

Supplementary File: A review on occurrence and spread of antibiotic resistance in wastewaters and in wastewater treatment plants: Mechanisms and perspectives

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16 **Keywords: antibiotics, antibiotic resistance genes, antibiotic resistant bacteria, spread**
17 **mechanisms, wastewater treatment plant**

Supplementary Table 1: Bacteria, resistant bacteria, and resistance genes remaining in biosolids after different treatment methods

Sludge/biosolids treatment, Wastewater plant	Resistant bacteria			Resistance genes (total cellular + free DNA)			Wastewater treatment process, source of biosolids, sludge treatment, measurement methods and other notes	Ref.
Belt press dewatering								
East Lansing, Michigan, USA (cake 18.05% solids) *	Total	CFU/g	$10^{10.0} - 10^{11.7}$	Total (16S rRNA)	copies/g	$10^{11.5} - 10^{12.1}$	Activated sludge treatment, biosolids from a mix of primary sludge and activated sludge dewatered by belt press only. Bacteria numbers by heterotrophic plate count on R2A media with antifungal cyclohexamide (200 ug/ml), gene copy numbers from qPCR, numbers per gram of biosolids (wet or dry weight not specified), absolute ranges from n = 3 samples taken at different times of the year. Biosolids disposed to landfill.	#: (Munir et al., 2011) PT&TP: (City of East Lansing Webpages, 2009; Munir et al., 2011)
	<i>tet</i> resistant (16 ug/mL <i>tet</i>)	CFU/g	$10^{7.4} - 10^{8.3}$	<i>tetW</i> <i>tetO</i>	copies/g copies/g	$10^{8.0} - 10^{8.5}$ $10^{8.8} - 10^{9.3}$		
	<i>sul</i> resistant (50.4 ug/ml <i>sul</i>)	CFU/g	$10^{8.7} - 10^{9.1}$	<i>sull</i>	copies/g	$10^{6.9} - 10^{9.2}$		
Gravity thickening								
Imlay, Michigan, USA (slurry 1.49% solids) *	Total	CFU/g	$10^{9.5} - 10^{10.0}$	Total (16S rRNA)	copies/g	$10^{12.6} - 10^{12.7}$	Oxidation ditch treatment, biosolids from unknown sludge mix, gravity thickening only. Bacteria numbers by heterotrophic plate count on R2A media with antifungal cyclohexamide (200 ug/ml), gene copy numbers from qPCR, numbers per gram of biosolids (wet or dry weight not specified), absolute ranges from n = 2 samples taken at different times of the year. Biosolids used as fertilizer on agricultural land.	#: (Munir et al., 2011) PT&TP: (Imlay City Webpages, 2020)
	<i>tet</i> resistant (16 ug/mL <i>tet</i>)	CFU/g	$10^{7.0} - 10^{9.0}$	<i>tetW</i> <i>tetO</i>	copies/g copies/g	$10^{8.7} - 10^{8.9}$ $10^{8.7} - 10^{8.9}$		
	<i>sul</i> resistant (50.4 ug/ml <i>sul</i>)	CFU/g	$10^{8.0} - 10^{9.3}$	<i>sull</i>	copies/g	$10^{7.5} - 10^{9.4}$		
Anaerobic digestion								
Romeo, Michigan, USA (slurry 7.98% solids) Traverse city, Michigan, USA (slurry 4.85% solids)	Total	CFU/g	$10^{7.3} - 10^{9.5}$	Total (16S rRNA)	copies/g	$10^{12.0} - 10^{12.6}$	Combined data from the Romeo and the Traverse city plants. Rotating biological contactors (Romeo) with biosolids from unknown sludge mix. Aeration basin and membrane biological reactor (Traverse city) with biosolids from a mix of primary sludge and activated sludge dewatered by a gravity	#: (Munir et al., 2011) PT&TP:
	<i>tet</i> resistant (16 ug/mL <i>tet</i>)	CFU/g	$10^{4.6} - 10^{5.7}$	<i>tetW</i> <i>tetO</i>	copies/g copies/g	$10^{7.8} - 10^{9.6}$ $10^{7.1} - 10^{8.4}$		

