



Biennial Review of 40 CFR Part 503 As Required Under the Clean Water Act Section 405(d)(2)(C)

**Reporting Period
2013 Biosolids Biennial Review**

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As Required Under the Clean Water Act Section
405(d)(2)(C)**

Reporting Period Biosolids Biennial Review 2013

U.S. Environmental Protection Agency
Office of Water
Office of Science and Technology
Washington, D.C.

May 2018

NOTICE

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This document can be downloaded from EPA's website at <http://www.epa.gov/biosolids>

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Executive Summary

In 1993, the U.S. Environmental Protection Agency (EPA) promulgated regulations in 40 CFR Part 503 for sewage sludge¹, as amended, that include general requirements, pollutant limits, management practices, operational standards, and requirements for monitoring, recordkeeping and reporting. Section 405(d)(2)(C) of the Clean Water Act (CWA) states that EPA shall review the biosolids regulations not less often than every two years for the purpose of identifying additional toxic pollutants and promulgating regulations for such pollutants consistent with the requirements of section 405(d).

In fulfilling this commitment for the 2013 biennial review cycle, EPA collected and reviewed publicly available information on the occurrence, fate and transport in the environment, human health and ecological effects, and other relevant information for toxic pollutants that may occur in U.S. biosolids. After conducting the review, if such data are available for pollutants that may occur in biosolids, the Agency will assess the potential risk to human health or the environment associated with exposure to such pollutants when biosolids are applied to land as a fertilizer or soil amendment, placed in a surface disposal site, or incinerated, and, if appropriate, EPA will set numeric limits for these pollutants.

This review process included information collected for pollutants that (1) have been identified in the Targeted National Sewage Sludge Survey (TNSSS; U.S. EPA, 2009) or in the open literature as having concentration data for biosolids or other evidence of occurrence in biosolids, and (2) have not been previously regulated or evaluated (e.g., as potentially causing harm to humans or the environment) in biosolids. Using this search approach, 77 new articles were identified as providing relevant information for pollutants that may occur in U.S. biosolids. Thirty-five new chemicals and six new microbial pollutants were identified in biosolids in this 2013 Biennial Review. Thirteen of the newly identified chemicals are perfluoroalkyl substances (PFASs). No human health toxicity data were identified for any of the 35 new chemicals or for chemicals identified in previous biennial reviews. However, EPA is currently engaged in efforts around PFAS, including developing toxicity values for certain PFAS chemicals. Ecological toxicity values were found for one chemical (triclosan) identified in a previous biennial review. New physical-chemical properties (log K_{ow} and half-life) were identified for 22 chemicals. New bioaccumulation factors were identified for five previously identified chemicals.

The available data for many of the chemicals and microbial pollutants identified are not sufficient at this time to evaluate risk using current biosolids modeling tools. EPA will continue to evaluate available toxicological information for PFASs. In addition, the EPA's Office of Pesticide Programs plans to complete a draft risk assessment for triclosan in late 2018². The Federal Drug Administration and EPA have been closely collaborating on scientific and regulatory issues related to triclosan to ensure government-wide consistency in the regulation of this chemical.

¹ EPA often uses the term "biosolids" interchangeably with "sewage sludge," which is defined in the regulations and used in the statute. Biosolids refers to treated sewage sludge.

² See additional information on triclosan on EPA's website (<https://www.epa.gov/ingredients-used-pesticide-products/triclosan>)

EPA has not identified any additional toxic pollutants for potential regulation during the 2013 Biosolids Biennial Review. The Agency will continue to assess the availability of sufficient information for these and other pollutants identified during the biennial review activities pursuant to section 405(d)(2)(C) of the CWA.

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1. Introduction

In Section 405 of the Clean Water Act (CWA), Congress set forth a comprehensive program designed to reduce potential health and environmental risks associated with using or disposing of sewage sludge. Under Section 405(d), the U.S. Environmental Protection Agency (EPA) establishes numeric limits and management practices that protect public health and the environment from the reasonably anticipated adverse effects of chemical and microbial pollutants in sewage sludge. Section 405(d) prohibits any person from using or disposing of sewage sludge from publicly owned treatment works (POTWs) or other treatment works treating domestic sewage, unless the use or disposal complies with regulations promulgated under section 405(d).

On February 19, 1993, EPA identified several pollutants which, based on available information on their toxicity, persistence, concentration, mobility, or potential for exposure, were present in sewage sludge in concentrations which may adversely affect public health or the environment. At that time, the Agency promulgated regulations, 40 CFR Part 503 *Standards for the Use or Disposal of Sewage Sludge*, specifying acceptable management practices, numeric standards for 10 metals (arsenic, cadmium, chromium III, copper, lead, mercury, molybdenum, nickel, selenium, and zinc), and operational standards for microbial organisms (58 FR 9248).

The 1993 rule also established requirements for the final use or disposal of sewage sludge when it is: (1) applied to land as a fertilizer or soil amendment; (2) placed in a surface disposal site, including sewage sludge-only landfills; or (3) incinerated. These requirements apply to publicly and privately owned treatment works that generate or treat domestic sewage sludge and to anyone who manages sewage sludge. The rule also requires monitoring, record keeping, and reporting of specific information regarding sewage sludge management.

Section 405(d)(2)(C) of the CWA requires EPA to review the biosolids regulations not less often than every two years for the purpose of identifying additional toxic pollutants and promulgating regulations for such pollutants consistent with the requirements of section 405(d). Prior to the reports known as “biennial reviews,” in order to fulfill this requirement the Agency made the following decisions and observations: (1) In 2001, EPA decided that regulation of dioxin and dioxin-like compounds disposed via incineration or land-filling was not needed for adequate protection of public health and the environment (66 FR 66227); (2) In 2003, EPA determined that regulation of dioxin and dioxin-like compounds in land-applied sewage sludge was not needed for adequate protection of public health and the environment (68 FR 61084); and (3) In conducting the biennial review for 2003 (68 FR 75531), EPA identified nine pollutants (barium, beryllium, manganese, silver, fluoranthene, pyrene, 4-chloroaniline, nitrate, and nitrite) for evaluation. Molybdenum was also added for reevaluation in 2003. Summaries of the evaluations and past biennial reviews are available on EPA’s Web site at <http://www.epa.gov/biosolids>.

For the 2013 Biennial Review, EPA searched publicly available information in databases and articles published in English in refereed journals from July 2011 through December 2013. The purpose of reviewing this information is to identify pollutants found in biosolids in this timeframe and to assess the availability and sufficiency of the data for conducting risk assessments. After conducting the review, if such data are available for pollutants that may occur in biosolids, the Agency will assess the potential risk to human health or the environment associated with exposure to such pollutants when biosolids are applied to land as a fertilizer or soil amendment, placed in a surface disposal site, or incinerated to determine whether to regulate the pollutants.

To inform the risk assessments of pollutants in biosolids, EPA typically uses models that require data from three major categories:

- **Toxicity to human and ecological receptors.** For human toxicity, this type of data include values such as a reference dose, reference concentration, cancer slope factor, or inhalation unit risk. For ecological toxicity, it includes values such as lethal dose, lethal concentration, or chronic endpoints related to fecundity.
- **Concentration data for pollutants in biosolids.** Both the ability to detect a given pollutant in biosolids and the determination of the concentration at which that pollutant is present are highly dependent on the existence of analytical methods for that pollutant in the biosolids matrix.
- **Environmental Fate and transport data for pollutants that may be present in biosolids.** These data are necessary for assessing exposure. Examples of chemical and physical properties that may be considered, depending on the nature of a given pollutant in biosolids, include:
 - Molecular weight
 - Solubility
 - Vapor pressure
 - Henry's law constant
 - Soil-water partitioning coefficients
 - Soil adsorption coefficients (K_d and K_{oc})
 - Degradation rates in various media
 - Log octanol-water partition coefficients ($\text{Log } K_{ow}$)
 - Diffusivities in air and water
 - Bioavailability
 - Air-to-plant transfer factors
 - Root uptake factors for above ground vegetation
 - Root concentration factors
 - Bioconcentration factors for animal products (e.g., meat and milk).

2. Literature Search Approach

To determine if data are available to evaluate human health risks or ecological risks, EPA searched databases and the published literature for articles in English in refereed journals from July 2011 through December 2013 to identify data sources published since the previous search performed in support of the 2011 Biosolids Biennial Review (EPA-830-R-13-009).

The bibliographic databases searched included PubMed, Science Citation Index Expanded (Web of Science), Toxline, Aquatic Sciences and Fisheries Abstracts, Biological Sciences Database, Environmental Sciences and Pollution Management, and Soil Science journal website. The data search included a combination of the following key words:

Biosolids-related keywords: (sewage sludge OR biosolids OR treated sewage OR sludge treatment OR sewage treatment)

AND

Pollutant- and health-related keywords: (pollutant* OR toxic* [toxicant, toxicology, etc.] OR pathogen* OR concentration* OR propert* OR fate OR transport OR health OR ecolog* OR effect OR effects OR micro* [microbial, etc.] OR *Salmonella*)

AND

Geographic keywords (limiters): (United States OR Canada OR USA OR U.S.A. OR U.S. OR US)

AND

Land Application-related keywords: (land application OR farm OR agriculture OR soil)

AND

Health-related keywords: (occurrence OR concentration OR properties OR fate OR transport OR health effects OR ecological effects).

In addition to the bibliographic databases searched, EPA also employed the search strategies described in **Sections 2.1** and **2.2** for human health toxicity values and ecological toxicity values, respectively.

The Agency applied an abstract screening process to the initial group of articles identified. Articles that included pollutants that fit the following criteria were formally reviewed:

- Identified in the Targeted National Sewage Sludge Survey (TNSSS; U.S. EPA, 2009) or the open literature as having concentration data or other evidence of occurrence in biosolids (see **Attachments A**).

- Not previously regulated or evaluated for biosolids.³

In the formal review process, articles addressing previously identified pollutants that appeared to provide new data on their behavior in the environment or toxicity were included. Articles were excluded from further review for any one of four reasons:

- The study addressed toxicity through a medium other than biosolids (e.g., wastewater effluent).
- The study was conducted in a country other than the United States or Canada.
- The study only described an analytical method.
- An abstract was not available and the title alone did not provide sufficient evidence for inclusion.

International studies that examined the occurrence of pollutants in biosolids were excluded from consideration, because treatment technologies and regulatory requirements in other countries are not necessarily representative of the United States. However, Canadian studies that examined the fate and transport of pollutants from agriculturally applied biosolids in soils were included because of the expected similarities in Canadian and U.S. soil types. Additionally, the Canadian governmental research group, Agriculture and Agri-Food Canada, has conducted numerous studies of interest on the fate and transport of pharmaceuticals and personal care products in agricultural soils.

2.1 Human Health Toxicity Values Data Sources and Selection

To estimate the potential for adverse human health risks from agricultural land application of biosolids, EPA assesses chronic oral and inhalation exposures. EPA uses reference doses (RfDs) and reference concentrations (RfCs) to evaluate non-cancer risk from oral and inhalation exposures, respectively. EPA uses oral cancer slope factors (CSFs) and inhalation unit risks (IURs) to evaluate risk for carcinogens from oral and inhalation exposures.⁴

The Integrated Risk Information System (IRIS; U.S. EPA, 2016a) is EPA's primary repository for human health toxicity values that have been developed specifically for human health risk assessment using standardized methods⁵ and have been thoroughly peer reviewed. IRIS is considered the most preferred source for human health toxicity values for EPA risk assessment. In addition to IRIS, EPA used several other peer reviewed, publicly available sources of toxicity

³ For more information on pollutants previously regulated or evaluated in biosolids, see the [Statistics Support Documentation for the 40 CFR Part 503 - Volume 1](https://www.epa.gov/sites/production/files/2015-04/documents/statistics_1992_support_document_-_biosolids_vol_i.pdf) (https://www.epa.gov/sites/production/files/2015-04/documents/statistics_1992_support_document_-_biosolids_vol_i.pdf) and the EPA's response to the National Research Council of the National Academy of Sciences report on biosolids (https://www.epa.gov/sites/production/files/2015-06/documents/technical_background_document.pdf)

⁴ For more information about these toxicity values, see <https://www.epa.gov/iris/basic-information-about-integrated-risk-information-system>.

⁵ For more information about these methods, see <https://www.epa.gov/iris/basic-information-about-integrated-risk-information-system#guidance>.

information. To make efficient use of resources, EPA developed a hierarchy (see **Table 1**) that gives higher priority to sources of information that:

- Are developed specifically for use in human health risk assessment using methodologies similar to those used by IRIS;
- Have been peer reviewed to at least some extent and have a transparent basis for the values; and
- Are more recent than published IRIS values.

