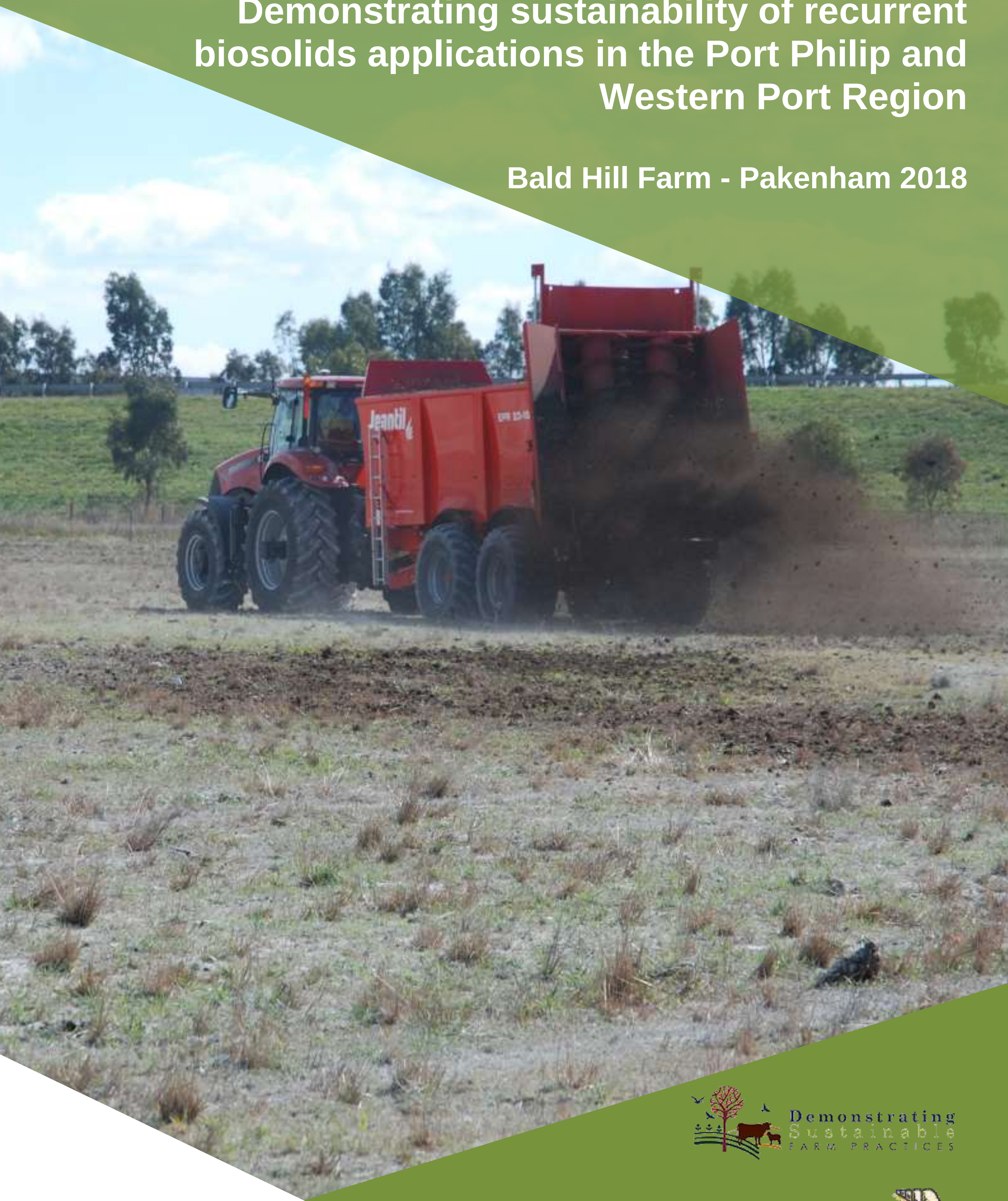
Demonstrating sustainability of recurrent biosolids applications in the Port Philip and Western Port Region

Bald Hill Farm - Pakenham 2018



Demonstrating Sustainable Farm Practices

CLEANAWAY

South East Water

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National Landcare Program

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Introduction

Biosolids, also referred to as 'treated' or 'stabilized sewage sludges', are generated from sewage treatment through a process that is designed to reduce pathogens and other environmental risks of wastewaters. Land application of biosolids has now been accepted as a beneficial and sustainable utilization of biosolids in many part of the world (Lu, 2012).