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*	<i>sul</i> resistant	CFU/g	$10^{6.7} - 10^{7.2}$	<i>sulI</i>	copies/g	$10^{7.6} - 10^{8.2}$	belt concentrator before digestion. Bacteria numbers by heterotrophic plate count on R2A media with antifungal cyclohexamide (200 ug/ml), gene copy numbers from qPCR, numbers per gram of biosolids (wet or dry weight not specified), interquartile ranges from n = 7 samples in total taken from different times of the year (unspecified how many samples from each site). Temperature during anaerobic digestion unspecified.	(Munir et al., 2011; Traverse City/Jacobs, 2018)
Guadarrama Medio, Brunete, Madrid, Spain (cake 16.5% solids)	Total	CFU/g	$10^{11.2}$				Biosolids used as fertilizer on agricultural land. Activated sludge treatment, biosolids from a mix of primary sludge and activated sludge. Gravity thickening of the sludge before digestion. Two stage digestion with heating. Mechanical dewatering of biosolids by centrifuges and thermal drying. Bacteria numbers by heterotrophic plate count on R2A media with antifungal cyclohexamide (200 ug/ml), fecal coliforms numbers by plate count on TTC medium. Numbers per gram dry weight of biosolids, average numbers from unknown number of samples. Temperature during anaerobic digestion unspecified.	#: (Gondim-Porto et al., 2016)
	<i>amp</i> resistant	CFU/g	$10^{8.8}$					PT&TP: (Gondim-Porto et al., 2016; Canal de Isabel II S.A., 2017)
	Fecal coliforms	CFU/g	$10^{8.6}$					
Galt, Ontario, Canada (slurry 4.9% solids)				Total (rrnS)	copies/g	$10^{10.1}$	Biosolids used as fertilizer on agricultural land. Activated sludge treatment, biosolids from a mix of primary sludge and mechanically thickened activated sludge. Total coliforms, fecal coliforms, and <i>E. coli</i> numbers by plate count on mEndo-LES medium, mFC medium, and MFC-BCIG medium respectively. Gene copy numbers from qPCR. Numbers per gram dry weight of biosolids. Average numbers from n = 3 samples for bacteria count and n = 4 samples for gene numbers. Temperature during anaerobic digestion unspecified.	#: (Lau et al., 2017)
				<i>sulI</i>	copies/g	$10^{9.9}$		PT&TP: (Lau et al., 2017; Region of Waterloo, 2018)
				<i>strA</i>	copies/g	$10^{8.5}$		
				<i>strB</i>	copies/g	$10^{7.4}$		
	Total coliforms	CFU/g	$10^{6.5}$					
Galt, Ontario, Canada (cake 30.1% solids)	Fecal coliforms	CFU/g	§ $< 10^{3.6}$				Biosolids used as fertilizer on agricultural land and for remediation of mine tailing ponds from mining industry. Landfill as contingency option. Activated sludge treatment, biosolids from a mix of primary sludge and mechanically thickened activated sludge. Mechanical dewatering of biosolids by centrifuges. Total coliforms, fecal coliforms, and <i>E. coli</i> numbers by plate count	#: (Lau et al., 2017)
	<i>E. coli</i>	CFU/g	§§ $< 10^{2.3}$					

