedingly useful tools to characterise areas that had been previously irrigated. Changes in the ratio between K_{sat} and K_{-40} served as useful indicators of different degrees of effect that land treatment of high strength wastes can have on soils.

INTRODUCTION

Background

Puhoi Valley Cheese Company (PVCC) produces specialty cheeses at a processing plant at Puhoi, 15 km north of Orewa. Factory growth and long term application of high-strength processing wastewater has required PVCC to review their land treatment system. Previously, the factory irrigated a raw, screened, process washwater to a pine plantation on-site.

To improve the quality of the effluent applied to land, as well as incorporate some wastewater reuse, PVCC has invested in a reverse-osmosis wastewater treatment plant (ROWTP). The permeate generated by the ROWTP is a very clean, low strength effluent. Once commissioned, it is designed to substantially reduce key wastewater constituents, by between 50% and 99%. As a result, future effluent application to the land treatment area would be primarily limited by soil hydraulics but historic organic and nutrient concentrations have degraded land treatment potential at the site.

The plant currently produces approximately 100 m^3/day of effluent. PVCC intends to increase production at the factory, possibly by as much as 50%, which would increase the total wastewater produced (before reuse or discharge) to 150 m^3/day. It is likely that a large proportion of this water would be reused within the factory, reducing the amount applied to land. Despite the best intentions for reuse, there is the possibility reuse could be minimal.

Past applications of high strength wastewater have resulted in the onset of anaerobic conditions in the soil. These areas display reduced hydraulic conductivity and have a characteristic odour.

Glasson Potts Fowler Limited (GPF) was contracted to review the site's land treatment operation and provide recommendations to assist with the ongoing management of the site. Soil moisture and hydraulic properties were measured *in situ*. Soil profiles were described, and ROWTP permeate was characterised to examine the potential environmental effects of the wastewater on the environment. Guidance was also provided on how to better manage the wastewater application area.

SITE CONDITIONS

Soils

Soils have been generally classified as argillic pallic soils of the Waitemata series. These soils are of sedimentary origin, with underlying clay and limestone deposits throughout the region (Lavery and Nicholas 2003).

Wastewater

Historically the PVCC process washwater has been treated by screening coarse material and settling in two 22,000 L holding tanks prior to discharge to land. The land treatment area consisted of a combination of sprinklers and driplines, with an average load of 4.5 mm/d across the area. This was managed on a "1 day on, 3 days off" manual operated rotation system (Puhoi Valley Cheese Co. 2004).

The most noticeable feature of the untreated wastewater is a high organic and cation concentration. This composition, along with only primary treatment and the hydraulic loading rate, created localised areas of failure. This was observed by the onset of odorous anaerobic conditions which led to reduced infiltration and post application overland flow.

To resolve issues with the land application area and pending water supply issues with expansion, PVCC have installed a ROWTP. At the time of writing, the ROWTP was still undergoing commissioning. Preliminary performance data was made available to GPF and is presented in Table 1. The table also provides an indication of untreated wastewater and the expected long-term performance data from the ROWTP.

Table 1. Wastewater composition.

Sample	Raw wastewater	Permeate (predicted)[1]	Permeate (effluent)[2]
BOD (g/m^3)	3475.0	13.5	6.12
Suspended Solids (g/m^3)	1586.7	1.4	4
Oil and Grease (g/m^3)	667.1	46.4	31.0
Total N (g/m^3)	122.5	1.6	6.4
Ammonia (g/m^3)	20.3	0.5	1.1
Nitrite (g/m^3)	0.3	0.0	0.1
Nitrate (g/m^3)	3.7	2.7	1.84
Total P (g/m^3)	30.3	0.1	0.13
Reactive P (g/m^3)	9.1	0.0	Not tested
Sulphate (g/m^3)	35.1	NA	NA
Calcium (g/m^3)	49.3	0.0	Not tested
Magnesium (g/m^3)	3.3	0.0	Not tested
Sodium (g/m^3)	404.8	4.7	12
Silicon (g/m^3)	31.9	0.3	Not tested
Chlorine (g/m^3)	2.8	0.2	6.09

Key constituents of interest are reduced by between 50%-99% in the permeate. These reductions result in a clean, low strength effluent that may be reused in the factory as wash water, with excesses discharged to land treatment.