Figure 1: Pakenham Water Recycling Plant and Bald Hill Farm

Western Port Catchment Landcare Network (WPCLN), in collaboration with South East Water and Cleanaway, set up a long-term demonstration site at Bald Hill Farm (Dryland paddock) near Pakenham (Figure 1) in 2015 to evaluate potential nutrient and trace metal build up in soils due to repeated biosolid application into agricultural lands. The primary aim of this flagship demonstration was to test and demonstrate whether recurrent applications of biosolids can be carried out sustainably in the region by adopting the State, National and International best management practices on biosolids land application.


Figure 2: Field day at Bald Hill Farm Biosolids demonstration site

This demonstration provided an opportunity for local farming communities, researchers, industry and policymakers to observe, monitor and evaluate the long term effects of repeat application of biosolids on soil as well as environmental health and land productivity (Figures 2, 6 and 8). Furthermore, it has been a showcase on the beneficial use of biosolids where any potential environmental risks associated with recurrent applications could be mitigated by following best management practices.

Bald Hill Farm

The demonstration trial site is within the Bald Hill Farm which is a cattle and sheep enterprise located north of Pakenham Water Recycling Plant (WRP) and to the south east of Pakenham Township. The property (Figure 3) is owned by South East Water (SEW) and is approximately 182 ha of which approximately 40 ha is used for a winter storage reservoir. Out of the 142 ha of arable land, 100 ha is under irrigation with recycled water while the rest is under dry land farming. Forage production (silage and hay) is the primary agricultural activity of the land with periodic grazing of dairy stock and beef cattle between seasons.

Figure 3: Bald Hill Farm

The farm is on an alluvial plain with relatively deep soils developed on a recent alluvium (Quaternary fluviatile and swamp deposits). Soils are duplex with brownish sandy clay loam surface layer overlying brownish grey to greyish brown with rusty brown mottled sandy clay loams to light clays around 15-25 cm, while medium to heavy clay occurs from 40 cm to a depth of at least 180 cm. The farm is within the high rainfall zone and receives approximately 790-820 mm of rainfall annually (Figure 4).

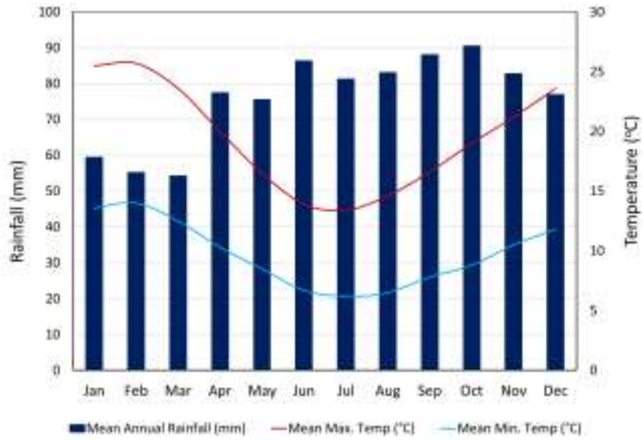

Figure 4: Long term average monthly rainfall, temperature of the local area surrounding Bald Hill Farm

Bald Hill Farm is managed by Mr Steve Jones who has 30 years of faming experience in the region.

The Biosolids demonstration trial

The purpose of the trial was to demonstrate that sustainable recurrent land applications of biosolids could realistically be achieved without compromising the safety of the environment, public and stock by persistently adopting the best management practices for biosolids land application prescribed by EPA Victoria and other National and International environmental regulatory frameworks. This demonstration was set up in 2015 on 6 ha of a dryland paddock (Figure 5) at Bald Hill Farm, which previously had received a single application of biosolids in 2007. A control site was also set up on a nearby dry land block (east of the demonstration site) which has been maintained identically to the demonstration site, except for application of biosolids for the purpose comparison.

The trial areas were formerly maintained as a mixed dry land pasture production system (with perennial rye/ clover mixed) until end of 2014. The site was pretreated with gypsum at a rate of 5t/ha in March 2015. Biosolids were applied annually in March 2015, 2016, and 2017. An annual rye/clover mix was sown each year to coincide with autumn rains; usually between mid-April to early May (Table 1).