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				<i>sull</i>	copies/g	10 ^{7.4}	on mEndo-LES medium, mFC medium, and MFC-BCIG medium respectively. Gene copy numbers from qPCR. Numbers per gram dry weight of biosolids. Average numbers from n = 3 samples for bacteria count and n = 4 samples for gene numbers. Temperature during anaerobic digestion unspecified.	PT&TP: (Lau et al., 2017; Region of Waterloo, 2018)
				<i>strA</i>	copies/g	10 ^{6.7}	Biosolids used as fertilizer on agricultural land and for remediation of mine tailing ponds from mining industry. Landfill as contingency option.	
				<i>strB</i>	copies/g	10 ^{5.6}		
Total coliforms CFU/g						10 ^{6.6}		
Fecal coliforms CFU/g						10 ^{6.0}		
<i>E. coli</i> CFU/g						10 ^{5.8}		
Aerobic digestion								
Campo Real, Madrid, Spain (cake 14.2% solids)	Total	CFU/g	10 ^{11.2}				Activated sludge treatment, biosolids from unknown sludge mix. Gravity thickening of the sludge before digestion. Biosolids are air-dried after digestion. Bacteria numbers by heterotrophic plate count on R2A media with antifungal cyclohexamide (200 ug/ml), fecal coliforms numbers by plate count on TTC medium. Numbers per gram dry weight of biosolids, average numbers from unknown number of samples. Temperature during aerobic digestion unspecified.	#: (Gondim-Porto et al., 2016)
**	<i>amp</i> resistant (32 ug/mL Amp)	CFU/g	10 ^{9.1}					PT&TP: (Gondim-Porto et al., 2016; Canal de Isabel II S.A., 2017)
	Fecal coliforms	CFU/g	10 ^{6.8}					
Tillsonburg, Ontario, Canada (slurry 1.6% solids)				Total (rrnS)	copies/g	10 ^{10.2}	Biosolids used as fertilizer on agricultural land. Activated sludge treatment, biosolids from unknown sludge mix. Aerobic digestion. Total coliforms, fecal coliforms, and <i>E. coli</i> numbers by plate count on mEndo-LES medium, mFC medium, and MFC-BCIG medium respectively. Gene copy numbers from qPCR. Numbers per gram dry weight of biosolids. Average numbers from n = 3 samples for bacteria count and n = 4 samples for gene numbers. Temperature during aerobic digestion unspecified.	#: (Lau et al., 2017)
***				<i>sull</i>	copies/g	10 ^{10.6}		PT&TP: (Oxford County; Lau et al., 2017; Oxford Country, 2017)
				<i>strA</i>	copies/g	10 ^{8.9}		
				<i>strB</i>	copies/g	10 ^{7.8}		
	Total coliforms	CFU/g	10 ^{6.6}					
	Fecal coliforms	CFU/g	10 ^{5.4}					
	<i>E. coli</i>	CFU/g	§ < 10 ^{3.6}					
Tillsonburg, Ontario, Canada (cake 17.7 % solids)				Total (rrnS)	copies/g	10 ^{8.8}	Biosolids used as fertilizer on agricultural land. Activated sludge treatment, biosolids from unknown sludge mix. Aerobic digestion followed by dewatering by centrifuges. Total coliforms, fecal coliforms, and <i>E. coli</i> numbers by plate count on mEndo-LES medium, mFC medium, and MFC-BCIG medium respectively. Gene copy	#: (Lau et al., 2017)
***				<i>sull</i>	copies/g	10 ^{9.3}		PT&TP: (Oxford County; Lau et al., 2017;
				<i>strA</i>	copies/g	10 ^{7.9}		
	Total coliforms	CFU/g	10 ^{6.7}	<i>strB</i>	copies/g	10 ^{6.7}		

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	Fecal coliforms	CFU/g	10 ^{6.3}				numbers from qPCR. Numbers per gram dry weight of biosolids. Average numbers from n = 3 samples for bacteria count and n = 4 samples for gene numbers. Temperature during aerobic digestion unspecified.	Oxford Country, 2017)	
	<i>E. coli</i>		10 ^{6.2}						
	CFU/g						Biosolids used as fertilizer on agricultural land.		
Lime stabilization									
Lansing, Michigan, USA	Total	CFU/g	10 ^{9.0} – 10 ^{9.4}	Total	copies/g	10 ^{11.5} – 10 ^{12.3}	Activated sludge treatment, biosolids from unknown sludge mix. Bacteria numbers by heterotrophic plate count on R2A media with antifungal cyclohexamide (200 ug/ml), gene copy numbers from qPCR, numbers per gram of biosolids (wet or dry weight not specified), absolute ranges from n = 2 samples taken at different times of the year.	#: (Munir et al., 2011)	
Lime stabilization only (slurry 9.2% solids) (pH unknown)	<i>tet</i> resistant	CFU/g	10 ^{5.4} – 10 ^{5.6}	<i>tetW</i>	copies/g	10 ^{7.3} – 10 ^{8.3}			
	(16 ug/mL Tet)			<i>tetO</i>	copies/g	10 ^{7.4} – 10 ^{7.6}			
*	<i>sul</i> resistant	CFU/g	10 ^{7.2} – 10 ^{8.0}	<i>sulI</i>	copies/g	10 ^{6.8} – 10 ^{7.0}		PT&TP: (Munir et al., 2011)	
	(50.4 ug/ml Sul)						Biosolids used as fertilizer on agricultural land.		
Advanced lime stabilization									
St. Marys, Ontario, Canada				Total	copies/g	10 ^{8.4}	Activated sludge anoxic/oxic biological treatment. Biosolids from gravity thickened wasted activated sludge. The thickened sludge is dosed with polymer and dewatered by centrifuges. Dewatered sludge is run through the proprietary Lystek process which involves a combination of heat, alkali, and high shear mixing. Total coliforms, fecal coliforms, and <i>E. coli</i> numbers by plate count on mEndo-LES medium, mFC medium, and MFC-BCIG medium respectively. Gene copy numbers from qPCR. Numbers per gram dry weight of biosolids. Average numbers from n = 3 samples for bacteria count and n = 3 samples for gene numbers.	#: (Murray et al., 2019)	
Lystek proprietary process				<i>sulI</i>	copies/g	10 ^{8.0}			
alkali + heat + high shear				<i>strA</i>	copies/g	10 ^{8.2}			
mixing				<i>strB</i>	copies/g	10 ^{6.8}			
(LysteGro)									
(slurry 10.8% solids)	Total coliforms	CFU/g	10 ^{4.1}				Biosolids marketed as LysteGro and used as fertilizer on agricultural land.	PT&TP: (Lystek International; Hornick and Blake, 2019)	
(pH 7.9 in final product)	Fecal coliforms	CFU/g	10 ^{3.8}						
	<i>E. coli</i>	§§	< 10 ^{2.3}						
	CFU/g								
Thorold, Ontario, Canada				Total	copies/g	10 ^{5.2}	Niagara Biosolids Processing Facility in Thorold, Ontario, which receives dewatered anaerobic digested sludge (typically 30% solids) from treatment plants in the Niagara Region and from the City of Toronto. The biosolids are mixed with cement kiln dust (primarily calcium oxide), byproduct	#: (Murray et al., 2019)	
Anaerobic digestion + lime				<i>sulI</i>	copies/g	§§ < ≈10 ⁴			PT&TP:
stabilization + heat drying									
(N-Viro/N-Rich)									