SITE INVESTIGATION METHODOLOGY

Soil Profile Characteristics

Soil profiles were examined to a depth of at least 0.6 m at a number of locations across the site. Road/track cuttings were observed to greater depth. Areas were chosen to confirm the similarity of profile characteristics, or identify areas with significantly different soil profiles across the site. Horizons at each test site were noted and included colour, texture, development, consistency, additives (i.e. mottling, stones etc.) and moisture content.

Saturated and Unsaturated Hydraulic Conductivity

Using a double-ring infiltrometer falling head method, measurements were taken to determine the saturated hydraulic conductivity (K_{sat}) of the soil. These conditions typically represent flow through all of the soil pores, including soil macro-pores.

In order to determine the water-transmitting and water-holding properties of the soil, unsaturated hydraulic conductivity was assessed for three matrix potentials (ψ_m ranging from -100 mm to -20 mm) *in-situ* using plate permeameters.

[1] Predicted permeate concentration based on information supplied by Puhoi Valley Cheese Company and Environment Products International Limited, September 2005

[2] Permeate concentration as monitored during commissioning (based on composite grab samples taken April 11th, 2006).

Soil Moisture Monitoring

To monitor the movement of water through the soil during and after irrigation, two Sentek EnviroSMART™ soil water content moisture probes were installed. Each probe measured volumetric soil water content at depths of 10cm, 30 cm and 50 cm. Top Probe was placed in an area that had been historically irrigated, but at the top of a slope. The soils were aerobic and appeared healthy. The conductivity tests, most closely related to the results of Top Probe, were observed at Site 2. Bottom probe was placed within Site 3, which was at the bottom of the same slope.

RESULTS AND DISCUSSION

Hydraulic properties and profile characteristics were assessed at three sites. The difference in hydraulic properties at each site reflected the history of that particular area of the site, and allowed us to extrapolate potential effects of the wastewater treatment to understand how to better manage the areas.

Some of the results, in particular the unsaturated hydraulic conductivities, provided strong evidence that the previous wastewater application had a detrimental effect on the soils. During the site visit localised saturation of the soil, resulting in anaerobic conditions (a grey sludge-like soil condition with a strong odour of rancid milk) was found to occur regularly. The localised areas are reminiscent of the irrigation areas in the mature stands as depicted in Lavery and Nicholas (2003), but are much reduced in their size and scope across the site. The predominant issues pertaining to effluent movement through the land treatment system are:

- the anaerobic areas within the soil which are likely to be being created by the hydraulic loading and high BOD/nutrient (historical) waste stream; and
- the steep site characteristics, and low hydraulic conductivity of the soil.

Overall, the site has reasonable drainage due to past forestry land use, but with high hydraulic loading of strong organic wastewater pore spaces can fill up with anaerobic bacterial detritus and slimes, resulting in a severe reduction in soil hydraulic conductivity. The results from Site 1 and 3 demonstrate this reduction, while the results from Site 2 are an example of a healthier system that has not been affected by anaerobic conditions.

Site 1

Site 1 was located within the Western Catchment on a slope with a westerly aspect. Slope was variable between 15^{o}-25^{o}. The area appeared to have had historical slippage, with an overgrown scarp upslope. Vegetation was 10 year old pines, with black berry, grass and bracken understorey. The area has been historically and is currently irrigated. The soils were free draining, with some areas having high moisture contents with depth. The higher moisture content seemed to indicate anaerobic conditions based on odour detected and possible reducing conditions (i.e. slight gleying).