Figure 5: Bald Hill Farm Biosolids demonstration site (2016)

Table 1: A summary of dry land forage mix established for the biosolids demonstration trial at Bald Hill Farm

Year	Date Sown	Forage mix	Seed rate (kg/ha)	Gypsum (t/ha)
2015	29/05/2015	Annual Rye Grass/Clover (Arnies & Wintersta)	30	5
2016	26/04/2016	Italian Ryegrass/Clover	30	-
2017	13/05/2017	Rejuvenator Italian/Clover	42	-

Application of biosolids (Treatment grade 1 and Contaminant grade C2) strictly followed the EPA Victoria Guidelines on Biosolids Land applications (EPA Victoria Guidelines No 943) ensuring actual application volumes were well within the prescribed limits. Project partner, Cleanaway carried out the annual biosolid applications, which involved surface spreading immediately followed by soil incorporation with disc plough and power harrow (Figure 9). The pasture mix was sown after a minimum of 30 days mandatory witholding period prescribed by EPA Victoria.

Figure 6: Site visit after pasture establishment

Monitoring and test protocols

As per the EPA biosolids land application guidelines, a rigorous annual environmental monitoring regime was implemented covering all aspects of biosolids (microbiological/pathogenic potential, chemical and contaminant levels) and the application site (soil, groundwater and pastures). Representative samples were collected from biosolids stockpiles. Soil samples were collected at up to a 90 cm profile from permanently marked locations, and pasture samples were cut from representative locations in each block. All samples were analysed at NATA accredited environmental analytical laboratories.

Figure 7 Collection of soil core samples for contaminant assessment

Figure 8: Site/Soil characterisation and sharing the information with farmers, scientists and the industry

Biosolids used

This demonstration used Treatment grade 1 (T1) and Contamination grade 2 (C2) biosolids from Water Recycling Pants run by South East Water where biosolids are produced following a comprehensive treatment process to achieve the highest treatment grade (T1). This process included; aerobic digestion of raw sewage initially, which are then subjected to anaerobic digestion in sludge lagoons followed by dewatering and drying sludge drying pans. The resultant product is then stockpiled for more than 1-3 years to minimise further pathogenic propensity and other potential environmental risks, particularly heavy metals.

Figure 9: Biosolids ready at site for application (in 2015)

The source of biosolids used for the demonstration varied depending on the availability of specified grades of biosolids for this purpose. The actual quantity of applications varied due to inherent variability in characteristics and compositions of biosolids from those sources and the rates were calculated using Nutrient Limiting Application Rates (NLAR) and Contaminants Limiting Application Rates (CLAR). For this demonstration, the NLAR was primarily based on Nitrogen (Table 2).

Table 2: Biosolids application details at the flagship demonstration site at Bald Hill Farm

Application year	Biosolids source	Biosolids nutrients (%)		NLAR[2] (dry t/ha)	Nitrogen uptake* (kg/ha/yr)	Actual application rates	
		Total Nitrogen[1]	Total Phosphorus			Product tons/ha	Dry tons/ha
March 2015	Somers	1.18-1.38	0.76-0.85	122	200 - 280	127	78.5
	Blind Bight	0.32	0.20	469		127	109
March 2016	Pakenham	0.70	0.40	123		116	84
March 2017	Blind Bight	0.15	0.22	518		666	520
	Pakenham	0.80	0.54	131		200	130

[1]*Kejeldahl N.* [2]*Nitrogen NLAR. *Source: EPA Victoria (1991)*

Details of chemical and microbiological characteristics of biosolids sourced from specific plant and stockpile for the Bald Hill Farm demonstration are given in Table 3, 4 and 5. It was clear that all sources of biosolids used for this demonstration met the microbiological criteria for the Treatment Grade T1 for three critical pathogens; *E. coli*, Salmonella and enteric viruses. Meanwhile, Cadmium, Copper, Selenium and Zinc levels of biosolids from the above sources were well within the limits for Contaminant Grade C2, which is prescribed for agriculture and a range of other uses (EPA Victoria, 2004 and SEW, 2014). In addition, chemical analysis also confirmed that pesticide residues (Organochlorides/Organophosphates) were more than 30 times below the prescribed limits for C2 Grade, except for PCBs (polychlorinated biphenyl) which were twice below the C2 limit for all sources at all applications (data not presented).

Considering the source dependent variability in chemical and microbiological properties, details of actual application rates of biosolids at each application for various sources are given in the Table 3.