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(dry granulate 59.3% solids) (pH 11.3 in final product)					<i>strA</i>	copies/g	§§	< ≈10 ⁴	from a nearby cement plant. The reaction is exothermic and raises the temperature (temperature unspecified), and it also raises the pH to about 12. This mix is then dried in a direct-fired rotary dryer system for 10 min (temperature unspecified). Plant operated by Walker Industries and uses their N-Viro process. Total coliforms, fecal coliforms, and <i>E. coli</i> numbers by plate count on mEndo-LES medium, mFC medium, and MFC-BCIG medium respectively. Gene copy numbers from qPCR. Numbers per gram dry weight of biosolids. Average numbers from n = 3 samples for bacteria count and n = 3 samples for gene numbers.	(Gunn, 2015; Walker Industries, 2017)
					<i>strB</i>	copies/g	§§	< ≈10 ⁴		
	Total coliforms	CFU/g	§§	< 10 ^{2.3}						
	Fecal coliforms	CFU/g	§§	< 10 ^{2.3}						
	<i>E. coli</i>	CFU/g	§§	< 10 ^{2.3}						
Biosolids marketed as N-Rich and used as fertilizer on agricultural land.										
Heat drying										
Windsor, Ontario, Canada (dry pellets 95.3 % solids) (2014)					Total (rrnS)	copies/g		10 ^{9.1}	Pellets produced at Windsor Biosolids Processing Facility, which receives dewatered and centrifuged biosolids (approx. 30% solids) from two WWTPs: Little River Pollution Control Plant and Lou Romano Water Reclamation Plant. The two WWTPs uses activated sludge treatment, with biological aerated filters at Lou Romano and aeration tanks at Little River. The biosolids are from a mix of primary and activated sludge. The biosolids are further heat dried and pelletized at the Windsor Biosolids Processing Facility. Total coliforms, fecal coliforms, and <i>E. coli</i> numbers by plate count on mEndo-LES medium, mFC medium, and MFC-BCIG medium respectively. Gene copy numbers from qPCR. Numbers per gram dry weight of biosolids. Average numbers from n = 3 samples for bacteria count and n = 4 samples for gene numbers. Temperature during heat drying 400 – 450 °C with a typical retention time of 20 min.	#: (Lau et al., 2017) PT&TP: (City of Windsor; Lau et al., 2017)
					<i>sull</i>	copies/g		10 ^{8.4}		
					<i>strA</i>	copies/g		10 ^{7.4}		
					<i>strB</i>	copies/g		10 ^{6.3}		
	Total coliforms	CFU/g	§§	< 10 ^{2.3}						
Fecal coliforms	CFU/g	§§	< 10 ^{2.3}							
<i>E. coli</i>	CFU/g	§§	< 10 ^{2.3}							
Biosolids used as fertilizer on agricultural land.										
Windsor, Ontario, Canada (dry pellets 93.2% solids) (2017)					Total (rrnS)	copies/g		10 ^{8.6}	Pellets produced at Windsor Biosolids Processing Facility, which receives dewatered and centrifuged biosolids (approx. 30% solids) from two WWTPs: Little River Pollution Control Plant and Lou Romano Water Reclamation Plant. The two	#: (Murray et al., 2019)
					<i>sull</i>	copies/g		10 ^{8.1}		