The K_{sat} and unsaturated hydraulic conductivities indicate that the soil hydraulic properties appear linked to past use of the existing irrigation fields, as well as current irrigation applications. The results are summarised in Table 2 below.

Table 2. Soil hydraulic measurements (mm/hr).[3]

Site	Hydraulic conductivity at matrix potentials			Saturated conductivity	Indicative soil moisture
	ψ_m -100	ψ_m - 40	ψ_m -20	K_{sat}	
S1-1				95	Wet
S1-2				>1,000	Dry
S1-3				160	Wet
S1-P1	0	0	2		Wet
S1-P2	0	4.4	18		Dry
S2-1				125	Dry
S2-2				100	Dry
S2-3				<250	Dry
S2-P1	0	4.3	18		Dry
S2-P2	0	2.9	25		Dry
S3-P1	0	0	11		Wet
S3-P2	0	0	2.3		Wet
Site average					
Wet soil average	0	0	5.3	128	
Dry soil average	0	3.9	20	365	

Note: Site = S[*site*] – [*replicate*]

The land treatment area exhibits high variability in K_{sat} rates. At Site 1 K_{sat} measurements varied from virtually nil to rates in excess of 100 mm/hr.

Unsaturated hydraulic conductivity measurements at Site 1 indicated that there was limited infiltration at ψ_m -100, while higher rates were noted in the drier soils with ψ_m -20 being 18 mm/hr and decreasing to around 2 mm/hr on the wetter soils. At a ψ_m of -40 no infiltration was observed for the wetter soils and an average 3.9 mm/hr was observed for the drier soil. Note the 10 fold difference, though, between the K_{sat} at S1-2 and the corresponding K_{-20} (S1-P2). By contrast, within a test just a few metres away, but where soils were observed to be wetter and anaerobic (S1-1/S1-P1) the difference is 50 fold. The difference in K_{-40} is infinite, as there was no near-saturated hydraulic flow at the wetter site. Variability in hydraulic conductivity for different matrix potentials at Site 1 appears to be indicative of localised, anaerobic soil conditions.

Site 2

Site 2 was located on the edge of the Eastern Catchment, with a northerly aspect and a slope of 12^o. Eleven year old pines and grass understory dominate. The area has only been recently zoned for irrigation. Low moisture contents throughout the soil profile were observed. The soils had a well horizonated structure, with a litter layer, structured clay silt horizons and a base clay pan.

At Site 2 K_{sat} measurements were approximately 100 mm/hr. The variability in K_{sat} at Site 1 appeared to be related to the soil's moisture content, with the wetter replicates having a lower infiltration rate.

[3] Rates reported as approximate averages.

Site 2 is a new irrigation area, and the soil's hydraulics were similar to that of the dry soil noted at Site 1. The plate permeameter testing at Site 2 showed that the amount of water movement through the soil is virtually nil at high matrix potential, around 3-4 mm/hr at near ψ_m -40, and 20-25 mm/hr at low matrix potential (ψ_m = -20). Site 2 had classic infiltration test curves, with saturated conductivity near 100 mm/hr. The comparison between the results at Site 2 and Site 1 allow further confirmation that the healthier soils observed are providing for near saturated flow, while the less healthy areas are not. Note though that the K_{sat} values remain similar, and if only this measurement had been made, a strong difference would not have been evident between the anaerobic and aerobic areas of the site.

Site 3

Site 3 was located in the Eastern Catchment and had a westerly aspect. It was located mid slope with a slope angle of 18^o. New pines were planted two years ago after harvest. The slopes appeared wet and localised anaerobic areas are visible on the surface. The area has been historically and is currently irrigated. The top horizons and humus layer are in places an anaerobic, grey profile that was very wet. Below this upper layer is a region of gleying, followed by massive mottled clayey layer. This soil profile has been modified by the high amounts of wastewater that have been applied to the site over time.

The plate permeameter results for Site 3 (Table 2) appear to be indicative of ongoing effects of the irrigation of a high BOD wastewater, with no infiltration at near saturated hydraulic conductivity, and reduced macropore conductivity compared to other sites.