Table 3: Microbiological assessment of biosolids applied to Bald Hill Farm demonstration site

	2015			2016		2017		
Source WRP	**Somers**		**Blind Bight**	**Pakenham**		**Blind Bight**	**Pakenham**	
Stockpile ID	**H2011A**	**H2011B**	**BB2011**	**P2012A**	**P2012B**	**BB2013**	**P2013A**	**P2013B**
Salmonella (D/ND)[1]	Not Detected			Not Detected		Not Detected		
E. coli (orgs/g) (dw)	<16 to 33	<16 to 93	<12 to <13	<13 to <15	<13 to <14	<12 to <14	<14 to <16	<15 to <16
Enteric Virus (MPNIU)[2]	<1.05	<1.05	<1.054	<0.053	<0.053	<0.05	<0.05	<0.05
Treatment Grade	**T1**	**T1**	**T1**	**T1**	**T1**	**T1**	**T1**	**T1**
Date of sampling	24/11/2014			18/11/2015		1/11/2016		

[1]D=Detected, ND=Not detected. [2]The biosolids guidelines requirement of enteric virus analysis in the units of PFU/100g is not performed by any NATA-accredited laboratories. Alternatively, analysis by a NATA-accredited laboratory of the Most Probable Number of Infectious Units (MPNIU) has been conducted.

Table 4: Biosolids Contaminant Concentrations (BBC[1], mg/kg dry wt) for different stockpiles of biosolids from each source (n=5). H= Somers, BB=Blind Blight and P=Pakenham.

Contaminant	**Year of Application ➔**		**2015**			**2016**		**2017**		
	Source WRP ➔		**Somers**		**Blind Bight**	**Pakenham**		**Blind Bight**	**Pakenham**	
	Stockpile ➔		**H2011A**	**H2011B**	**BB2011**	**P2012A**	**P2012B**	**BB2013**	**P2013A**	**P2013B**
	Prescribed Limits									
	C1	**C2**								
Arsenic	20	60	8.9	10.3	6.6	2.5	2.5	8.1	2.5	2.5
Cadmium	1	10	1.2	1.5	0.2	0.6	0.6	0.2	0.9	0.7
Chromium	400	3,000	34	35	19	26	28	19.8	27.8	28.7
Copper	100	2,000	250	299	35	121	122	38.4	177	187
Lead	300	500	26	46	15	25	25	9.8	31	23
Mercury	1	5	1.3	1	0.08	0.32	0.32	0.1	0.7	0.6
Nickel	60	270	14	15	13	12	14	9.1	13.7	16
Selenium	3	50	3.2	3.2	1.5	1.5	1.5	1.5	1.5	3.1
Zinc	200	2,500	423	421	79	256	240	79.7	403	399
FINAL GRADE			**C2**	**C2**	**C1**	**C2**	**C2**	**C1**	**C2**	**C2**
Date of sampling			24/11/2014			18/11/2015		1/11/2016		

[1]BCC=m+(s*y), where m=mean; s=Std Deviation and y=co-efficient (Calculations based on EPA Victoria, 2004).

Table 5: Quantities of Biosolids (from different sources) applied to the treatment paddocks (in each year[1]) based on the limiting contaminant.

Year	**Biosolids Stockpile Location**	**Stockpile ID**	**Limiting Contaminant**	**NLAR (dry t/ha)**	**Application area (ha)**	**Actual application rate (dry t/ha)**	**Actual dry tonnes applied**
2015	Somers	H2011A	Nitrogen	108	2.8	78	221
		H2011B		135	1.5	79	117
	Blind Bight	BB2011		469	1.3	109	140
	Total				**5.6**		**477**
2016	Pakenham	P2012A	Cadmium	122	1.8	81	146
		P2012B		129	3.8	86	325
	Total				**5.6**		**471**
2017	Blind Bight	BB2013	Nitrogen	518	0.6	520	312
	Pakenham	P2013A		123	3.1	124	385
		P2013B		138	1.8	136	244
	Total				**5.5**		**629**

Results

Soil chemical properties

Soil analytical data from the demonstration trial shows that the application of biosolids markedly increased soil nutrient levels, particularly nitrogen, phosphorous and cations which are essential for crop growth and productivity (Table 6). These observations are consistent with previous studies conducted elsewhere (Sullivan *et.al*., 2015; Lu *et.al*., 2012). Furthermore, the increases in total soil carbon content during the last three years were 15% - 40% compared to the 2014 soil carbon levels.

Post-application soil electrical conductivity (EC) levels were higher in soils applied with biosolids compared to the same before application. This is expected due to elevated levels of salts in biosolids (data not presented). However, soil salinity levels were below the threshold level (0.8 dS/m) for pasture/fodder production. Interestingly, Exchangeable Sodium Percentage (ESP) levels as well as exchangeable Na levels in soils treated with biosolids did not show such an increase. It seems that gypsum application (5 t/ha) in 2015 had countered potential negative effect, which is generally anticipated with recurrent application of biosolids due to relatively high sodium loading.