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				<i>sull</i>	copies/g	§§	< 10 ^{3.9}	from qPCR. Numbers are reported per gram dry weight of the biochar remains after pyrolysis.	PT&TP: (Kimbell et al., 2018)
Soil (for comparison)									
Nebraska, USA	Total	CFU/g	10 ^{5.0} – 10 ^{5.9}					Soil from native prairies where landowners could confirm no grazing by food animals for the last 20 years. Total and resistant bacteria numbers by heterotrophic plate count on R2A media. Coliforms and <i>E.coli</i> enumerated using Quantitray (IDEXX Laboratories). Gene copy numbers from qPCR. Numbers per gram dry weight. 20 different sites/prairies studied. The ranges given are the minimum to maximum of the average numbers for each site. 99 of 100 samples had <i>E. coli</i> levels lower than 1 CFU/g.	#: (Durso et al., 2016)
Ungrazed native prairie soil	<i>tet</i> resistant (16 ug/mL Tet)	CFU/g	10 ^{4.1} – 10 ^{5.6}	<i>tetA</i>	copies/g	10 ^{4.2} – 10 ^{5.3}			
*6	Total coliforms <i>E. coli</i>	CFU/g	10 ^{2.3} – 10 ^{4.2} < 1	<i>sull</i>	copies/g	10 ^{3.0} – 10 ^{3.4}			
Tartu, Estonia	Total	copies/g	10 ^{8.0} – 10 ^{8.2}	(16S rRNA)				Experimental field plots with grass. No fertilizer applied for 4 years before the experiment; before that sporadic application of mineral fertilizer. Gene copy numbers from qPCR. Numbers per gram dry weight of soil. 25-75% ranges from 33 soil samples over a time period 151 days.	#: (Nölvak et al., 2016)
“Eerika” experimental station				<i>tetA</i>	copies/g	10 ^{4.8} – 10 ^{5.1}			
Estonian University of Life Science				<i>sull</i>	copies/g	< 10 ^{3.0}			
Arganda del Rey, Spain	Total	CFU/g	10 ^{9.0}					Experimental field plots. No information about history of previous applications of manure, biosolids, or artificial fertilizers. Bacteria numbers by heterotrophic plate count on R2A media with antifungal cyclohexamide (200 ug/ml), fecal coliforms numbers by plate count on TTC medium. Numbers per gram dry weight of soil, average numbers from unknown number of samples.	#: (Gondim-Porto et al., 2016)
“La Isla” experimental farm	<i>amp</i> resistant (32 ug/mL Amp)	CFU/g	10 ^{8.4}						
	Fecal coliforms	CFU/g	10 ^{4.4}						
London, Ontario, Canada	Total	copies/g	10 ^{8.6}	(rrnS)				Experimental field plots previously cropped with mixed grains and with no known history of manure or biosolids applications. Total and fecal coliforms numbers by plate count on mEndo-LES medium and mFC medium, respectively. Gene copy numbers from qPCR. Numbers are per gram wet weight of soil and the average from 3 fields with different crop types (lettuce, radish, and carrot) each sampled at different times throughout the growth season, 8 samples per field. Total of n = 24 samples.	#: (Lau et al., 2017) (Tabs. S12 and S14)
Environmental Science Western Field Station				<i>sull</i>	copies/g	(n=9) 10 ^{5.7} §§ (n=15) < 10 ^{3.9}			
	Total coliforms	CFU/g	(n=23) 10 ^{3.0} § (n=1) < 10 ^{1.9}	<i>strA</i>	copies/g	(n=2) 10 ^{4.1} §§ (n=22) < 10 ^{3.9}			
	Fecal coliforms	CFU/g	(n=10) 10 ^{2.6} § (n=14) < 10 ^{1.9}	<i>strB</i>	copies/g	(n=1) 10 ^{4.2} §§ (n=23) < 10 ^{3.9}			

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In the measurement of resistance genes 15 samples (Sul-I), 22 samples (Str-A), and 23 samples (Str-B) were below the detection limit of $10^{3.9}$ copies/(g wet soil).