Recent harvesting, and possibly more importantly the onset over time of anaerobic soil conditions, have resulted in a reduction in K_{-20} and K_{-40}. The anaerobic conditions may be a result of an excessive irrigation hydraulic loading, coupled with a high BOD.

Moisture probe observations

In a number of cases, it appears that the high hydraulic loading may also be resulting from upslope effects. The effects of reduced infiltration causing surface flow, or alternatively the high rate of drainage and slope, result in horizontal drainage, buildup, and breakout at the tail of the slope. This slope effect is generally a natural occurrence, but it is likely to be exacerbated by the onset of anaerobic conditions resulting from the hydraulic loading and the wastewater strength.

Soil moisture measurements indicated similar effects to the permeameter results. The 10 cm Top Probe (Fig. 1) sensor displays strong wetting and drying cycles, indicating that the soil is displacing irrigated volume and rainfall quickly through the top 10 cm of soil. The 10 cm sensor achieved both higher and lower volumetric water contents than either the 30 cm sensor or 50 cm sensor, which remained quite constant. The soil is able to conduct the water rapidly through the top 10 cm of soil, either vertically or (more likely) horizontally. This is likely due to the combination low permeability in the deeper soils, and steep slope of the site which inhibits the moisture reaching the lower sensors, and moves the water more quickly in a horizontal direction.

The data from Bottom Probe (Fig 2.) demonstrate a very different profile than those from the Top Probe. The 10 cm sensor at the Bottom Probe indicates continuously high water content, with only small variations, peaks and troughs to indicate the irrigation cycle. The 30 cm sensor also appears to have very gentle peaks and troughs, but not regularly, only occasionally. The 50 cm sensor, was consistently wetter than the 30 cm sensor, which is unusual. This indicates that there was a higher volumetric water content in the 10 cm and 50 cm depths than at 30 cm, making the soil water profile a wet-dry-wet profile with depth. This can be interpreted several ways. Some possible interpretations of higher water content below:

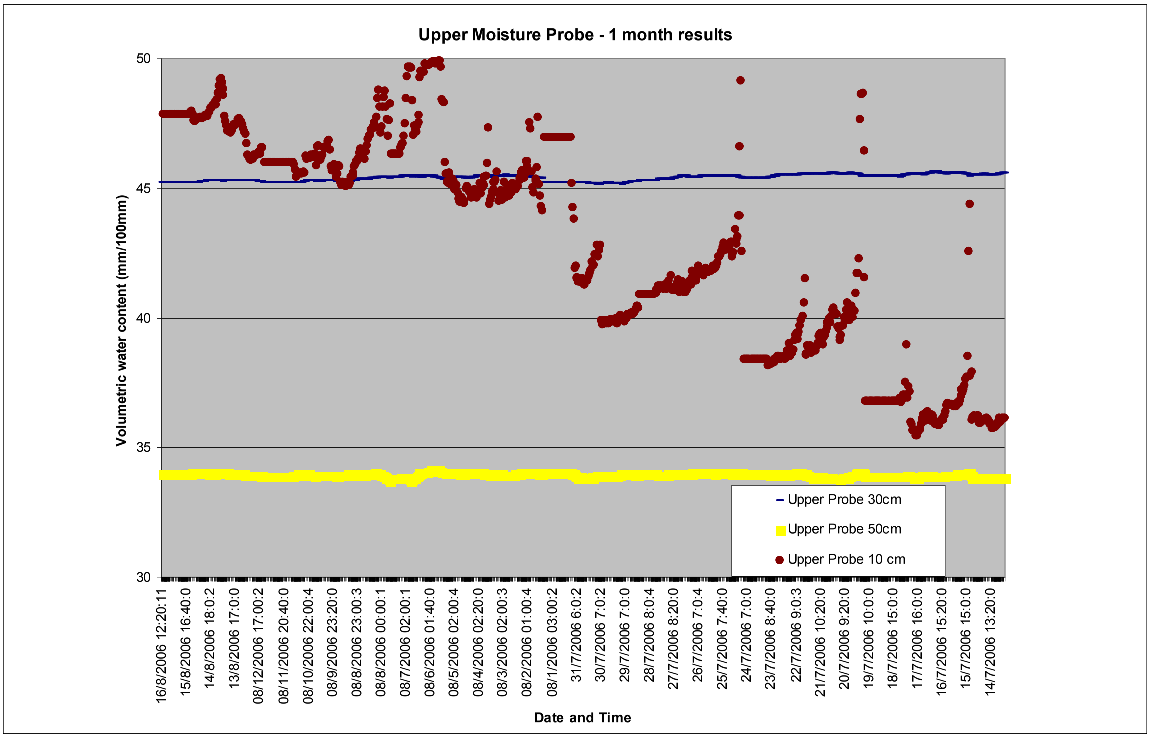

Fig. 1. Moisture monitoring results – top probe.

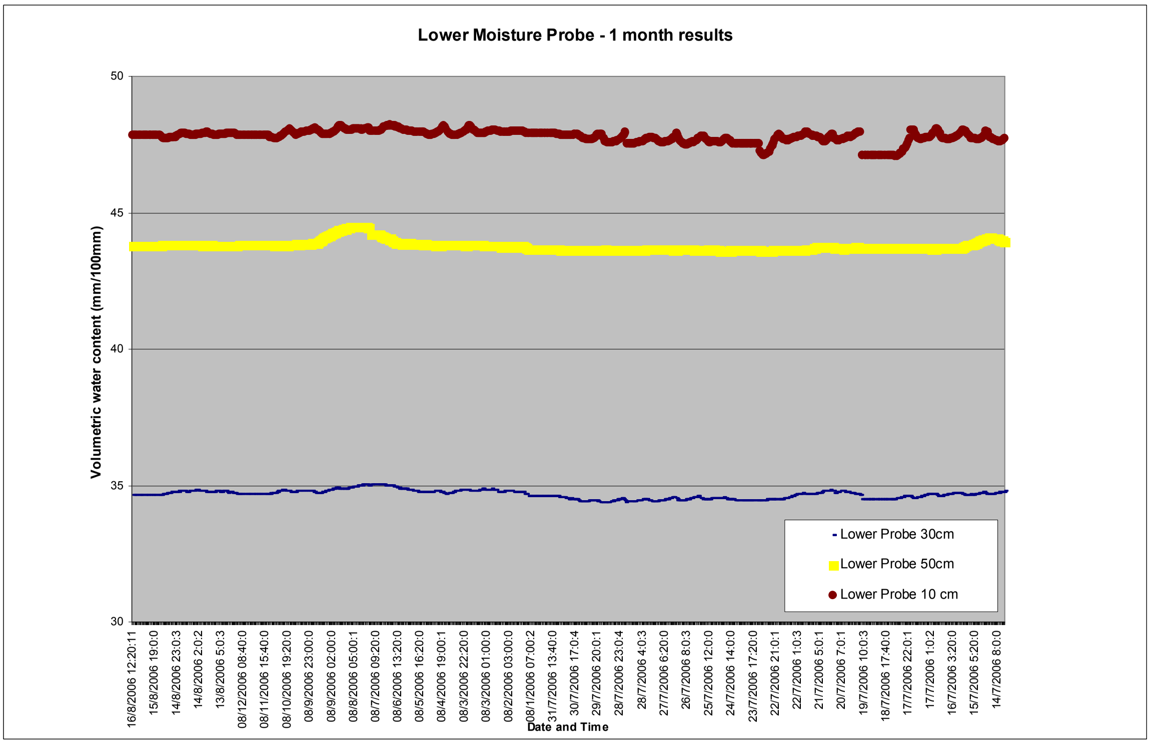

Fig. 2. Moisture monitoring results – bottom probe.