Table 1. Hierarchy for Human Health Toxicity Value Data

Data Sources Included
<p>Tier 1: Highest Quality EPA Sources Sources in Tier 1 contain values developed by EPA specifically for human health risk assessment according to standard methods and represent the highest quality human health toxicity values available. These toxicity values are frequently used to support EPA risk analyses.</p>
<p>Integrated Risk Information System (IRIS): IRIS is EPA's primary repository for human health toxicity values that have been developed specifically for human health risk assessment using standardized methods and have been thoroughly peer reviewed. IRIS is considered the most preferred source for human health toxicity values for EPA risk assessment; however, for pesticides, toxicity values are developed by EPA's Office of Pesticide Programs (U.S. EPA, 2016a).</p>
<p>Human Health Benchmarks for Pesticides (HHBPs): EPA develops chronic <i>oral</i> health benchmarks (RfDs and CSFs) for pesticides for surface and groundwater sources of drinking water using health effects data submitted during the pesticide registration process (U.S. EPA, 2016b).</p>
<p>Provisional Peer Reviewed Toxicity Values (PPRTVs): The Superfund Health Risk Technical Support Center (in the National Center for Environmental Assessment, Office of Research and Development) develops PPRTVs using the same methods as IRIS (U.S. EPA, 2016c).</p>
<p>Office of Water Health Effects Support Documents (HESDs): These documents may provide additional toxicity values not elsewhere available, but developed using the same methodology as IRIS.</p>
<p>Tier 2: Non-EPA Sources Using a Similar Methodology to Tier 1 Sources in Tier 2 contain toxicity values developed specifically for human health risk assessment by another organization using methods similar to IRIS. They represent the highest quality human health toxicity values available and are frequently used to support EPA risk analyses.</p>
<p>ATSDR Minimum Risk Levels (MRLs): The Agency for Toxic Substances and Disease Registry (ATSDR) develops MRLs, which are oral non-cancer toxicity values equivalent to RfDs (ATSDR, 2016).</p>
<p>CalEPA Reference Exposure Levels (RELs) and Cancer Potency Factors (CPFs): The California Environmental Protection Agency (CalEPA) develops RELs, which are non-cancer toxicity values equivalent to RfDs or RfCs (CalEPA, 2016) and CPFs, which are cancer toxicity values equivalent to CSFs or IURs (CalEPA, 2011).</p>
<p>Tier 3: Other Non-EPA Sources Tier 3 sources represent high-quality human health toxicity values that have been developed by other organizations for a use other than human health risk assessment or using methodologies that differ from IRIS.</p>
<p>JECFA Acceptable Daily Intakes (ADIs): The Joint Expert Committee on Food Additives (JECFA) of the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) meets annually and issues ADIs, which are roughly equivalent to an RfD (FAO/WHO, 2014).</p>
<p>NAS Tolerable Upper Intake Levels: The National Academies of Science (specifically the Food and Nutrition Board of the Institutes of Medicine) issues Dietary Reference Intakes every 5 years; in concert with this, although less often, they also issue Tolerable Upper Limits for vitamins and elements. These Tolerable Upper Intake Levels are expressed in mg/day (or µg/day), so have been divided by a body weight of 70 kg to produce a toxicity value comparable to an RfD for use here. Values for non-pregnant, non-lactating adults aged 31–50 were used (male and female are presented separately but are the same values for elements) (NAS, 2010).</p>

Data Sources Included
RIVM Maximum Permissible Risk Levels (MPRs): RIVM, the Dutch National Institute of Public Health and the Environment, maintains MPRs, which may be tolerable day intakes or tolerable concentrations in air for noncarcinogens (analogous to RfDs and RfCs), or may be a cancer risk oral or inhalation. These latter are not equivalent to a CSF or IUR, in that they are expressed as the dose or concentration in air, respectively, that results in a risk of 1E-4. To obtain a value comparable to a CSF or IUR, divide 1E-4 by the RIVM MPR (Baars et al., 2001). Note that RIVM reviewed a subset of these values in 2009 (Tiesjema and Baars, 2009), but none of the ones used here.
Tier 4: Other EPA Sources <i>This tier consists of outdated or no-longer-maintained EPA sources.</i>
Health Effects Assessment Summary Tables (HEAST): HEAST, once an alternative for chemicals without IRIS toxicity values, has not been updated since 1997 and has largely been superseded by IRIS and other more recent EPA sources described in Tier 1. It is rarely used, and only if no higher tier health toxicity values data are available (U.S. EPA, 1997).
Tier 5: Open Literature <i>These sources include journal articles that contain ADI values similar to RfDs and developed for potential use in assessing human risks but using methods or data (e.g., minimum therapeutic dose) that differ from IRIS.</i>
Tier 6: Other Sources <i>These sources have limited use in human health risk evaluations. For example, the U.S. Food and Drug Administration's (FDA's) tolerances for residues of drugs in food are for animal meat tissue (beef, fish, milk). These values are only used if no other health toxicity values data are available.</i>
FDA Tolerances for Residues of New Animal Drugs in Food. (21CFR556).
FDA Center For Veterinary Medicine. (http://www.fda.gov/AnimalVeterinary/default.htm).
FDA Center for Drug Evaluation and Research. (http://www.fda.gov/Drugs/default.htm).
European Union European Medicines Agency. (http://www.emea.europa.eu/).

For each chemical, the sources presented in Table 1 were searched from most preferred (IRIS) to least preferred. Once a value was found for a particular toxicity value (RfD, RfC, CSF, IUR), no lower ranked sources in the hierarchy were searched for that chemical. The lower tiers (Tiers 4, 5, and 6) were only used if no toxicity value of any kind was found in higher tiers (e.g., if IRIS had a RfD but no CSF, Tiers 2 and 3 would be searched for a CSF, but if none were found, Tiers 4, 5, and 6 would not be searched, as at least one toxicity value was available from a higher tier source).

2.2 Ecological Toxicity Value Data Sources and Selection

To assess the potential for ecological risks from biosolids, EPA assesses direct contact and ingestion pathways. For the direct contact exposure pathway, species assemblages (or communities) are assessed in soil, sediment, and surface water, where they are assumed to be exposed through direct contact with the contaminated medium. For the ingestion pathway, mammals and birds are assumed to ingest contaminated food and prey from agricultural fields and a modeled farm pond receiving runoff from biosolids-treated fields.

The Agency uses articles published in: 1) English in peer-reviewed journals; 2) databases such as ECOTOX, Aquatic Sciences and Fisheries Abstracts, Biological Sciences Database, and the Environmental Sciences and Pollution Management Database.

The ecological toxicity values are expressed in terms of media concentration (e.g., mg/L for surface water and mg/kg for soil) for the direct contact pathway and in terms of dose (mg/kg-d) for the ingestion pathway. Because there is no single repository for approved ecological toxicity values analogous to IRIS, ecological toxicity values were derived from various EPA and other government reports and data sources (e.g., ECOTOX), and from toxicological studies in the open literature.

Data quality objectives for ecological ingestion toxicity values for use in this analysis included the following:

- Study should include test species, test species body weight, and study duration.
- Route of administration should be oral, not intraperitoneal injection.

Table 2 summarizes the selection criteria for ingestion toxicity values. Note that non-preferred data are used, but only if preferred data are not found. For studies that meet the above two primary criteria, the lowest toxicity values for ingestion exposures for each chemical/receptor combination is selected using a simple hierarchy:

- Endpoints relevant to population-level impacts (e.g., survival, growth, reproduction) are preferred over other endpoints (e.g., neurological effects). Sublethal endpoints are considered but are less preferred.
- Studies with exposure durations that are multigenerational or could be considered chronic or subchronic are preferred over studies conducted with acute exposure durations.

For direct contact toxicity values, environmental quality criteria are identified in existing EPA sources (e.g., national ambient water quality criteria). Other reputable sources of information, such as studies conducted at the Oak Ridge National Laboratories, or published by the Canadian Council of Ministries of the Environment are also used.

Table 2. Summary of Criteria for Selecting Ecological Ingestion Toxicity Data

All Studies
Assessment Endpoint (Effect)
Preferred: Effects related to population or community viability: reproduction, growth
Not Preferred: Mortality as a short-term result is less preferred than long-term or chronic effects
Not used: Effects not related to population or community viability
Study Duration
Preferred: Chronic, longest
Not Preferred: Acute, shorter
Measurement Endpoint
Preferred: Long-term or chronic NOAEL, LOAEL, MATL, or other threshold effects level
Not Preferred: Short-term or acute LC ₅₀ , LD ₅₀ , EC ₅₀
Measured vs. Predicted Values
Preferred: Measured

All Studies
Not Preferred: Predicted
Mammal and Bird Studies
Type
Preferred: Ingestion (dietary and other) studies
Not used: Injection studies
Reported Data
Preferred: Test species, test duration, and body weight reported
Not Preferred: Test species, test duration, or body weight not reported
Aquatic Studies
Study Design
Preferred: Flow-through for long-term or chronic studies
Not Preferred: Static for short-term or acute studies

3. Results of the 2013 Biosolids Biennial Review

Using the search strategy outlined above for the 2013 Biosolids Biennial Review, the Agency identified 77 articles that met the eligibility criteria and provided relevant information on pollutants that have been identified in U.S. biosolids. Review of these articles found the following:

- Thirty-five new chemicals and six new microbial pollutants were identified in biosolids in the 2013 Biennial Review (see Section 3.1).
- No new human health toxicity data were identified in either the 35 new chemicals, or in chemicals identified in previous biennial reviews.
- New ecological toxicity data were identified for one previously identified chemical (see Section 3.2.2).
- New physical-chemical property data (log K_{ow} and half-life) were identified for 22 chemicals; 18 new chemicals and four chemicals previously identified in biosolids (see Section 3.3).
- New bioaccumulation factors (for soil biota and/or plants) were identified for five chemicals previously identified in biosolids (see Section 3.3).

The abstracts for the articles that provided relevant information are provided in **Attachment B**.⁶ Toxicity data for Human Health and Ecological Effects are identified below for new pollutants identified in this 2013 review and new data for pollutants identified in previous biennial reviews.

⁶ Note: A limited number of abstracts presented in Attachment B are reported with a 2014 publication date corresponding to a hardcopy conversion publication date. These abstracts were captured as part of the electronic search with a December 31, 2013 limit due to the fact that these records have 2013 epub dates (initially published electronically).

3.1 Pollutants Newly Identified in the 2013 Biennial Review

Table 3 lists 35 new chemicals and six microbial pollutants identified in the 2013 Biosolids Biennial Review. Many of these chemicals were identified from re-analysis of samples collected in EPA's Targeted National Sewage Sludge Survey (TNSSS; U.S. EPA, 2009) and archived in the National Biosolids Repository. Using new analytical methods Chari and Halden (2012) and Venkatesan and Halden (2013) identified a variety of pharmaceuticals and 13 perfluoroalkyl substances (PFASs) in biosolids.

Table 3. Pollutants Identified in Biosolids in the 2013 Biennial Review

Chemical Analyte	Class
Alprazolam	Other drugs
Amitriptyline	Other drugs
Amlodipine	Other drugs
Atenolol	Other drugs
Atorvastatin	Other drugs
Benzoyllecgonine	Other drugs
Benztropine	Other drugs
Cocaine	Other drugs
Desmethyldiltiazem	Other drugs
Furosemide	Other drugs
Glyburide	Other drugs
Hydrocodone	Other drugs
Hydroxyamitriptyline, 10-	Other drugs
Norverapamil	Other drugs
Oxycodone	Other drugs
Paroxetine	Other drugs
Perfluorobutanoate (PFBA)	PFASs
Perfluoropentanoate (PFPeA)	PFASs
Perfluorohexanoate (PFHxA)	PFASs
Perfluorheptanoate (PFHpA)	PFASs
Perfluorooctanoate (PFOA)	PFASs
Perfluorononanoate (PFNA)	PFASs
Perfluorodecanoate (PFDA)	PFASs
Perfluoroundecanoate (PFUnDA)	PFASs
Perfluorododecanoate (PFDoDA)	PFASs
Perfluorobutanesulfonate (PFBS)	PFASs
Perfluorohexanesulfonate (PFHxS)	PFASs
Perfluorooctanesulfonate (PFOS)	PFASs
Perfluorooctane sulfonamide (PFOSA)	PFASs
Promethazine	Other drugs
Propoxyphene	Other drugs
Sertraline	Other drugs
Triamterene	Other drugs
Valsartan	Other drugs
Verapamil	Other drugs

Chemical Analyte	Class
Aerobic endospores	bacteria
Antibiotic-resistant bacteria (ARB) or Antibiotic-resistant genes (ARG)	bacteria
Coronavirus HKU1	virus
Cosavirus	virus
Klassevirus	virus
Human norovirus	virus

3.1.1 Human Health Toxicity Values for Newly Identified Chemicals

No human health toxicity values were found for any of the new chemicals identified in biosolids in the 2013 Biosolids Biennial Review. While PFASs were identified in this 2013 Biennial Review, EPA is currently engaged in efforts concerning PFAS, including the development of new toxicity information for certain PFAS chemicals. The EPA will continue to evaluate available toxicological information to support scoping assessments for PFASs.

3.1.2 Ecological Toxicity Values for Newly Identified Chemicals

No ecological toxicity values were found for any of the new chemicals identified in biosolids in the 2013 Biosolids Biennial Review. While PFASs were identified in this 2013 Biennial Review, EPA is currently engaged in efforts concerning PFAS, including the development of new toxicity information for certain PFAS chemicals. The EPA will continue to evaluate available toxicological information to support scoping assessments for PFASs.

3.1.3 Information on Newly Identified Microbial Pollutants

Information on the six new microbial pollutants identified in the 2013 Biosolids Biennial Review includes prevalence and concentration in biosolids, as well as the inactivation of certain pathogens during dewatering of activated sludge biosolids. Information on the correlation of antibiotic resistant bacteria and corresponding concentrations of antibiotics in treated sludge was also identified.

3.2 *New Information on Pollutants Previously Identified in Biennial Reviews*

In each new biennial review, EPA searches for new human health and ecological toxicity data, and environmental fate data for pollutants identified in biosolids in the TNSSS, open literature, or previous biosolids reviews. These chemicals are identified in **Attachment A**.

3.2.1 Human Health Toxicity Values

No new human health toxicity values were found in chemicals previously identified in biennial reviews as a result of the 2013 Biosolids Biennial Review.

3.2.2 Ecological Toxicity Values

Table 4 presents data for one chemical (triclosan) previously identified in biennial reviews.

Table 4. Ecological Toxicity Values for Triclosan

Receptor	Endpoint	Value (mg/kg)	Reference
Triclosan			
Radish, Lettuce, Bahia grass, Corn, & Soybean	NOEC	≥11	Pannu, O'Connor, & Toor (2012b)
Soil community	NOEC (microbial respiration)	10	Pannu, O'Connor, & Toor (2012b)
Earthworm	NOEC	≤1	Pannu, O'Connor, & Toor (2012a)
Earthworm ^a	LC50	>1	Pannu, O'Connor, & Toor (2012a)

^a Pannu, O'Connor, & Toor (2012a) note "A definitive earthworm lethal concentration (LC50) value cannot be calculated from the data, because no significant adverse effect occurred up to the maximum tested concentration. An estimated LC50 value in the IFS soil was greater than 1mg TCS/kg (equivalent to a biosolids concentration of >100 mg/kg). Data from the range-finding test can be used to estimate an LC50 of greater than 100 mg/kg soils (equivalent biosolids TCS concentration >10,000 mg/kg) in the ASL and artificial soils. The toxic levels estimated herein are much greater than the typical TCS concentrations (mean 16 mg/kg, 95th percentile=62 mg/kg) in biosolids."

3.2.3 Information on Previously Identified Microbial Pollutants

In each new biennial review, EPA searches for new data for microbial pollutants identified in biosolids in the TNSSS, open literature, or previous biosolids reviews. These microbes are identified in Attachment A. Information on previously identified microbial pollutants includes prevalence and concentration in biosolids and water runoff from biosolid-treated agricultural fields, as well as the inactivation of these pathogens during dewatering of activated sludge biosolids.