Figure 10: Effects of biosolids on pasture: visual differences in foliage possibly due to additional nitrogen input through biosolids

Substantial increases in exchangeable calcium levels in soils treated with biosolid (90%-160%) over the pre-application year (2014) could primarily be attributed to the application of gypsum in 2015. However, biosolids could have also been a contributory factor for increased soil calcium levels due to high calcium loading through biosolids.

Table 6: Chemical properties of soils of Bald Hill Farm demonstration site

Soil analysis (0-10 cm depth)	Units	Pre-application	Post application		
		2014	2015	2016	2017
pH (1:5) water	pH units	5.9	5.6	5.6	6.2
$EC_{1:5}$	dS/m	0.14	0.30	0.40	0.28
ESP	%	6.3	4.3	2.3	3.1
Total N (Kjeldahl)	mg/kg	3000	4667	5200	3600
Total C	%	3.4	4.9	4.0	4.8
C/N ratio		11.3	10.5	7.7	13.3
Total P	mg/kg	450	910	1465	540
Olsen P	mg/kg	31	112	135	163
Available potassium	mg/kg	53	140	590	77
CEC	cmol(+)/kg	14	17	18	18
Exch. Calcium	cmol(+)/kg	5	12	13	10
Exch. Magnesium	cmol(+)/kg	4.6	4.1	3.4	3.7
Exch. Potassium	cmol(+)/kg	0.15	0.4	0.4	0.2
Exch. Sodium	cmol(+)/kg	0.91	0.8	0.4	0.56
Ca/Mg ratio		1.09	2.93	3.82	2.52
Date sampled		26/11/2014	7/10/2015	10/08/2016	18/09/2017
Laboratory		ALS			

n = number of samples

Heavy metals in soils

Accumulation of heavy metal is one of the primary concerns of biosolids land applications as exceedance of such contaminants beyond environmental threshold could potentially endanger on and off-site ecological health. The results of the current study indicate that nine critical heavy metal contaminant concentrations in soils were well below the Receiving Soil Contamination Limits (RSCL) prescribed by EPA Victoria despite three annual consecutive applications of biosolids to the same site at Bald Hill Farm (Table 7).

Table 7: Concentration of heavy metal contaminants (mg/kg) in the top layer (0-10 cm) of soil prior to application of biosolids at Paddock 36 of Bald Hill Farm.

Contaminant	Receiving Soil Contaminant Limits (RSCL)* (mg/kg)	Application Site Average Contaminant Concentration (mg/kg)		
		2015	2016	2017
Arsenic (As)	20	<5	1	1.4
Cadmium (Cd)	1	<0.2	<0.5	<0.5
Chromium (Cr)	400	14	19	22
Copper (Cu)	100	27	50	74
Lead (Pb)	300	12	14	17
Mercury (Hg)	1	0.07	<0.2	0.2
Nickel (Ni)	60	5	6.7	8.5
Selenium (Se)	3	<3	<0.5	0.7
Zinc (Zn)	200	40	65	110

Pasture quality

Biosolids application improved the nutritional quality (Table 8) of forage produced from the demonstration site. For example, protein content of foliage from biosolids demonstration site increased by 48% in average over three years (2001-2017) compared to no-biosolid control. Similarly, phosphorous and sulphur contents for the same period were over 50% higher in forage cut from biosolids demonstration site than the control site.