- There is a perched restrictive or layer at 10-20 cm, making downward movement from the upper 10 cm of the soil difficult, while the absence of this layer upslope allows the lower, more permeable soils to collect and transmit water.
- The site has been overloaded hydraulically, leading to saturation at depth over time, while the organic fraction in the top 10 cm is becoming anaerobic due to fungal and microbial intervention and preventing infiltration.
- The 30 cm area is more permeable than either 10 cm or 50 cm layers.

The conditions at the Bottom Probe site require management in order to ensure that the land treatment system is functioning effectively.

The Top Probe soil moisture monitoring site demonstrates the manner in which the soil profile should react when irrigated, while the Bottom Probe site demonstrates some of the issues indicating that the site is not coping well with the volume and characteristics of the effluent applied. The 10 cm sensor in the Top Probe displays strong wetting and drying cycles, indicating that the soil is displacing the irrigated volume quickly through the top 10 cm of soil. This contrasts with the 10 cm sensor in Bottom Probe, which never appears to undergo the complete drying cycle, likely though the combination of anaerobic blockage of the soil pores, and continuous water movement from upslope. These theories correspond well with what was visually observed at the site, with anaerobic masses and breakout occurring near the Bottom Probe.

Further moisture monitoring, by shifting the moisture probes around the site has been recommended, as the relative moisture contents around the site will enable PVCC to assess whether or not the improved effluent and the reduced irrigation are having the desired effect.

Site investigation recommendations

To compensate hydraulic overloading of the steep site relating to previous overloading and anaerobic conditions, GPF recommended that the system's average daily irrigation rate for active zones be reduced from 4.5 mm/day to 3 mm/day, while the number of zones in use over time increases, allowing for a rotation system. This reduction, coupled with resting zones on a regular basis, and the vastly improved quality and lower strength of the effluent being applied, should allow for maintaining sustainable effluent application rates.

A crop rotation was recommended to ensure that only a small proportion of the site, the equivalent of one sector, which is a grouping of several irrigation zones, is removed from service due to harvesting at any one time. This will ensure that the hydraulic pressures on the other irrigation blocks within the system are not exaggerated due to the harvest.

CONCLUSIONS

The hydraulic conductivities examined suggest that reduced irrigation rates, and rehabilitation of the site through resting and reduced effluent strength is required. There are areas of the site that require remediation from an anaerobic state, either through resting or through low dosage of clean, high quality aerobic effluent.

Distribution of the effluent using a sector rotation system that encompasses a larger proportion of the site which includes current reserve areas, and resting sectors on a regular or harvesting basis, will allow the system to maintain a lower average irrigation rate. This sector rotation system, be it a three or four active sector system, will be more sustainable than trying to apply the entirety of the volume to only 50% of the site.

A reduction from the current irrigation rate, coupled with the dramatic improvement in the quality of the effluent due to the ROWTP will improve the soil conditions in the irrigation areas over time, provided that the current remediation actions continue on schedule. The most interesting information gleaned from this project, however, was the contrast in hydraulic conductivity measurements within the sites of differing histories, and the stories that they told of the pressures exerted on the soils during historical land treatment. The key points of the conclusions and recommendation are the following;

1) In assessing the effects of land treatment on the soils, K_{sat} and K_{-40} are both valuable tools and should be used together to give robust information, rather than exclusive of one another;

2) Soil moisture monitoring using probes can offer similarly valuable information with the included dimension of time, versus the two dimensional, point evaluation data of the K_{sat} and K_{-40} tests.

3) The high quality permeate will result in reduced nutrient additions that will have negligible impacts on the soils or receiving environments;

4) Resting, using a sector-based rotation cycle and low proposed irrigation rates may remediate the areas that have been subjected to high BOD wastewater and resulted in anaerobic conditions in the environment;

5) Soil moisture monitoring should continue, and be cycled through the proposed sectors, to ensure that the proposed rates, once enacted, are performing to the required standards.

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