3.3 Environmental Fate and Transport Properties

Table 5 presents pollutant-specific physical and chemical properties for 18 of the chemicals identified in the 2013 Biosolids Biennial Review, as well as 4 chemicals previously identified in biosolids that could be used to determine the fate and transport of these pollutants.

Table 5. Physical-Chemical and Other Properties^a Identified in the 2013 Biennial Review

Chemical	Half-life (days)	log K _{ow}
Alprazolam	75	2.12
Amitriptyline	120	4.92
Amlodipine	75	3
Atenolol	75	0.16
Atorvastatin	—	3.85
Benzoyllecgonine	30	-1.32
Benztropine	75	4.28
Cocaine	75	2.3
DEET ^b	75	2.18
Furosemide	120	2.03
Glyburide	360	4.79
Hydrocodone	—	2.16
Metoprolol ^b	75	1.88
Norfluoxetine ^b	—	4.18
Oxycodone	360	0.66
Paroxetine	—	2.57
Promethazine	120	4.81

Chemical	Half-life (days)	log K _{ow}
Propoxyphene	120	4.18
Propranolol ^b	30	3.48
Sertraline	—	5.29
Triamterene	75	0.98
Verapamil	360	3.79

^a Chari & Halden (2012) estimated half-life using EPA's PBT Profiler and obtained log K_{ow} from the Royal Society of Chemistry database.

^b Identified in previous Biennial Reviews.

New bioaccumulation factors (for soil biota and/or plants) were identified for five pollutants (albuterol, carbamazepine, diphenhydramine, triclocarban, and triclosan [including transformation product methyl triclosan]) previously identified in biosolids. **Table 6** presents bioaccumulation factors for soil biota. **Table 7** presents bioaccumulation factors for plants.

Table 6. Bioaccumulation Factors for Soil Biota

Receptor	Subtype	Value [mg/kg biota]/ [mg/kg soil]	Reference
Triclocarban			
Earthworm	Anecic	0.15	Macherius et al. (2014)
Earthworm	Endogeic	1.6	Macherius et al. (2014)
Triclosan			
Earthworm	Anecic	5.9	Macherius et al. (2014)
Earthworm	Endogeic	13.9	Macherius et al. (2014)
Earthworm ^a	IFS soil	6.5	Pannu, O'Connor, & Toor (2012a)
Earthworm ^a	ASL soil	12	Pannu, O'Connor, & Toor (2012a)
Earthworm (methyl triclosan) ^b	Anecic	1.25	Macherius et al. (2014)
Earthworm (methyl triclosan) ^b	Endogeic	5.1	Macherius et al. (2014)

^a Pannu, O'Connor, and Toor (2012a) note that "[t]he average measured BAFs in the two soils were significantly different ($p < 0.05$). The difference was attributed to differences in soil OC contents (11 g/kg for IFS soil and 34 g/kg for ASL soil; Table 1), with a greater TCS accumulation by earthworms in high OC soil (ASL)."

^b Methyl triclosan is a transformation product of triclosan

Table 7. Bioaccumulation Factors for Plants

Receptor	Plant Part ^a	Value	Reference
Albuterol (Salbutamol)			
Chinese cabbage	conc. in roots	0.715 mg/kg	Holling et al. (2012) ^c
Chinese cabbage	conc. in aerials	0.026 mg/kg	Holling et al. (2012) ^c
Carbamazepine			
Pepper	RCF	3.34 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Pepper	SCF	23.4 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Collard	RCF	1.62 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Collard	SCF	8.28 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Lettuce	RCF	1.66 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Lettuce	SCF	7.42 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Radish	RCF	1.12 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Radish	SCF	3.42 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Tomato	RCF	1.06 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Tomato	SCF	4.16 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Chinese cabbage	conc. in roots	2.59 mg/kg	Holling et al. (2012) ^c
Chinese cabbage	conc. in aerials	0.423 mg/kg	Holling et al. (2012) ^c
Diphenhydramine			
Pepper	RCF	0.18 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Pepper	SCF	0.22 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Collard	RCF	0.06 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Collard	SCF	0.03 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Lettuce	RCF	0.06 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Lettuce	SCF	0.05 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Radish	RCF	0.03 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Radish	SCF	0.05 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Tomato	RCF	0.23 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Tomato	SCF	0.07 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Triclocarban			
Pumpkin	root	11.01 [mg/kg plant]/[mg/kg soil]	Aryal & Reinhold (2011)
Zucchini	root	40.27 [mg/kg plant]/[mg/kg soil]	Aryal & Reinhold (2011)
Switch grass	root	30.92 [mg/kg plant]/[mg/kg soil]	Aryal & Reinhold (2011)
Pepper	RCF	0.73 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Pepper	SCF	0.73 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Collard	RCF	0.67 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Collard	SCF	0.12 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Lettuce	RCF	0.34 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Lettuce	SCF	0.25 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Radish	RCF	0.31 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Radish	SCF	0.36 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)

Receptor	Plant Part ^a	Value	Reference
Tomato	RCF	0.72 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Tomato	SCF	0.48 [mg/kg plant]/[mg/kg soil]	Wu et al. (2012)
Triclosan			
Radish	root	0.43 [mg/kg plant]/[mg/kg soil]	Pannu, O'Connor, & Toor (2012b) ^b
Radish	leaf	0.004 [mg/kg plant]/[mg/kg soil]	Pannu, O'Connor, & Toor (2012b) ^b
Lettuce	leaf	0.04 [mg/kg plant]/[mg/kg soil]	Pannu, O'Connor, & Toor (2012b) ^b
Bahia grass	–	<0.001 [mg/kg plant]/[mg/kg soil]	Pannu, O'Connor, & Toor (2012b) ^b
Soybean grain	grain (2001)	0.06 [mg/kg plant]/[mg/kg soil]	Pannu, O'Connor, & Toor (2012b) ^b
Soybean grain	grain (2002)	0.16 [mg/kg plant]/[mg/kg soil]	Pannu, O'Connor, & Toor (2012b) ^b
Corn	leaf (2004)	0.07 [mg/kg plant]/[mg/kg soil]	Pannu, O'Connor, & Toor (2012b) ^b
Corn	leaf (2005)	<0.01 [mg/kg plant]/[mg/kg soil]	Pannu, O'Connor, & Toor (2012b) ^b
Pumpkin	Root	972 [mg/kg plant]/[mg/kg soil]	Aryal & Reinhold (2011)
Zucchini	Root	1822 [mg/kg plant]/[mg/kg soil]	Aryal & Reinhold (2011)
Switch grass	Root	874 [mg/kg plant]/[mg/kg soil]	Aryal & Reinhold (2011)
Chinese cabbage	conc. in roots	1.52 mg/kg	Holling et al. (2012) ^c
Chinese cabbage	conc. in aerials	0.041 mg/kg	Holling et al. (2012) ^c

^a RCF stands for root concentration factor; SCF stands for shoot concentration factor.

^b Pannu, O'Connor, & Toor (2012) suggest a conservative first approximate BAF value of 0.4 for risk assessment in plants.

^c Holling et al. (2012) reported mean measured concentrations from plants grown in biosolids amended soils. The data is available to calculate bioaccumulation factors. However, the authors did not make these calculations.

4. Conclusions

To complete a risk assessment using current tools, the following data are needed:

- **Human health and ecological toxicity values** (i.e., studies that are adequate for evaluating hazards following acute or chronic exposure).
- **Exposure data and/or physical chemical properties**
 - **Pollutant concentrations in U.S. biosolids.** Pollutant concentration data are considered adequate when details are provided regarding sampling, handling, and analysis based on a suitable analytical methodology for detecting and quantifying pollutant concentrations. An analytical methodology is acceptable when the processes and techniques have been independently replicated and/or validated, and when written standard operating procedures exist.
 - **Environmental fate and transport properties.** Data on half-life, mobility, and bioaccumulation are needed to model exposure to humans and wildlife.

Thirty-five new chemicals and six new microbial pollutants were identified in biosolids in this 2013 Biennial Review. Thirteen of the newly identified chemicals are perfluoroalkyl substances (PFASs). No human health toxicity data were identified for any of the 35 new chemicals or for chemicals identified in previous biennial reviews. However, EPA is currently engaged in efforts around PFAS, including developing toxicity values for certain PFAS chemicals

Ecological toxicity values were found for one chemical (triclosan) identified in a previous biennial review. New physical-chemical properties (log Kow and half-life) were identified for 22 chemicals; 18 newly identified chemicals and four previously identified in biosolids. Also, new bioaccumulation factors were identified for five previously identified chemicals.

The available data for many of the chemicals identified are not sufficient at this time to evaluate risk using current biosolids modeling tools. The EPA's Office of Pesticide Programs plans to complete a draft risk assessment for triclosan in late 2018. The Federal Drug Administration and EPA have been closely collaborating on scientific and regulatory issues related to triclosan to ensure government-wide consistency in the regulation of this chemical. In addition, EPA will continue to evaluate available toxicological information to support scoping assessments for PFASs.

EPA has not identified any additional toxic pollutants for potential regulation during the 2013 Biosolids Biennial Review. The Agency will continue to assess the availability of sufficient information for these and other pollutants identified during future biennial review activities pursuant to section 405(d)(2)(C) of the CWA.

5. Additional Information

For additional information about EPA's Biosolids Program, please visit EPA's website at: <http://epa.gov/biosolids>.

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Attachment A. List of Pollutants Identified in Biosolids

Pollutant	CAS No.	Category	TNSSS Analyte?	When Identified?	Last BR Mention^a
Acetaminophen	103-90-2	Other drugs	X	2005BR	2005
Albuterol/Salbutamol	18559-94-9	Other drugs	X	2005BR	2013
Alprazolam	28981-97-7	Other drugs		2013BR	2013
Aluminum	7429-90-5	Metals	X	2005BR	2007
Amitriptyline	549-18-8	Other drugs		2013BR	2013
Amlodipine	88150-42-9	Other drugs		2013BR	2013
Amphetamine	300-62-9	Other drugs		2007BR	2007
Androstenedione	63-05-8	Hormones	X	2009 TNSSS	2009
Androsterone	53-41-8	Hormones	X	2009 TNSSS	2009
Anhydrochlortetracycline	13803-65-1	Antibiotics	X	2009 TNSSS	2009
Anhydrotetracycline	4496-85-9	Antibiotics	X	2009 TNSSS	2009
Antimony	7440-36-0	Metals	X	2005BR	2005
Aspirin	50-78-2	Other drugs		2005BR	2005
Atenolol	29122-68-7	Other drugs		2013BR	2013
Atorvastatin	134523-00-5	Other drugs		2013BR	2013
Azithromycin	83905-01-5	Antibiotics	X	2007BR	2011
Barium	7440-39-3	Metals	X	2009 TNSSS	2009
BDE-100 (2,2',4,4',6-PeBDE)	97038-97-6	PBDEs	X	2009 TNSSS	2009
BDE-138 (2,2',3,4,4',5'-HxBDE)	67888-98-6	PBDEs	X	2009 TNSSS	2009
BDE-153 (2,2',4,4',5,5'-HxBDE)	68631-49-2	PBDEs	X	2009 TNSSS	2009
BDE-154 (2,2',4,4',5,6'-HxBDE)	207122-15-4	PBDEs	X	2009 TNSSS	2009
BDE-183 (2,2',3,4,4',5',6'-HpBDE)	207122-16-5	PBDEs	X	2009 TNSSS	2009
BDE-209 (2,2',3,3',4,4',5,5',6,6'-DeBDE)	1163-19-5	PBDEs	X	2009BR	2009
BDE-28 (2,4,4'-TrBDE)	6430-90-6	PBDEs	X	2009 TNSSS	2009
BDE-47 (2,2',4,4'-TeBDE)	5436-43-1	PBDEs	X	2009 TNSSS	2009

Pollutant	CAS No.	Category	TNSSL Analyte?	When Identified?	Last BR Mention ^a
BDE-66 (2,3',4,4'-TeBDE)	84303-45-7	PBDEs	X	2009 TNSSS	2009
BDE-85 (2,2',3,4,4'-PeBDE)	32534-81-9	PBDEs	X	2009BR	2009
BDE-99 (2,2',4,4',5-PeBDE)	60348-60-9	PBDEs	X	2009 TNSSS	2009
Benz(a)anthracene	56-55-3	PAHs		2005BR	2005
Benzenesulfonic acid, 2,2'-(1,2-ethenediyl)bis[5-amino]	42615-29-2	Other drugs		2005BR	2005
Benzo(a)pyrene	50-32-8	PAHs	X	2005BR	2005
Benzo(b)fluoranthene	205-99-2	PAHs		2005BR	2005
Benzo(k)fluoranthene	207-08-9	PAHs		2005BR	2005
Benzoylecgonine	519-09-5	Other drugs		2013BR	2013
Benzotropine	86-13-5	Other drugs		2013BR	2013
Benzyl-4-chlorophenol, 2-	120-32-1	Antimicrobial		2015BR	2015
Beryllium	7440-41-7	Metals	X	2009 TNSSS	2009
Bezafibrate	41859-67-0	Other drugs		2005BR	2005
Bis (2-ethylhexyl) phthalate	117-81-7	SVOCs	X	2005BR	2005
Bis(5-chloro-2-hydroxyphenyl)methane	97-23-4	Antimicrobial		2015BR	2015
Bisphenol A	80-05-7	Plastics		2007BR	2011
Boron	7440-42-8	Metals	X	2005BR	2005
Butylated hydroxy toluene	128-37-0	Other drugs		2005BR	2005
Caffeine	58-08-2	Other drugs	X	2005BR	2011
Calcium	7440-70-2	Inorganics	X	2007BR	2007
Campesterol	474-62-4	Steroids	X	2009 TNSSS	2009
Carbadox	6804-07-5	Antibiotics	X	2005BR	2005
Carbamazepine	298-46-4	Other drugs	X	2005BR	2013
Carbon tetrachloride	56-23-5	Organics		2005BR	2005
Cefotaxime	63527-52-6	Antibiotics	X	2009 TNSSS	2009
Cerium	7440-45-1	Metals		2005BR	2005
Chloro-4-phenylphenol, 2-	92-04-6	Antimicrobial		2015BR	2015
Chloroaniline, 4-	106-47-8	SVOCs	X	2009 TNSSS	2009
Chloroform	67-66-3	Organics		2005BR	2005
Chloronaphthalene, 2-	91-58-7	Organics		2005BR	2005
Chlortetracycline	57-62-5	Antibiotics	X	2009BR	2009