Table 8: Feed test results

Parameter	Units	Control Area (No biosolids)			Biosolids Application Area Mean value		
		2015	2016	2017	2015	2016	2017
Crude Protein[1]	%	20.7	21.9	16.7	24.2	31.9	31.9
Digestible Protein	%	14.5	15.3	11.7	16.9	22.4	22.4
Acid Detergent Fibre	%	30.7	24.7	21.9	34.1	22	22.8
Neutral Detergent Fibre (NDF)	%	51.2	48.7	45.5	53.1	41.7	44.4
Digestible Dry Matter	%	63.1	66.1	68.1	61.3	69.3	68.1
Total Digestible Nutrient	%	64.7	69.4	71.6	62	71.5	70.9
DM Intake % of Body Weight	%	2.4	2.5	2.6	2.3	2.9	2.7
Net Energy Lactation	MJ/kg	6.2	6.6	6.9	5.9	6.9	6.8
Net Energy Gain	MJ/kg	3.6	4.2	4.5	3.3	4.5	4.4
Net Energy Maintenance	MJ/kg	6.7	7.2	7.5	6.3	7.5	7.4
Relative Feed Value		118.5	133	147	109.3	160	149
Metabolizable Energy (ME)	MJ/kg	9.3	9.8	10.1	8.9	10.3	10.1
DOMD	%	60.3	62.8	64.5	58.7	65.5	64.5
Chloride	mg/kg	2.74	1.4	1.2	2.67	2.3	0.8
Cobalt	mg/kg	0.4	0.4	0.22	0.5	0.3	0.25
Iron	mg/kg	275	280	390	258	220	240
Manganese	mg/kg	108	150	66	74	73	92
Calcium	%	0.61	0.70	0.44	0.63	0.65	0.56
Magnesium	%	0.3	0.23	0.25	0.33	0.24	0.28
Sodium	%	1.4	0.48	0.26	2.6	1.20	1.3
Phosphorus	%	0.47	0.34	0.25	0.57	0.59	0.49
Potassium	%	3.1	1.70	2.24	3	2.20	1.98
Sulphur	%	0.53	0.30	0.24	0.56	0.42	0.62

[1]Protein is N x 6.25

In terms of bio-accumulation of heavy metals, Cu and Zn content seems to be the only concern, three-year average levels of metals in forage cut from biosolids applied site were more than twice the levels of those metals in biomass from no-biosolid control block for the same period (Table 9) however they are well below the Receiving Soil Contaminant Limits (Table 7).

Foliage Cd contents remained more or less the same regardless of biosolids application.

Table 9: Heavy metals in forage samples

Parameter	Units	Control Area (No biosolids)			Biosolids Application Area Mean value		
		2015	2016	2017	2015	2016	2017
Arsenic (As)	mg/kg	<1	n.a.	n.a.	<1	n.a.	n.a.
Cadmium (Cd)	mg/kg	<0.1	0.04	<0.1	<0.1	0.03	<0.1
Chromium (Cr)	mg/kg	<1	n.a.	n.a.	<1	n.a.	n.a.
Copper (Cu)	mg/kg	9	5	7	15	14	16
Lead (Pb)	mg/kg	<1	n.a.	n.a.	<1	n.a.	n.a.
Mercury (Hg)	mg/kg	<0.1	n.a.	n.a.	<0.1	n.a.	n.a.
Nickel (Ni)	mg/kg	<1	n.a.	n.a.	<1	n.a.	n.a.
Selenium (Se)	mg/kg	<0.1	n.a.	n.a.	<0.1	n.a.	n.a.
Zinc (Zn)	mg/kg	40	20	19	72	57	62

Surface and ground water

Apart from the biosolids application to the dryland demonstration site, other sections of Bald Hill Farm (Figure 3) also received biosolids in the past, in addition to the use of recycled water for irrigation purposes. Currently there are no signs of adverse effects resulting from both biosolids use and recycled water use at Bald Hill Farm on the quality of groundwater and surface water (Deep Creek). A detailed investigation on surface and groundwater quality, and contaminant levels across the soil profile at Bald Hill Farm is currently being planned by SEW to confrim this.

Summary

This case study is a successful demonstration of effective and sustainable utilisation of a locally available resource such as biosolids in local agriculture to improve farming outcomes in the region. The Bald Hill Farm demonstration (dryland paddock) has been a showcase for how to manage potential environmental risks associated with recurrent application of biosolids through adoption of best practices combined with an implementation appropriate control and monitoring frameworks supported by science.

The most important finding from the current case study is that despite the applications of biosolids for three consecutive years in the same patch of land (dryland paddock), contaminants levels in the soils and plant biomass remained within the environmentally safe levels while improving ability of the land to produce better quality pastures for farm animals.

Key learnings from the Bald Hill Farm demonstration

- Application of biosolids; a locally available resource rich in nutrients, has shown to improve soil fertility on the area it was applied.
- Biosolids applied soils have the capacity to produce consistently better quality forage.
- Fertiliser value and contaminant potential of biosolids can vary significantly depending on the source of the material.
- Detailed characterisation (i.e. pathogenic and contaminant risks) of biosolids and receiving soils and carefully planned Environmental Improvement Plan (EIP) covering all aspects of the environment (soil, water and vegetation) is the key to ensure environmentally safe input levels of biosolids and minimise the accumulation of environmental pollutants such as heavy metals in the landscape.

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