The table includes levels of resistant bacteria and resistance genes reported in the literature for resistance against four selected antibiotics: *ampicillin (amp)*, *tetracycline (tet)*, *sulfonamide (sul)*, and *streptomycin (str)*. In addition to the numbers reported from the scientific literature (references marked with #), we have also gathered extended information on plant type, treatment processes, sludge sources, and the normal use of biosolids from each plant from public reports and webpages from municipalities and plant operators (references marked with PT&TP). We have designated sludge/biosolids with solids content below 12% as slurry, sludge/biosolids with solids content from 12-55% as cake, and biosolids with solids content above 55% as dry.

Note that the more advanced methods are not used instead of the simple methods listed at the top of the table, but in addition. E.g., thickened/dewatered sludge is used as input for aerobic or anaerobic digestion, and heat drying is done with sludge that has already been digested and/or thickened/dewatered.

Numbers originally reported as ranges are given as ranges with a note detailing whether the range is absolute (min-max), quartiles, or in any other format. Numbers given as averages are reported as a single average number, and variance numbers are disregarded as there is inconsistency on how these are reported (e.g., as variance, as standard deviation (SD), or even as standard error of the mean (SEM)) and from how many samples they are calculated. All numbers are rounded to one decimal digit in the exponent. All gene numbers are total, most studies do not distinguish between cellular DNA and external DNA.

* These plants showed a significant reduction of resistance genes (copies/100ml) and a significant reduction of resistant bacteria (CFU/100ml) from the raw influent sewage to the treated water effluent, but no significant reduction of resistance genes nor resistant bacteria from the raw influent sewage to the sludge biosolids (Munir et al., 2011).

** It is unknown whether the sludge is aerobically digested in a digester, or if the aerobic digestion happens during or as part of an air-drying process (the sludge is aerobically digested according to (Gondim-Porto et al., 2016), but no specific information about an aerobic digester is found on the plant fact sheet from the operator (Canal de Isabel II S.A., 2017)).

*** Note that the gene copy numbers from this study indicate that the aerobic biosolids contains a roughly 3 times higher number of *sul1* genes than *rrnS* genes which were used as a reference for total amount of bacteria. The authors of the study do not comment on this anomaly. However, in their Supplementary Material they report that 0.0018 copies of *sul1* genes was detected for each copy of the 16S rRNA gene (reference for total amount of bacteria) in a sample of aerobic slurry analyzed by a different method (next generation sequencing) (Lau et al., 2017).

**** The density of living bacteria in the pelletized biosolids from Windsor are below the detection limits in this study, but the number of genes still seems relatively high. However, the same study reports that the abundance of the same gene targets quantified in agricultural soil directly (2-hours, + 24-48 hours storage at 4° C) after application of the pelletized material was remarkably low compared to digested slurry or cake biosolids from other plants. The authors hypothesize that the DNA are carried in non-viable cells or as free DNA segments with lower than normal stability (due to the heat treatment) in the pellets and that it is rapidly destroyed following contact with soil (Lau et al., 2017).

*5 The biosolids from the Windsor Biosolids Pelletizing Facility was tested in both 2014 (Lau et al., 2017) and 2017 (Murray et al., 2019). The plant was built in 1999 and operated from 1999-2019 by American Water (formerly Prism-Berlie) (City of Windsor, 2020). The treatments and processing involved to create the pelletized biosolids have to the authors' knowledge not changed from 2014 to 2017 (Lau et al., 2017; Murray et al., 2019; City of Windsor, 2020).

*6 The Tet-A range is from 18 of 20 of the different prairies, *tetA* was not detected in 2 of the prairies.

§ Numbers below quantification limit, quantification limit given in the respective table cell.

§§ Numbers below detection limit, detection limit given in the respective table cell.

References for numbers of bacteria and genes.

PT&TP References for plant type and treatment processes.

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