Pollutant	CAS No.	Category	TNSSS Analyte?	When Identified?	Last BR Mention ^a
Cholestanol	80-97-7	Steroids	X	2009 TNSSS	2009
Cholesterol	57-88-5	Steroids	X	2005BR	2007
Chrysene	218-01-9	PAHs		2005BR	2005
Cimetidine	51481-61-9	Other drugs	X	2005BR	2005
Ciprofloxacin	85721-33-1	Antibiotics	X	2005BR	2011
Clarithromycin	81103-11-9	Antibiotics	X	2007BR	2009
Clinafloxacin	105956-97-6	Antibiotics	X	2009 TNSSS	2009
Clindamycin	18323-44-9	Antibiotics		2011BR	2011
Clofibric acid	882-09-7	Other drugs		2005BR	2005
Clotrimazole	23593-75-1	Antibiotics		2011BR	2011
Cloxacillin	61-72-3	Antibiotics	X	2009 TNSSS	2009
Cobalt	7440-48-4	Metals	X	2005BR	2007
Cocaine	50-36-2	Other drugs		2013BR	2013
Codeine	76-57-3	Other drugs	X	2005BR	2005
Coprostanol (3-beta)	360-68-9	Steroids	X	2007BR	2007
Cotinine	486-56-6	Other drugs	X	2005BR	2005
Cresol, p- (4-methylphenol)	106-44-5	Preservative		2005BR	2007
Cyanide	57-12-5	Organics		2005BR	2005
Cyclophosphamide	50-18-0	Other drugs		2005BR	2005
Decamethylcyclopentasiloxane (D5)	541-02-6	Emollients		2015BR	2015
DEET (N,N-diethyltoluamide)	134-62-3	Pesticides		2005BR	2013
Dehydronifedipine	67035-22-7	Other drugs	X	2009 TNSSS	2009
Demeclocycline	127-33-3	Antibiotics	X	2009 TNSSS	2009
Desmethyldiltiazem	130606-60-9	Other drugs		2013BR	2013
Desmosterol	313-04-2	Steroids	X	2009 TNSSS	2009
Diazepam	439-14-5	Other drugs		2005BR	2005
Dichlorobenzene, 1,3-	541-73-1	Pesticides		2005BR	2005
Dichlorobenzene, 1,4-	106-46-7	Pesticides		2005BR	2005
Dichlorocarbaniide	1219-99-4	Antibiotics		2011BR	2011
Diclofenac	15307-86-5	Antibiotics/ Pesticides		2011BR	2011
Diclofenac sodium	15307-79-6	Other drugs		2005BR	2005
Digoxigenin	1672-46-4	Other drugs	X	2009 TNSSS	2009

Pollutant	CAS No.	Category	TNSSS Analyte?	When Identified?	Last BR Mention ^a
Digoxin	20830-75-5	Other drugs	X	2005BR	2005
Dihydroequilin, 17 α -	651-55-8	Hormones	X	2009 TNSSS	2009
Diltiazem	42399-41-7	Other drugs	X	2005BR	2011
Dimethoate	60-51-5	Pesticides		2005BR	2005
Dimethyl phthalate	131-11-3	Organics		2005BR	2005
Dimethyl-3,5-dinitro-4-tert-butylacetophenone, 2,6-	81-14-1	Odorants		2005BR	2005
Dimethylaminophenazone	58-15-1	Other drugs		2005BR	2005
Dimethylxanthine, 1,7-	611-59-6	Other drugs	X	2005BR	2005
Di-n-butyl phthalate (Butoxyphosphate ethanol, 2-)	84-74-2	Plasticizers		2005BR	2005
Di-n-octyl phthalate	117-84-0	Organics		2005BR	2005
Diphenhydramine	58-73-1	Other drugs	X	2007BR	2013
Di-tert-butylphenol, 2,6-	128-39-2	Other drugs		2005BR	2005
Doxycycline	564-25-0	Antibiotics	X	2005BR	2009
Endosulfan, α	959-98-8	Pesticides		2005BR	2005
Endosulfan, β	33213-65-9	Pesticides		2005BR	2005
Enrofloxacin	93106-60-6	Antibiotics	X	2009 TNSSS	2009
Epianhydrochlortetracycline, 4-	158018-53-2	Antibiotics	X	2009 TNSSS	2009
Epianhydrotetracycline, 4-	4465-65-0	Antibiotics	X	2009 TNSSS	2009
Epichlortetracycline, 4-	14297-93-9	Antibiotics	X	2009 TNSSS	2009
Epicoprostanol	516-92-7	Steroids	X	2009 TNSSS	2009
Epioxytetracycline, 4-	14206-58-7	Antibiotics	X	2009 TNSSS	2009
Epitetracycline, 4-	23313-80-6	Antibiotics	X	2009 TNSSS	2009
Equilenin	517-09-9	Hormones	X	2009 TNSSS	2009
Equilin	474-86-2	Hormones	X	2005BR	2005
Ergosterol	57-87-4	Steroids	X	2009 TNSSS	2009
Erythromycin	114-07-8	Antibiotics	X	2005BR	2009
Estradiol, 17 α -	57-91-0	Hormones	X	2005BR	2005
Estradiol, 17 β -	50-28-2	Hormones	X	2005BR	2009

Pollutant	CAS No.	Category	TNSSS Analyte?	When Identified?	Last BR Mention ^a
Estradiol-3-benzoate, β -	50-50-0	Hormones	X	2009 TNSSS	2009
Estriol (estradiol)	50-27-1	Hormones	X	2005BR	2005
Estrone	53-16-7	Hormones	X	2005BR	2011
Ethanol, 2-butoxy-phosphate	78-51-3	Organics		2005BR	2005
Ethylbenzene	100-41-4	Organics		2005BR	2005
Ethynyl estradiol, 17 α -	57-63-6	Hormones	X	2005BR	2005
Fenofibric acid	26129-32-8	Other drugs		2005BR	2005
Fenthion	55-38-9	Pesticides		2005BR	2005
Fipronil	120068-37-3	Antibiotics		2011BR	2011
Floxacillin	5250-39-5	Antibiotics		2005BR	2005
Flumequine	42835-25-6	Antibiotics	X	2009 TNSSS	2009
Fluoranthene	206-44-0	PAHs	X	2009 TNSSS	2009
Fluoride	16984-48-8	Inorganics	X	2005BR	2005
Fluoxetine	54910-89-3	Other drugs	X	2005BR	2007
Furosemide	54-31-9	Other drugs		2013BR	2013
Galaxolide	1222-05-5	Fragrance		2005BR	2011
Gemfibrozil	25812-30-0	Other drugs	X	2005BR	2011
Glyburide	10238-21-8	Other drugs		2013BR	2013
Heptabromodibenzofuran, 1,2,3,4,6,7,8-	107555-95-3	PBDF		2015BR	2015
Heptabromodibenzofuran, 1,2,3,4,7,8,9-	161880-51-9	PBDF		2015BR	2015
Heptabromodibenzo-p-dioxin, 1,2,3,4,6,7,8-	103456-43-5	PBDD		2015BR	2015
Heptachlor epoxide	1024-57-3	Pesticides		2005BR	2005
Hexabromobiphenyl, 2,2',4,4',5,5'-	59080-40-9	PBBs		2005BR	2005
Hexabromodibenzofuran, 1,2,3,4,7,8-	70648-26-9	PBDF		2015BR	2015
Hexabromodibenzofuran, 1,2,3,6,7,8-	107555-94-2	PBDF		2015BR	2015
Hexabromodibenzofuran, 1,2,3,7,8,9-	161880-49-5	PBDF		2015BR	2015
Hexabromodibenzofuran, 2,3,4,6,7,8-	60851-34-5	PBDF		2015BR	2015
Hexabromodibenzo-p-dioxin, 1,2,3,4,7,8-	110999-44-5	PBDD		2015BR	2015
Hexabromodibenzo-p-dioxin, 1,2,3,6,7,8-	110999-45-6	PBDD		2015BR	2015
Hexabromodibenzo-p-dioxin, 1,2,3,7,8,9-	110999-46-7	PBDD		2015BR	2015
Hydrocodone	125-29-1	Other drugs		2013BR	2013

Pollutant	CAS No.	Category	TNSSS Analyte?	When Identified?	Last BR Mention ^a
Hydroxyamitriptyline, 10-	1246833-15-7	Other drugs		2013BR	2013
Ibuprofen	15687-27-1	Other drugs	X	2005BR	2005
Indole	120-72-9	Fragrance		2007BR	2007
Indometacine	53-86-1	Other drugs		2005BR	2005
Iron	7439-89-6	Metals	X	2005BR	2005
Isochlortetracycline	514-53-4	Antibiotics	X	2009 TNSSS	2009
Ketoprofen	22071-15-4	Other drugs		2005BR	2005
Limonene, d-	5989-27-5	Fragrance		2007BR	2007
Lincomycin	154-21-2	Antibiotics	X	2009BR	2009
Lomefloxacin	98079-51-7	Antibiotics	X	2009 TNSSS	2009
Magnesium	7439-95-4	Metals	X	2007BR	2007
Manganese	7439-96-5	Metals	X	2009 TNSSS	2009
Mefenamic acid	61-68-7	Other drugs		2005BR	2005
Mesalazine	89-57-6	Other drugs		2005BR	2005
Mestranol	72-33-3	Other drugs		2005BR	2005
Metformin	657-24-9	Other drugs	X	2009 TNSSS	2009
Methamphetamine	537-46-2	Other drugs		2007BR	2009
Methylenedioxymethamphetamine, 3,4-	42542-10-9	Other drugs		2009BR	2009
Methylnaphthalene, 2-	91-57-6	PAHs	X	2005BR	2005
Metoprolol	37350-58-6	Other drugs		2005BR	2013
Miconazole	22916-47-8	Other drugs	X	2009 TNSSS	2009
Minocycline	10118-90-8	Antibiotics	X	2009 TNSSS	2009
Molybdenum	7439-98-7	Metals	X	2009 TNSSS	2009
Monuron	150-68-5	Pesticides		2005BR	2005
Nadolol	42200-33-9	Other drugs		2005BR	2005
Naproxen	22204-53-1	Other drugs	X	2005BR	2005
Napthalene	91-20-3	PAHs		2005BR	2005
Nitrate	14797-55-8	Inorganics	X	2009 TNSSS	2009
Nitrite	14797-65-0	Inorganics	X	2009 TNSSS	2009
Nitrofen	1836-75-5	Pesticides		2005BR	2005

Pollutant	CAS No.	Category	TNSSS Analyte?	When Identified?	Last BR Mention ^a
Nitrogen	7727-37-9	Inorganics		2007BR	2007
Nitrogen, organic	14798-03-9	Organics		2007BR	2007
Nitrophenol, p-	100-02-7	Organics		2005BR	2005
N-nitrosodibutylamine (NDBA) 924-16-3	924-16-3	Nitrosamines		2015BR	2015
N-nitrosodiethylamine (NDEA) 55-18-5	55-18-5	Nitrosamines		2015BR	2015
N-nitrosodimethylamine (NDMA) 62-75-9	62-75-9	Nitrosamines		2015BR	2015
N-nitroso-di-n-propylamine (NDPA) 621-64-7	621-64-7	Nitrosamines		2015BR	2015
N-nitrosodiphenylamine (NDPhA) 86-30-6	86-30-6	Nitrosamines		2015BR	2015
N-nitrosopiperidine (NPIP) 100-75-4	100-75-4	Nitrosamines		2015BR	2015
N-nitrosopyrrolidine (NPYR) 930-55-2	930-55-2	Nitrosamines		2015BR	2015
Nonylphenol	25154-52-3	Surfactants		2005BR	2011
Nonylphenol (branched), 4-	84852-15-3	Surfactants		2005BR	2005
Nonylphenol monoethoxylate	27986-36-3	Surfactants		2007BR	2007
Nonylphenol, 4-	104-40-5	Surfactants		2005BR	2007
Nonylphenol, diethoxy- (total)	NA	Surfactants		2007BR	2007
Norethindrone (norethisterone)	68-22-4	Hormones	X	2005BR	2005
Norfloxacin	70458-96-7	Antibiotics	X	2005BR	2011
Norfluoxetine	57226-68-3	Antibiotics		2011BR	2013
Norgestimate	35189-28-7	Other drugs	X	2009 TNSSS	2009
Norgestrel (levonorgestrel)	797-63-7	Hormones	X	2005BR	2005
Norverapamil	67812-42-4	Other drugs		2013BR	2013
Octabromodibenzofuran, 1,2,3,4,6,7,8,9-	103582-29-2	PBDF		2015BR	2015
Octabromodibenzo-p-dioxin, 1,2,3,4,6,7,8,9-	2170-45-8	PBDD		2015BR	2015
Octylphenol	67554-50-1	Organics		2005BR	2005
Octylphenol, 4-	1806-26-4	Organics		2007BR	2007
Ofloxacin	82419-36-1	Antibiotics	X	2009 TNSSS	2009
Ormetoprim	6981-18-6	Antibiotics	X	2009 TNSSS	2009
Oxacillin	66-79-5	Antibiotics	X	2009 TNSSS	2009
Oxolinic acid	14698-29-4	Antibiotics	X	2009 TNSSS	2009

Pollutant	CAS No.	Category	TNSSL Analyte?	When Identified?	Last BR Mention ^a
Oxycodone	76-42-6	Other drugs		2013BR	2013
Oxytetracycline	79-57-2	Antibiotics	X	2005BR	2009
Paroxetine	61869-08-7	Other drugs		2013BR	2013
Penicillin G	61-33-6	Antibiotics	X	2009 TNSSL	2009
Penicillin V (phenoxymethylpenicillin)	87-08-1	Antibiotics	X	2005BR	2005
Pentabromodibenzofuran, 1,2,3,7,8-	107555-93-1	PBDF		2015BR	2015
Pentabromodibenzofuran, 2,3,4,7,8-	131166-92-2	PBDF		2015BR	2015
Pentabromodibenzo-p-dioxin, 1,2,3,7,8-	109333-34-8	PBDD		2015BR	2015
Pentachloronitrobenzene	82-68-8	Pesticides		2005BR	2005
Perfluorheptanoate (PFHpA)	375-85-9	PFASs		2013BR	2013
Perfluorobutanesulfonate (PFBS)	45187-15-3	PFASs		2013BR	2013
Perfluorobutanoate (PFBA)	375-22-4	PFASs		2013BR	2013
Perfluorodecanoate (PFDA)	335-76-2	PFASs		2013BR	2013
Perfluorododecanoate (PFDoDA)	307-55-1	PFASs		2013BR	2013
Perfluorohexanesulfonate (PFHxS)	108427-53-8	PFASs		2013BR	2013
Perfluorohexanoate (PFHxA)	307-24-4	PFASs		2013BR	2013
Perfluoronoanoate (PFNA)	375-95-1	PFASs		2013BR	2013
Perfluorooctane sulfonamide (PFOSA)	754-91-6	PFASs		2013BR	2013
Perfluorooctanesulfonate (PFOS)	45298-90-6	PFASs		2013BR	2013
Perfluorooctanoate (PFOA)	335-67-1	PFASs		2013BR	2013
Perfluoropentanoate (PFPeA)	2706-90-3	PFASs		2013BR	2013
Perfluoroundecanoate (PFUnDA)	2058-94-8	PFASs		2013BR	2013
Phenanthrene	85-01-8	PAHs		2007BR	2007
Phenazone	60-80-0	Other drugs		2005BR	2005
Phosphate (total)	14265-44-2	Inorganics		2005BR	2005
Phosphorus	7723-14-0	Inorganics	X	2007BR	2007
Polyethylene glycol	25322-68-3	Organics		2005BR	2005
Potassium	7440-09-7	Metals		2007BR	2007
Progesterone	57-83-0	Hormones	X	2005BR	2009
Promethazine	60-87-7	Other drugs		2013BR	2013
Propoxyphene	469-62-5	Other drugs		2013BR	2013
Propranolol	525-66-6	Other drugs		2005BR	2013
Pyrene	129-00-0	PAHs	X	2009 TNSSL	2009
Quinine sulfate	7778-93-0	Other drugs		2005BR	2005
Ranitidine	66357-35-5	Other drugs	X	2005BR	2005

Pollutant	CAS No.	Category	TNSSL Analyte?	When Identified?	Last BR Mention ^a
Roxithromycin	80214-83-1	Antibiotics	X	2007BR	2007
Rubidium	7440-17-7	Metals		2005BR	2005
Salicylic acid	69-72-7	Other drugs		2005BR	2005
Sarafloxacin	98105-99-8	Antibiotics	X	2009 TNSSL	2009
Sertraline	79617-96-2	Other drugs		2013BR	2013
Silver	7440-22-4	Metals	X	2009 TNSSL	2009
Sitosterol, β -	83-46-5	Steroids	X	2007BR	2007
Skatole	83-34-1	NA		2007BR	2007
Sodium	7440-23-5	Metals	X	2009 TNSSL	2009
Sodium valproate	1069-66-5	Other drugs		2005BR	2005
Stigmastanol, β -	19466-47-8	Steroids	X	2007BR	2007
Stigmasterol	83-45-4	Steroids	X	2009 TNSSL	2009
Styrene	100-42-5	Organics		2005BR	2005
Sulfachloropyridazine	80-32-0	Antibiotics	X	2009 TNSSL	2009
Sulfadiazine	68-35-9	Antibiotics	X	2009 TNSSL	2009
Sulfadimethoxine	122-11-2	Antibiotics	X	2009BR	2009
Sulfamerazine	127-79-7	Antibiotics	X	2005BR	2005
Sulfamethazine	57-68-1	Antibiotics	X	2005BR	2009
Sulfamethizole	144-82-1	Antibiotics	X	2009 TNSSL	2009
Sulfamethoxazole	723-46-6	Antibiotics	X	2009 TNSSL	2009
Sulfanilamide	63-74-1	Antibiotics	X	2009 TNSSL	2009
Sulfasalazine	599-79-1	Other drugs		2005BR	2005
Sulfathiazole	72-14-0	Antibiotics	X	2009 TNSSL	2009
tert-Butyl-4-hydroxy anisole, 3-	25013-16-5	Other drugs		2005BR	2005
Testosterone	58-22-0	Hormones	X	2009BR	2009
Tetrabromobisphenol A	79-94-7	Organics		2005BR	2005
Tetrabromodibenzofuran, 2,3,7,8-	67733-57-7	PBDF		2015BR	2015
Tetrabromodibenzo-p-dioxin, 2,3,7,8-	50585-41-6	PBDD		2015BR	2015
Tetrachloroethylene	127-18-4	Solvents		2005BR	2005
Tetracycline	60-54-8	Antibiotics	X	2009BR	2009

Pollutant	CAS No.	Category	TNSSS Analyte?	When Identified?	Last BR Mention ^a
Thallium	7440-28-0	Metals	X	2005BR	2005
Thiabendazole	148-79-8	Other drugs	X	2009 TNSSS	2009
Tin	7440-31-5	Metals	X	2005BR	2005
Titanium	7440-32-6	Metals	X	2009 TNSSS	2009
Toluene	108-88-3	Solvents		2005BR	2005
Tonalide (AHTN)	21145-77-7	Fragrance		2007BR	2011
Triamterene	396-01-0	Other drugs		2013BR	2013
Trichlorobenzene, 1,3,5-	108-70-3	Organics		2005BR	2005
Trichlorofon	52-68-6	Pesticides		2005BR	2005
Trichlorophenol, 2,4,5-	95-95-4	Antimicrobial		2015BR	2015
Triclocarban	101-20-2	Antibiotics	X	2007BR	2013
Triclosan	3380-34-5	Antibiotics	X	2005BR	2013
Trimethoprim	738-70-5	Antibiotics	X	2005BR	2009
Triphenyl phosphate	115-86-6	Pesticides		2005BR	2005
Tris(2-chloroethyl) phosphate	115-96-8	Organics		2005BR	2005
Tylosin	1401-69-0	Antibiotics	X	2005BR	2007
Valsartan	137862-53-4	Other drugs		2013BR	2013
Vanadium	7440-62-2	Metals	X	2005BR	2005
Verapamil	52-53-9	Other drugs		2013BR	2013
Virginiamycin	11006-76-1	Antibiotics	X	2005BR	2009
Warfarin	81-81-2	Other drugs	X	2009 TNSSS	2009
Xylene, m-	108-38-3	Solvents		2005BR	2005
Xylene, musk	81-15-2	Odorants		2005BR	2005
Xylene, o-	95-47-6	Solvents		2005BR	2005
Xylene, p	106-42-3	Solvents		2005BR	2005
Yttrium	7440-65-5	Metals	X	2005BR	2005
Microbial Pollutants					
Aerobic endospores	Not applicable	Bacteria		2013BR	2013
<i>Aeromonas</i> spp.	Not applicable	Bacteria		2009BR	2009
Antibiotic-resistant bacteria (ARB) or Antibiotic-resistant genes (ARG)	Not applicable	Bacteria		2013BR	2013
<i>Clostridia</i> spp.	Not applicable	Bacteria		2007BR	2011
Coronavirus HKU1	Not applicable	Virus		2013BR	2013
Cosavirus	Not applicable	Virus		2013BR	2013
<i>Cryptosporidium parvum</i>	Not applicable	Protozoan parasite		2007BR	2007

Pollutant	CAS No.	Category	TNSSS Analyte?	When Identified?	Last BR Mention ^a
Enterovirus	Not applicable	Virus		2009BR	2013
<i>Escherichia coli</i> (<i>E. coli</i>)	Not applicable	Bacteria		2009BR	2013
Endotoxin	Not applicable	Microbial toxin		2007BR	2007
<i>Giardia</i> spp.	Not applicable	Protozoan parasite		2009BR	2011
Human Adenoviruses	Not applicable	Virus		2009BR	2013
Human polyomaviruses	Not applicable	Virus		2011BR	2011
Klassevirus	Not applicable	Virus		2013BR	2013
<i>Listeria</i> spp.	Not applicable	Bacteria		2009BR	2011
Human norovirus	Not applicable	Virus		2013BR	2013
<i>Salmonella</i> spp.	Not applicable	Bacteria		2007BR	2013

^a This is the date of the most recent biennial report that mentions this pollutant. That does not necessarily mean there was new data found, just that it came up in the literature search that year.

Attachment B. Reference Abstracts

Akbar-Khanzadeh, F., A. Ames, et al. (2012) "Particulate matter (PM) exposure assessment--horizontal and vertical PM profiles in relation to agricultural activities and environmental factors in farm fields." *J Occup Environ Hyg* **9**(8): 502-16.

Reports profiling airborne particulate matter (PM) in farm fields, especially during a Class B biosolids land-injection process, are scarce. Thus, this study characterized PM in such a farm field located in northwest Ohio. For comparison, a control farm field with no biosolids application history was also monitored. During 11 days of varied agricultural activities, the concentrations of particle mass and number (count) and also metal content were monitored in the study field, and their interactions with environmental factors were examined. The monitoring was performed across the farm field at four heights of 0.5, 1.5, 2.5, and 3.5 m from the ground. The overall mean (SD) concentration ($\mu\text{g}/\text{m}^3$) of respirable suspended particulate matter (RPM) was 30.8 (23.1) with means ranging from 15.9 (3.80) during post-tilling Event 1, 19.9 (12.4) during biosolids application to 56.1 (11.7) during post-harvest (including baling) activity. The maximum concentration of RPM ($\mu\text{g}/\text{m}^3$) was 43 during biosolids application, 90 during post-harvest, and 183 during post-tilling Event 2 activities. Overall, 93.7% (8.98%) of the total suspended particulate matter (TPM) was respirable. The levels of RPM significantly ($p < 0.01$) correlated with TPM and particle counts of ultrafine particles (UFP) and 0.3 μm particle size. Ambient temperature showed no effect, whereas wind speed and relative humidity had an inverse effect on RPM concentration. Particle concentrations changed minimally during each set of monitoring across the field, except during major activities or sudden weather changes. For particles with sizes of 2, 5, and 10 μm , the counts decreased with increasing height from the ground and were significantly ($p < 0.05$) higher at 0.5 m than at other heights. The levels of nine metals within particles monitored were well below current recommended occupational exposure criteria. These results suggest that injection of the biosolids into agricultural land provides significant protection against exposure to biosolids particles.

Allen, R.C., Y.K. Tu, et al. (2013) "The mercury resistance (mer) operon in a marine gliding flavobacterium, *Tenacibaculum discolor* 9A5." *FEMS Microbiol Ecol* **83**(1): 135-48.

Genes conferring mercury resistance have been investigated in a variety of bacteria and archaea but not in bacteria of the phylum Bacteroidetes, despite their importance in many environments. We found, however, that a marine gliding Bacteroidetes species, *Tenacibaculum discolor*, was the predominant mercury-resistant bacterial taxon cultured from a salt marsh fertilized with mercury-contaminated sewage sludge. Here we report characterization of the mercuric reductase and the narrow-spectrum mercury resistance (mer) operon from one of these strains - *T. discolor* 9A5. This mer operon, which confers mercury resistance when cloned into *Flavobacterium johnsoniae*, encodes a novel mercury-responsive ArsR/SmtB family transcriptional regulator that appears to have evolved independently from other mercury-responsive regulators, a novel putative transport protein consisting of a fusion between the integral membrane Hg(II) transporter MerT and the periplasmic Hg(II)-binding protein MerP, an additional MerP protein, and a mercuric reductase that is phylogenetically distinct from other known mercuric reductases.

Andaluri, G., R.P. Suri, et al. (2012) "Occurrence of estrogen hormones in biosolids, animal manure and mushroom compost." Environ Monit Assess **184**(2): 1197-205.

The presence of natural estrogen hormones as trace concentrations in the environment has been reported by many researchers and is of growing concern due to its possible adverse effects on the ecosystem. In this study, municipal biosolids, poultry manure (PM) and cow manure (CM), and spent mushroom compost (SMC) were analyzed for the presence of seven estrogen hormones. 17α -estradiol, 17β -estradiol, 17α -dihydroequilin, and estrone were detected in the sampled biosolids and manures at concentrations ranging from 6 to 462 ng/g of dry solids. 17α -estradiol, 17β -estradiol, and estrone were also detected in SMC at concentrations ranging from 4 to 28 ng/g of dry solids. Desorption experiments were simulated in the laboratory using deionized water (milli-Q), and the aqueous phase was examined for the presence of estrogen hormones to determine their desorption potential. Very low desorption of 0.4% and 0.2% estrogen hormones was observed from municipal biosolids and SMC, respectively. An estimate of total estrogen contribution from different solid waste sources is reported. Animal manures (PM and CM) contribute to a significant load of estrogen hormones in the natural environment.

Antonious, G.F., M.R. Silitonga, et al. (2013) "Elevated concentrations of trace elements in soil do not necessarily reflect metals available to plants." J Environ Sci Health B **48**(3): 219-25.

Bioaccumulation and entry of trace elements from soil into the food chain have made trace-elements major environmental pollutants. The main objective of this investigation was to study the impact of mixing native agricultural soil with municipal sewage sludge (SS) or SS mixed with yard waste (SS+YW) compost on total concentration of trace elements in soil, metals available to plants, and mobility of metals from soil into peppers and melon fruits. Regardless of soil treatment, the average concentrations of Ni, Cd, Pb, Cr, Cu, Zn, and Mo in melon fruits were 5.2, 0.7, 3.9, 0.9, 34.3, 96.1, and $3.5\mu\text{g g}^{-1}$, respectively. Overall concentrations of Ni, Cd, Pb, and Zn in melon fruits were significantly greater ($P < 0.05$) than pepper fruits. No significant differences were found in Cr, Cu, and Mo concentrations between pepper and melon fruits at harvest time. Total metal concentrations and metal ions in soil available to melon and pepper plants were also determined. Total concentration of each metal in the soil was significantly greater than concentration of metal ions available to plants. Elevated Ni and Mo bioaccumulation factor ($\text{BAF} > 1$) of melon fruits of plants grown in SS+YW mixed soil is a characteristic that would be less favorable when plants grown on sites having high concentrations of these metals.

Antonious, G.F., T.S. Kochhar, et al. (2012) "Yield, quality, and concentration of seven heavy metals in cabbage and broccoli grown in sewage sludge and chicken manure amended soil." J Environ Sci Health A Tox Hazard Subst Environ Eng **47**(13): 1955-65.

The mobility of heavy metals from soil into the food chain and their subsequent bioaccumulation has increased the attention they receive as major environmental pollutants. The objectives of this investigation were to: i) study the impact of mixing native agricultural soil with municipal sewage sludge (SS) or chicken manure (CM) on yield and quality of cabbage and broccoli, ii) quantify the concentration of seven heavy metals (Cd, Cr, Mo, Cu, Zn, Pb, and Ni) in soil amended with SS or CM, and iii) determine bioavailability of heavy metals to cabbage leaves and broccoli heads at harvest. Analysis of the two soil amendments used in this investigation indicated that Cr, Ni, Cu, Zn, Mo, Cd, Pb, and organic matter

content were significantly greater ($P < 0.05$) in premixed sewage sludge than premixed chicken manure. Total cabbage and broccoli yields obtained from SS and CM mixed soil were both greater than those obtained from no-mulch (bare) soil. Concentration of Ni in cabbage leaves of plants grown in soil amended with CM was low compared to plants grown in no-mulch soil. No significant differences were found in Cd and Pb accumulation between cabbage and broccoli. Concentrations of Ni, Cu, Zn, and Mo were greater in broccoli than cabbage. Total metals and plant available metals were also determined in the native and amended soils. Results indicated that the concentration of heavy metals in soils did not necessarily reflect metals available to plants. Regardless of soil amendments, the overall bioaccumulation factor (BAF) of seven heavy metals in cabbage leaves and broccoli heads revealed that cabbage and broccoli were poor accumulators of Cr, Ni, Cu, Cd, and Pb (BAF < 1), while BAF values were > 1 for Zn and Mo. Elevated Ni and Mo bioaccumulation factor (BAF > 1) of cabbage grown in chicken manure mixed soil is a characteristic that would be less favorable when cabbage is grown on sites having high concentrations of these two metals.

Aryal, N. and D.M. Reinhold. (2011) "Phytoaccumulation of antimicrobials from biosolids: impacts on environmental fate and relevance to human exposure." *Water Res* **45**(17): 5545-52.

Triclocarban and triclosan, two antimicrobials widely used in consumer products, can adversely affect ecosystems and potentially impact human health. The application of biosolids to agricultural fields introduces triclocarban and triclosan to soil and water resources. This research examined the phytoaccumulation of antimicrobials, effects of plant growth on migration of antimicrobials to water resources, and relevance of phytoaccumulation in human exposure to antimicrobials. Pumpkin, zucchini, and switch grass were grown in soil columns to which biosolids were applied. Leachate from soil columns was assessed every other week for triclocarban and triclosan. At the end of the trial, concentrations of triclocarban and triclosan were determined for soil, roots, stems, and leaves. Results indicated that plants can reduce leaching of antimicrobials to water resources. Pumpkin and zucchini growth significantly reduced soil concentrations of triclosan to less than 0.001 mg/kg, while zucchini significantly reduced soil concentrations of triclocarban to 0.04 mg/kg. Pumpkin, zucchini, and switch grass accumulated triclocarban and triclosan in mg per kg (dry) concentrations. Potential human exposure to triclocarban from consumption of pumpkin or zucchini was substantially less than exposure from product use, but was greater than exposure from drinking water consumption. Consequently, research indicated that pumpkin and zucchini may beneficially impact the fate of antimicrobials in agricultural fields, while presenting minimal acute risk to human health.

Azizi, A.B., M.P.M. Lim, et al. (2013) "Vermiremoval of heavy metal in sewage sludge by utilising *Lumbricus rubellus*." *Ecotoxicol Environ Saf* **90**: 13-20.

Experiments were conducted to remove heavy metals (Cr, Cd, Pb, Cu and Zn) from urban sewage sludge (SS) amended with spent mushroom compost (SMC) using worms, *Lumbricus rubellus*, for 105 days, after 21 days of pre-composting. Five combinations of SS/SMC treatments were prepared in triplicate along with a control for each treatment in microcosms. Analysis of the earthworms' multiplication and growth and laboratory analysis were conducted during the tenth and fifteenth week of vermicomposting. Our result showed that the final biomass of earthworms (mg) and final number of earthworms showed significant

differences between treatments i.e. $F=554.70$, $P=0.00$ and $F=729.10$, $P=0.00$ respectively. The heavy metals Cr, Cd and Pb contained in vermicompost were lower than initial concentrations, with 90-98.7percent removal on week ten. However, concentrations of Cu and Zn, that are considered as micronutrients, were higher than initial concentrations, but they were 10-200-fold lower than the EU and USA biosolid compost limits and Malaysian Recommended Site Screening Levels for Contaminated Land (SSLs). An increment of heavy metals was recorded in vermicompost for all treatments on week fifteen compared to week ten, while concentration of heavy metals in earthworms' tissue were lower compared to vermicompost. Hence, it is suggested that earthworms begin to discharge heavy metals into their surroundings and it was evident that the earthworms' heavy metals excretion period was within the interval of ten to fifteen weeks.

Benskin, J.P., M.G. Ikonou, et al. (2013) "Biodegradation of N-ethyl perfluorooctane sulfonamido ethanol (EtFOSE) and EtFOSE-based phosphate diester (SAM-PAP diester) in marine sediments." *Environ Sci Technol* **47**(3): 1381-9.

Investigations into the biodegradation potential of perfluorooctane sulfonate (PFOS)-precursor candidates have focused on low molecular weight substances (e.g., N-ethyl perfluorooctane sulfonamido ethanol (EtFOSE)) in wastewater treatment plant sludge. Few data are available on PFOS-precursor biodegradation in other environmental compartments, and nothing is known about the stability of high-molecular-weight perfluorooctane sulfonamide-based substances such as the EtFOSE-based phosphate diester (SAM-PAP diester) in any environmental compartment. In the present work, the biodegradation potential of SAM-PAP diester and EtFOSE by bacteria in marine sediments was evaluated over 120 days at 4 and 25 degrees C. At both temperatures, EtFOSE was transformed to a suite of products, including N-ethyl perfluorooctane sulfonamidoacetate, perfluorooctane sulfonamidoacetate, N-ethyl perfluorooctane sulfonamide, perfluorooctane sulfonamide, and perfluorooctane sulfonate. Transformation was significantly more rapid at 25 degrees C ($t(1/2) = 44 \pm 3.4$ days; error represents standard error of the mean (SEM)) compared to 4 degrees C ($t(1/2) = 160 \pm 17$ days), but much longer than previous biodegradation studies involving EtFOSE in sludge ($t(1/2)$ approximately 0.7-4.2 days). In contrast, SAM-PAP diester was highly recalcitrant to microbial degradation, with negligible loss and/or associated product formation observed after 120 days at both temperatures, and an estimated half-life of >380 days at 25 degrees C (estimated using the lower bounds 95% confidence interval of the slope). We hypothesize that the hydrophobicity of SAM-PAP diester reduces its bioavailability, thus limiting biotransformation by bacteria in sediments. The lengthy biodegradation half-life of EtFOSE and recalcitrant nature of SAM-PAP diester in part explains the elevated concentrations of PFOS-precursors observed in urban marine sediments from Canada, Japan, and the U.S, over a decade after phase-out of their production and commercial application in these countries.

Bhat, A. and A. Kumar. (2012) "Particulate characteristics and emission rates during the injection of class B biosolids into an agricultural field." *Sci Total Environ* **414**: 328-34.

A field study was conducted during the summer of 2009 to collect airborne particulate matter emitted during the agricultural activities. The activities surrounding the injection application of class B biosolids were targeted for the sampling. The sampling was carried out before (pre-application), during (application), and after (post-application) the application. This study

characterized the particulate emissions deposited on the aerosols spectrometer. The effect of different biosolids related activities was significant on the mass concentration, the number concentration, and the size distribution. The mass concentration of fine (PM(2.5)) and ultrafine (PM(1.0)) was highest during the pre-application. The mass concentration of thoracic fraction (PM(2.5-10)) increased significantly during the application. A bimodal size distribution was observed throughout the sampling. Nuclei mode formation was predominant during the pre-application and the post-application, whereas the accumulation mode was distinctive during the application. The number concentration of ultrafine particles was highest during the entire sampling period. The application of biosolids resulted into a higher number of coarse particle emission. It was also observed that the ultrafine and fine particles traveled longer downwind distances. The emission rates were determined for pre-application, application, and post-application activities.

Bibby, K. and J. Peccia. (2013) "Identification of viral pathogen diversity in sewage sludge by metagenome analysis." *Environ Sci Technol* **47**(4): 1945-51.

The large diversity of viruses that exist in human populations are potentially excreted into sewage collection systems and concentrated in sewage sludge. In the U.S., the primary fate of processed sewage sludge (class B biosolids) is application to agricultural land as a soil amendment. To characterize and understand infectious risks associated with land application, and to describe the diversity of viruses in human populations, shotgun viral metagenomics was applied to 10 sewage sludge samples from 5 wastewater treatment plants throughout the continental U.S, each serving between 100,000 and 1,000,000 people. Nearly 330 million DNA sequences were produced and assembled, and annotation resulted in identifying 43 (26 DNA, 17 RNA) different types of human viruses in sewage sludge. Novel insights include the high abundance of newly emerging viruses (e.g., Coronavirus HKU1, Klassevirus, and Cosavirus) the strong representation of respiratory viruses, and the relatively minor abundance and occurrence of Enteroviruses. Viral metagenome sequence annotations were reproducible and independent PCR-based identification of selected viruses suggests that viral metagenomes were a conservative estimate of the true viral occurrence and diversity. These results represent the most complete description of human virus diversity in any wastewater sample to date, provide engineers and environmental scientists with critical information on important viral agents and routes of infection from exposure to wastewater and sewage sludge, and represent a significant leap forward in understanding the pathogen content of class B biosolids.

Borden, R.K. and R. Black. (2011) "Biosolids Application and Long-Term Noxious Weed Dominance in the Western United States." *Restor Ecol* **19**(5): 639-47.

Vegetation characteristics were assessed on three sets of 10-year-old test plots and one set of 5-year-old plots that received 0, 34, 45, and 67 tons/ha (0, 15, 20, and 30 short tons/acre) of biosolids at a semiarid mine reclamation site in Utah. On average, noxious weed species such as *Bromus tectorum* L. (cheatgrass) provided two-thirds of the cover on the biosolids test plots, but only one-tenth of the cover on adjacent control plots that received no biosolids. Cheatgrass provided more than half of the total cover on every biosolids test plot. Seeded species provided about two times more cover at the control plots than at the biosolids plots. Surfaces treated with 45 tons/ha composted biosolids (one part biosolids and two parts wood chips) had a much lower percentage of noxious weed cover compared to biosolids alone. The

relatively heavy initial nitrogen load associated with biosolids application may have promoted cheatgrass dominance. Although the available nitrogen eventually declines, once cheatgrass is established it may maintain its dominance indefinitely. Given the risk of weed invasion, heavy biosolids applications should be used with caution for reclamation projects in semiarid climates if perennial species establishment is desired. Consideration should instead be given to light applications (<45 tons/ha) of biosolids/wood chip compost or forgoing the use of biosolids entirely. The underapplication of nutrients may provide a slower, but ultimately more reliable, strategy for the establishment of a healthy, native perennial vegetation community.

Brisolara, K.F., R.S. Reimers, et al. (2012) "Impact of Treatment Temperature Decline on Stability of Advanced Alkaline Biosolids." *Int J Environ Res* 6(4): 925-32.

Biosolids must be stabilized in order to reduce odors, which have been noted as a major concern with respect to alkaline stabilization. Stabilization is designed to address potential putrefaction processes, odiferous releases and vector attraction concerns. Also, most alkaline processes are open systems in which temperature and mixing are more difficult to control, and factors such as increased pressure or bactericidal action of un-ionized ammonia are not present to aid in disinfection. The purpose of this project was to begin assessment of the long-term stability of an advanced alkaline product resulting from operating conditions established by testing previously conducted and approved by EPA's Pathogen Equivalency Committee. The conditions formerly established as optimum to achieve required pathogen destruction resulted in the ability of advanced alkaline system to operate at a lower temperature of 55 degree C as opposed to the temperature of 70 degree C required by the U.S. EPA 40CFR Part 503 Final Rule Standards for the Use or Disposal of Sewage Sludge. All previous data collected regarding the ability of the advanced alkaline product to remain stabilized over long periods of time were related to the material produced at the higher temperatures which indicated no significant decline in pH over a time of 5 years. The goal of this research is to obtain better understanding of the stabilization of biosolids over time, lower costs, reduce odor formation and to reduce vector and pathogen attraction so to comply with the current requirements.

Brown, S., K. Kurtz, et al. (2011) "Quantifying benefits associated with land application of organic residuals in Washington State." *Environ Sci Technol* 45(17): 7451-8.

This study was conducted to quantify soil C storage, N concentration, available P, and water holding capacity (WHC) across a range of sites in Washington State. Composts or biosolids had been applied to each site either annually at agronomic rates or at a one-time high rate. Site ages ranged from 2 to 18 years. For all but one site sampled, addition of organic amendments resulted in significant increases in soil carbon storage. Rates of carbon storage per dry Mg of amendment ranged from 0.014 (not significant) in a long-term study of turf grass to 0.54 in a commercial orchard. Soils with the lowest initial C levels had the highest rates of amendment carbon storage ($r(2) = 0.37, p < 0.001$). Excess C stored with use of amendments in comparison with control fields ranged from 8 to 72 Mg ha⁻¹. For sites with data over time, C content increased or stabilized. Increases in total N were observed at all sites, with increased WHC and available P observed at a majority of sites. Using a 50 Mg ha application rate, benefits of application of biosolids and compost ranged from 7 to 33 Mg C ha. This estimate does not account for yield increases or water conservation savings.

Chari, B.P. and R.U. Halden. (2012) "Predicting the concentration range of unmonitored chemicals in wastewater-dominated streams and in run-off from biosolids-amended soils." *Sci Total Environ* 440: 314-20.

Organic compounds such as sterols and hormones have been detected in surface waters at ecologically relevant concentrations with sources including effluent discharged from publicly owned treatment works (POTWs) as well as leachate and runoff from land amended with municipal sludge (biosolids). Greater than 20% of regulated effluents discharged into U.S. surface waters experience in-stream dilution of <10-fold and potential impacts are particularly likely in receiving waters dominated by POTW effluents. The increasing use of biosolids on agricultural land exerts additional stress, thereby necessitating environmental monitoring for potential ecological and human health effects. Alternatively, or in addition to monitoring efforts, screening for potentially hazardous chemicals can be performed using empirical models that are scalable and can deliver results rapidly. The present study makes use of data from U.S. EPA's Targeted National Sewage Sludge Survey (TNSSS) to predict the aqueous-phase concentrations and removal efficiencies of 10 sterols (campesterol, beta-sitosterol, stigmasterol, beta-stigmastanol, cholesterol, desmosterol, cholestanol, coprostanol, epicoprostanol, and ergosterol) as well as the putative toxicity posed by four specific hormones based on their reported biosolids concentrations using published empirical models. Model predictions indicate that removal efficiencies for sterols are uniformly high (~99%) and closely match removal rates calculated from chemical monitoring at POTWs (paired t-test; p=0.01). Results from toxicity modeling indicate that the hormones estrone, estradiol and estriol had the highest leaching potentials amongst the compounds considered here and that 17 beta-ethinylestradiol was found to pose a potentially significant threat to fathead minnows (*Pimephales promelas*) via run-off or leaching from biosolids-amended fields. This study exemplifies the use of in silico analysis to (i) identify potentially problematic organic compounds in biosolids, (ii) predict influent and effluent levels for hydrophobic organic compounds (HOCs) of emerging concern, and (iii) provide initial estimates of runoff concentrations, in this case for four prominent hormones known to act as endocrine disruptors.

Chari, B.P. and R.U. Halden. (2012) "Validation of mega composite sampling and nationwide mass inventories for 26 previously unmonitored contaminants in archived biosolids from the U.S National Biosolids Repository." *Water Res* 46(15): 4814-24.

In the present study, archived U.S biosolids from the 2001 Environmental Protection Agency (EPA) National Sewage Sludge Survey were analyzed with an expanded U.S EPA Method 1694, to determine the occurrence of 26 previously unmonitored pharmaceuticals and personal care products (PPCPs) among a total of 120 analytes. The study further served to examine the reproducibility of a mega-composite approach for creating chemical mass inventories in biosolids based on pooled samples from wastewater treatment plants (WWTPs) nationwide. Five mega-composites reflecting 94 WWTPs in 32 states and the District of Columbia were constructed from archived biosolids and analyzed by LC/ESI-MS/MS using a newly introduced analytical method expanding upon U.S EPA Method 1694. In addition, soil-biosolids mixtures from a mesocosm setup were analyzed to experimentally determine the half-lives of biosolids-borne compounds applied on U.S land. Among 59 analytes detected, 33 had been reported previously, whereas 26 are reported in biosolids for the first time, at levels ranging from 1.65 to 673 $\mu\text{g kg}^{-1}$ dry weight. Newly recognized

biosolids constituents were identified as Ca²⁺ channel blockers, antidepressants, diuretics, β -blockers and analgesics. Using a mass balance approach, the total loading of these 26 pharmaceuticals to U.S soils from biosolids land application was estimated at 5-15 tons year⁻¹. Past and present datasets for 30 pharmaceuticals and personal care products (PPCPs) were determined to be statistically indistinguishable (paired t-test; p = 0.01). This study expands the list of PPCPs reported in U.S biosolids, provides the first estimates of nationwide release rates to and environmental half-lives in U.S agricultural soils, and confirms the utility of using mega-composite sampling for economical tracking of chemical inventories in biosolids on a national scale.

Cline, E.T., Q.T.N. Nguyen, et al. (2012) "Metal stress and decreased tree growth in response to biosolids application in greenhouse seedlings and in situ Douglas-fir stands." Environ Pollut: **160**(1): 139-44.

To assess physiological impacts of biosolids on trees, metal contaminants and phytochelatins were measured in Douglas-fir stands amended with biosolids in 1982. A subsequent greenhouse study compared these same soils to soils amended with fresh wastewater treatment plant biosolids. Biosolids-amended field soils had significantly higher organic matter, lower pH, and elevated metals even after 25 years. In the field study, no beneficial growth effects were detected in biosolids-amended stands and in the greenhouse study both fresh and historic biosolids amendments resulted in lower seedling growth rates. Phytochelatins - bioindicators of intracellular metal stress - were elevated in foliage of biosolids-amended stands, and significantly higher in roots of seedlings grown with fresh biosolids. These results demonstrate that biosolids amendments have short- and long-term negative effects that may counteract the expected tree growth benefits.

Cunningham, V.L., V.J. D'Aco, et al. (2012) "Predicting concentrations of trace organic compounds in municipal wastewater treatment plant sludge and biosolids using the PhATE model." Integr Environ Assess Manag **8**(3): 530-42.

This article presents the capability expansion of the PhATE™ (pharmaceutical assessment and transport evaluation) model to predict concentrations of trace organics in sludges and biosolids from municipal wastewater treatment plants (WWTPs). PhATE was originally developed as an empirical model to estimate potential concentrations of active pharmaceutical ingredients (APIs) in US surface and drinking waters that could result from patient use of medicines. However, many compounds, including pharmaceuticals, are not completely transformed in WWTPs and remain in biosolids that may be applied to land as a soil amendment. This practice leads to concerns about potential exposures of people who may come into contact with amended soils and also about potential effects to plants and animals living in or contacting such soils. The model estimates the mass of API in WWTP influent based on the population served, the API per capita use, and the potential loss of the compound associated with human use (e.g., metabolism). The mass of API on the treated biosolids is then estimated based on partitioning to primary and secondary solids, potential loss due to biodegradation in secondary treatment (e.g., activated sludge), and potential loss during sludge treatment (e.g., aerobic digestion, anaerobic digestion, composting). Simulations using 2 surrogate compounds show that predicted environmental concentrations (PECs) generated by PhATE are in very good agreement with measured concentrations, i.e., well within 1 order of magnitude. Model simulations were then carried out for 18 APIs

representing a broad range of chemical and use characteristics. These simulations yielded 4 categories of results: 1) PECs are in good agreement with measured data for 9 compounds with high analytical detection frequencies, 2) PECs are greater than measured data for 3 compounds with high analytical detection frequencies, possibly as a result of as yet unidentified depletion mechanisms, 3) PECs are less than analytical reporting limits for 5 compounds with low analytical detection frequencies, and 4) the PEC is greater than the analytical method reporting limit for 1 compound with a low analytical detection frequency, possibly again as a result of insufficient depletion data. Overall, these results demonstrate that PhATE has the potential to be a very useful tool in the evaluation of APIs in biosolids. Possible applications include: prioritizing APIs for assessment even in the absence of analytical methods; evaluating sludge processing scenarios to explore potential mitigation approaches; using in risk assessments; and developing realistic nationwide concentrations, because PECs can be represented as a cumulative probability distribution. Finally, comparison of PECs to measured concentrations can also be used to identify the need for fate studies of compounds of interest in biosolids.

Davis, E.F., S.L. Klosterhaus, et al. (2012) "Measurement of flame retardants and triclosan in municipal sewage sludge and biosolids." *Environ Int* 40: 1-7.

As polybrominated diphenyl ethers (PBDEs) face increasing restrictions worldwide, several alternate flame retardants are expected to see increased use as replacement compounds in consumer products. Chemical analysis of biosolids collected from wastewater treatment plants (WWTPs) can help determine whether these flame retardants are migrating from the indoor environment to the outdoor environment, where little is known about their ultimate fate and effects. The objective of this study was to measure concentrations of a suite of flame retardants, and the antimicrobial compound triclosan, in opportunistic samples of municipal biosolids and the domestic sludge Standard Reference Material (SRM) 2781. Grab samples of biosolids were collected from two WWTPs in North Carolina and two in California. Biosolids samples were also obtained during three subsequent collection events at one of the North Carolina WWTPs to evaluate fluctuations in contaminant levels within a given facility over a period of three years. The biosolids and SRM 2781 were analyzed for PBDEs, hexabromobenzene (HBB), 1,2-bis(2,4,6-tribromophenoxy)ethane (BTBPE), 2-ethylhexyl 2,3,4,5-tetrabromobenzoate (TBB), di(2-ethylhexyl)-2,3,4,5-tetrabromophthalate (TBPH), the chlorinated flame retardant Dechlorane Plus (syn- and anti-isomers), and the antimicrobial agent 5-chloro-2-(2,4-dichlorophenoxy)phenol (triclosan). PBDEs were detected in every sample analyzed, and SigmaPBDE concentrations ranged from 1750 to 6358ng/g dry weight. Additionally, the PBDE replacement chemicals TBB and TBPH were detected at concentrations ranging from 120 to 3749 ng/g dry weight and from 206 to 1631 ng/g dry weight, respectively. Triclosan concentrations ranged from 490 to 13,866 ng/g dry weight. The detection of these contaminants of emerging concern in biosolids suggests that these chemicals have the potential to migrate out of consumer products and enter the outdoor environment.

Doud, C.W., D.B. Taylor, et al. (2012) "Dewatered Sewage Biosolids Provide a Productive Larval Habitat for Stable Flies and House Flies (Diptera: Muscidae)." *J Med Entomol* 49(2): 286-92.

Species diversity and seasonal abundance of muscoid flies (Diptera: Muscidae) developing in

biosolid cake (dewatered biosolids) stored at a wastewater treatment facility in northeastern Kansas were evaluated. Emergence traps were deployed 19 May through 20 October 2009 (22 wk.) and 27 May through 18 November 2010 (25 wk.). In total, 11,349 muscoid flies were collected emerging from the biosolid cake. Stable flies (*Stomoxys calcitrans* (L.)) and house flies (*Musca domestica* (L.)), represented 80 and 18% of the muscoid flies, respectively. An estimated 550 stable flies and 220 house flies per square-meter of surface area developed in the biosolid cake annually producing 450,000 stable flies and 175,000 house flies. Stable fly emergence was seasonally bimodal with a primary peak in mid-July and a secondary peak in late August. House fly emergence peaked with the first stable fly emergence peak and then declined gradually for the remainder of the year. House flies tended to emerge from the biosolid cake sooner after its deposition than did stable flies. In addition, house fly emergence was concentrated around midsummer whereas stable fly emergence began earlier in the spring and continued later into the fall. Biosolid age and temperature were the most important parameters affecting emergence for house flies and stable flies, whereas precipitation was not important for either species. This study highlights the importance of biosolid cake as a larval developmental habitat for stable flies and house flies.

Egan M. (2013) "Biosolids management strategies: an evaluation of energy production as an alternative to land application." *Environ Sci Pollut Res Int* **20**(7): 4299-310.

Currently, more than half of the biosolids produced within the USA are land applied. Land application of biosolids introduces organic contaminants into the environment. There are potential ecological and human health risks associated with land application of biosolids. Biosolids may be used as a renewable energy source. Nutrients may be recovered from biosolids used for energy generation for use as fertilizer. The by-products of biosolids energy generation may be used beneficially in construction materials. It is recommended that energy generation replace land application as the leading biosolids management strategy.

Esseili, M.A., I.I. Kassem, et al. (2012) "Genetic evidence for the offsite transport of *E. coli* associated with land application of Class B biosolids on agricultural fields." *Sci Total Environ* **433**: 273-80.

The land-application of Class B biosolids is tightly regulated to allow for natural attenuation of co-applied pathogens. Since many agricultural fields that receive biosolids are artificially drained through subsurface tiles, it is possible that under scenarios of excessive drainage associated with heavy rainfall events, co-applied pathogens might be carried offsite to contaminate nearby surface waters. To address this concern, we used genetic as well as traditional methods to investigate the impact of rainfall on the offsite drainage of *Escherichia coli* from agricultural fields during biosolids application. Water samples from field drain tiles and a reference field (no biosolids applied) were collected pre-, during and post-biosolids application, while samples of applied biosolids were collected on site during application. The samples were analyzed for *E. coli*-density and community- and isolate-fingerprinting to assess the genetic link between *E. coli* in drainage water and those co-applied with biosolids. In contrast to *E. coli* densities present in the reference field drainage, our results revealed that post-application drainage water collected from biosolids treated fields contained significantly higher *E. coli* densities following heavy rainfall events, as compared to light rainfall events. Also, in contrast to the reference field, heavy rainfall correlated significantly with increased similarity of *E. coli* community fingerprints occurring in biosolids to those draining from

treated field. Fingerprinting of individual *E. coli* revealed a high similarity (>94%) between some isolates collected from biosolids and post-application drainage water. Using a combination of enumeration and genetic typing methods, we show that heavy rainfall following biosolids application to agricultural fields induced the offsite transport of biosolids-associated *E. coli*, potentially compromising the quality of water draining through the watershed.

Gao, P., M. Munir, et al. (2012) "Correlation of tetracycline and sulfonamide antibiotics with corresponding resistance genes and resistant bacteria in a conventional municipal wastewater treatment plant." *Sci Total Environ* 421-422: 173-83.

Antibiotics and corresponding resistance genes and resistant bacteria have been considered as emerging pollutants worldwide. Wastewater treatment plants (WWTPs) are potential reservoirs contributing to the evolution and spread of antibiotic resistance. In this study, total concentrations of tetracycline and sulfonamide antibiotics in final effluent were detected at 652.6 and 261.1ng/L, respectively, and in treated sludge, concentrations were at 1150.0 and 76.0μg/kg dry weight (dw), respectively. The quantities of antibiotic resistance genes and antibiotic resistant bacteria in final effluent were quantified in the range of 9.12×10^5 - 1.05×10^6 gene abundances /100mL (genomic copies/100mL) and 1.05×10^1 - 3.09×10^3 CFU/mL, respectively. In treated sludge, they were quantified at concentrations of 1.00×10^8 - 1.78×10^9 gene abundances/100mL and 7.08×10^6 - 1.91×10^8 CFU/100mL, respectively. Significant reductions (2-3 logs, $p < 0.05$) of antibiotic resistance genes and antibiotic resistant bacteria were observed between raw influent and final effluent. The gene abundances of tetO and tetW normalized to that of 16S rRNA genes indicated an apparent decrease as compared to sulI genes, which remained stable along each treatment stage. Significant correlations ($R(2)=0.75-0.83$, $p < 0.05$) between numbers of resistant bacteria and antibiotic concentrations were observed in raw influent and final effluent. No significance ($R(2)=0.15$, $p > 0.05$) was found between tet genes (tetO and tetW) with concentration of tetracyclines identified in wastewater, while a significant correlation ($R(2)=0.97$, $p < 0.05$) was observed for sulI gene and total concentration of sulfonamides. Correlations of the quantities of antibiotic resistance genes and antibiotic resistant bacteria with corresponding concentrations of antibiotics in sludge samples were found to be considerably weak ($R(2)=0.003-0.07$).

Gelsleichter, J. and N.J. Szabo, et al. (2013) "Uptake of human pharmaceuticals in bull sharks (*Carcharhinus leucas*) inhabiting a wastewater-impacted river." *Sci Total Environ* 456-457:196-201.

The presence of human pharmaceuticals in sewage-impacted ecosystems is a growing concern that poses health risks to aquatic wildlife. Despite this, few studies have investigated the uptake of active pharmaceutical ingredients (APIs) in aquatic organisms. In this study, the uptake of 9 APIs from human drugs was examined and compared in neonate bull sharks (*Carcharhinus leucas*) residing in pristine (Myakka River) and wastewater-impacted (Caloosahatchee River) tributaries of Florida's Charlotte Harbor estuary. The synthetic estrogen used in human contraceptives (17α-ethynylestradiol) and 6 of the selective serotonin/norepinephrine reuptake inhibitors (citalopram, fluoxetine, fluvoxamine, paroxetine, sertraline, venlafaxine) used in human antidepressants were observed at detectable and, in some cases, quantifiable levels in plasma of Caloosahatchee River sharks.

Comparatively, only venlafaxine was detected in the plasma of a single Myakka River shark at a level below the limit of quantitation. These results suggest that sharks residing in wastewater-impacted habitats accumulate APIs, a factor that may pose special risks to *C. leucas* since it is one of few shark species to regularly occupy freshwater systems. Further research is needed to determine if the low levels of API uptake observed in Caloosahatchee River bull sharks pose health risks to these animals.

Gerba, C.P., A.H. Tamimi, et al. (2011) "Sources of microbial pathogens in municipal solid waste landfills in the United States of America." *Waste Manag Res* **29**(8): 781-90.

Municipal solid waste (MSW) categories, as specified by United States Environmental Protection Agency (US EPA), were evaluated for their relative contribution of pathogenic viruses, bacteria, and protozoan parasites into MSW landfills from 1960 to 2007. The purpose of this study was to identify trends and quantify the potential contribution of pathogens in MSW as an aid to the assessment of potential public health risks. A review of the literature was conducted to estimate values for the concentrations of faecal indicator bacteria and pathogens in the major categories of MSW. The major sources of MSW contributing enteric pathogens were food waste, pet faeces, absorbent products, and biosolids. During the last 47 years, recycling of glass, metals, plastic, paper and some organic wastes in MSW has increased, resulting in a decreased proportion of these materials in the total landfilled MSW. The relative proportion of remaining waste materials has increased; several of these waste categories contain pathogens. For all potential sources, food waste contributes the greatest number of faecal coliforms (80.62%). The largest contribution of salmonellae (97.27%), human enteroviruses (94.88%) and protozoan parasites (97%) are expected to come from pet faeces. Biosolids from wastewater treatment sludge contribute the greatest number of human noroviruses (99.94%). By comparison, absorbent hygiene products do not appear to contribute significantly to overall pathogen loading for any group of pathogens. This is largely due to the relatively low volume of these pathogen sources in MSW, compared, for example, with food waste at almost 40% of total MSW.

Gerrity, D. and S. Snyder. (2011) "Review of Ozone for Water Reuse Applications: Toxicity, Regulations, and Trace Organic Contaminant Oxidation." *Ozon Sci Eng* **33**(4): 253-66.

Increased public awareness, potential human health effects, and demonstrated impacts on aquatic ecosystems have stimulated recent interest in pharmaceuticals, personal care products (PPCPs), and endocrine-disrupting compounds (EDCs) in water and wastewater. Due to the potential public and environmental health implications, some agencies are taking a proactive approach to controlling trace organic contaminant (TOrc) concentrations in water supplies. This review describes some of the research related to the toxicity and estrogenicity of wastewater-derived TOrcs in addition to regulatory guidance from several international agencies. This review also evaluates pilot- and full-scale studies to characterize the efficacy of ozonation for TOrc mitigation in wastewater applications.

Gewurtz, S.B., S.M. Backus, et al. (2013) "Perfluoroalkyl acids in the Canadian environment: multi-media assessment of current status and trends." *Environ Int* **59**: 183-200.

In Canada, perfluoroalkyl acids (PFAAs) have been the focus of several monitoring programs and research and surveillance studies. Here, we integrate recent data and perform a multi-media assessment to examine the current status and ongoing trends of PFAAs in

Canada. Concentrations of perfluorooctane sulfonate (PFOS), perfluorooctanoate (PFOA), and other long-chain perfluorocarboxylates (PFCAs) in air, water, sediment, fish, and birds across Canada are generally related to urbanization, with elevated concentrations observed around cities, especially in southern Ontario. PFOS levels in water, fish tissue, and bird eggs were below their respective Draft Federal Environmental Quality Guidelines, suggesting there is low potential for adverse effects to the environment/organisms examined. However, PFOS in fish and bird eggs tended to exceed guidelines for the protection of mammalian and avian consumers, suggesting a potential risk to their wildlife predators, although wildlife population health assessments are needed to determine whether negative impacts are actually occurring. Long-term temporal trends of PFOS in suspended sediment, sediment cores, Lake Trout (*Salvelinus namaycush*), and Herring Gull (*Larus argentatus*) eggs collected from Lake Ontario increased consistently from the start of data collection until the 1990s. However, after this time, the trends varied by media, with concentrations stabilizing in Lake Trout and Herring Gull eggs, and decreasing and increasing in suspended sediment and the sediment cores, respectively. For PFCAs, concentrations in suspended sediment, sediment cores, and Herring Gulls generally increased from the start of data collection until present and concentrations in Lake Trout increased until the late 1990s and subsequently stabilized. A multimedia comparison of PFAA profiles provided evidence that unexpected patterns in biota of some of the lakes were due to unique source patterns rather than internal lake processes. High concentrations of PFAAs in the leachate and air of landfill sites, in the wastewater influent/effluent, biosolids, and air at wastewater treatment plants, and in indoor air and dust highlight the waste sector and current-use products (used primarily indoors) as ongoing sources of PFAAs to the Canadian environment. The results of this study demonstrate the utility of integrating data from different media. Simultaneous evaluation of spatial and temporal trends in multiple media allows inferences that would be impossible with data on only one medium. As such, more co-ordination among monitoring sites for different media is suggested for future sampling, especially at the northern sites. We emphasize the importance of continued monitoring of multiple-media for determining future responses of environmental PFAA concentrations to voluntary and regulatory actions.

Gore, J.M. (2012) "Effects of moisture augmentation of municipal solid waste through addition of food waste or wastewater treatment biosolids on bio-gas formation for power generation. Masters Abstracts International. Vol. 51, no. 03, 99 p." Masters Abstracts Int **51**(03): 1-100.

An investigation into the effect of moisture augmentation by manipulation of food waste proportion or wastewater treatment plant biosolids proportion was undertaken to determine the effects on production of methane and other biogases from municipal solid waste (MSW). Laboratory microcosm experiments were performed to determine the effect of various proportions of influent waste streams on the production of biogas. Results indicated that moisture augmentation through the addition of food waste to MSW increases the overall bio-gas and hydrogen gas formed during fermentation. Moisture augmentation through addition of wastewater treatment bio-solids lead to inconclusive results. Addition of food waste to MSW would allow for an increase in combustible gas production through formation of additional hydrogen gas in arid region landfills.

Gottschall, N., E. Topp, et al. (2012) "Pharmaceutical and personal care products in groundwater, subsurface drainage, soil, and wheat grain, following a high single application of municipal biosolids to a field." *Chemosphere* **87**(2): 194-203.

Dewatered municipal biosolids (DMBs) were applied to a field at a rate of ~22 Mg dw ha⁽⁻¹⁾ in October 2008. Pharmaceuticals and personal care products (PPCPs) were monitored in groundwater, tile drainage, soil, DMB aggregates incorporated into the soil post-land application, and in the grain of wheat grown on the field for a period of ~1 year following application. Over 80 PPCPs were analyzed in the source DMB. PPCPs selected for in-depth monitoring included: antibiotics (tetracyclines, fluoroquinolones), bacteriocides (triclosan, triclocarban), beta-blockers (atenolol, propranolol, metoprolol), antidepressants (fluoxetine, citalopram, venlafaxine, sertraline), antifungals (miconazole), analgesics (acetaminophen, ibuprofen) and anticonvulsants (carbamazepine). PPCPs in tile were observed twice, ~3 weeks and 2 months post-application. Of all PPCPs measured in tile drainage, only carbamazepine, ibuprofen, acetaminophen, triclosan, triclocarban, venlafaxine, and citalopram were detected (5-74 ng L⁽⁻¹⁾). PPCPs were not detected in groundwater >2 m depth below the soil surface, and concentrations above detection limits at 2 m depth were only observed once just after the first rain event post-application. In groundwater, all compounds found in tile, except carbamazepine, acetaminophen and citalopram, were detected (10-19 ng L⁽⁻¹⁾). PPCPs were detected in DMB aggregates incorporated in soil up to 1 year post-application, with miconazole and fluoxetine having the lowest percent reductions over 1 year (~50%). For several compounds in these aggregates, concentration declines were of exponential decay form. No PPCPs were detected in the grain of wheat planted post-application on the field. No PPCPs were ever detected in water, soil or grain samples from the reference plot, where no DMB was applied.

Gottschall, N., E. Topp, et al. (2013) "Hormones, sterols, and fecal indicator bacteria in groundwater, soil, and subsurface drainage following a high single application of municipal biosolids to a field." *Chemosphere* **91**(3): 275-86.

A land application of dewatered municipal biosolids (DMB) was conducted on an agricultural field in fall 2008 at a rate of 22Mg dry weight (dw) ha⁽⁻¹⁾. Pre- and post-application, hormone, sterol and fecal indicator bacteria concentrations were measured in tile drainage water, groundwater (2, 4, 6m depth), surface soil cores, and DMB aggregates incorporated in the soil (~0.2m depth) for a period of roughly 1year post-application. Hormones and sterols were detected up to 1year post-application in soil and in DMB aggregates. Hormone (androsterone, desogestrel, estrone) contamination was detected briefly in tile water samples (22d and ~2months post-app), at lowngL⁽⁻¹⁾ concentrations (2-34ngL⁽⁻¹⁾). Hormones were not detected in groundwater. Sterols were detected in tile water throughout the study period post-application, and multiple fecal sterol ratios suggested biosolids as the source. Coprostanol concentrations in tile water peaked at >1000ngL⁽⁻¹⁾ (22d post-app) and were still >100ngL⁽⁻¹⁾ at 6months post-application. Fecal indicator bacteria were detected throughout the study period in tile water, groundwater (≤2m depth), soil and DMB aggregate samples. These bacteria were strongly linearly related to coprostanol in tile water (R⁽²⁾>0.92, p<0.05). The limited transport of hormones and sterols to tile drainage networks may be attributed to a combination of the hydrophobicity of these compounds and limited macroporosity of the field soil. This transitory contamination from hormones and sterols is unlikely to result in any significant pulse exposure risk in subsurface

drainage and groundwater.

Hale, R.C., M.J. La Guardia, et al. (2012) "Polybrominated diphenyl ethers in U.S. sewage sludges and biosolids: temporal and geographical trends and uptake by corn following land application." *Environ Sci Technol* **46**(4): 2055-63.

Polybrominated diphenyl ethers (PBDEs) have been used extensively to flame-retard polymers and textiles. These persistent chemicals enter wastewater streams following manufacture, use, and disposal, concentrating in the settled solids during treatment. Land application of stabilized sewage sludge (known as biosolids) can contribute PBDEs to terrestrial systems. Monitoring sludge/biosolids contaminant burdens may be valuable in revealing trends in societal chemical usage and environmental release. In archived Chicago area sludges/biosolids from 1975 to 2008, penta-BDE concentrations increased and then plateaued after about 2000. Penta-BDE manufacture in the United States ended in December 2004. Deca-BDE concentrations in biosolids rose from 1995 to 2008, doubling on a 5-year interval. Evaluation of U.S. Environmental Protection Agency Targeted National Sewage Sludge Survey data from 2006 to 2007 revealed highest penta-BDE biosolids levels from western and lowest from northeastern wastewater treatment plants (2120 and 1530 mug/kg, respectively), consistent with patterns reported in some recent indoor dust and human blood studies. No significant regional trends were observed for deca-BDE concentrations. Congener patterns in contemporary Chicago biosolids support the contention that BDE-209 can be dehalogenated to less brominated congeners. Biosolids application on agricultural fields increased PBDE soil concentrations. However, corn grown thereon did not exhibit measurable PBDE uptake; perhaps due to low bioavailability of the biosolids-associated flame retardants.

Hamid, H. and C. Eskicioglu. (2012) "Fate of estrogenic hormones in wastewater and sludge treatment: A review of properties and analytical detection techniques in sludge matrix." *Water Res* **46**(18): 5813-33.

Estrogenic hormones (estrone (E1), 17 β -estradiol (E2), estriol (E3), 17 α -ethinylestradiol (EE2)) are the major contributor to the total estrogenicity in waterways. Presence of these compounds in biosolids is also causing concern in terms of their use as soil amendment. In comparison with wastewater treatment, removal of estrogenic compounds in sewage sludge has received less attention. This paper presents a literature review regarding the source and occurrence of these pollutants in our environment. The removal pathways of estrogenic compounds in engineered systems, such as full-scale wastewater treatment plants (WWTPs), are also discussed. Review of the fate studies revealed that activated sludge system with nutrient removal shows very high (>90%) removal of estrogenic hormones in most of the cases. Although, aerobic digestion showed better attenuation of estrogenic compounds, anaerobic digestion increased the overall estrogenicity of biosolids. Finally, this paper highlights the challenges involved in analytical determination of these compounds in sewage sludge matrix.

Holling, C.S., J.L. Bailey, et al. (2012) "Uptake of human pharmaceuticals and personal care products by cabbage (*Brassica campestris*) from fortified and biosolids-amended soils." *J Environ Monit* **14**(11): 3029-36.

Human pharmaceuticals and personal care products (PPCPs) are routinely found in biosolids

from wastewater treatment plants (WWTPs). Once land applied, the PPCPs in biosolids are potentially available for plant uptake and bioaccumulation. This study used a greenhouse model to investigate uptake of PPCPs commonly detected in biosolids by the agricultural plant Chinese cabbage (*Brassica campestris*). Two series of greenhouse experiments were conducted as part of this project. In the first set of experiments, four pharmaceuticals were added to an organic matter-rich soil in environmentally relevant concentrations based on typical biosolids application rates, resulting in final soil concentrations of 2.6 ng g⁻¹ carbamazepine, 3.1 ng g⁻¹ sulfamethoxazole, 5.4 ng g⁻¹ salbutamol, and 0.5 ng g⁻¹ trimethoprim. In the second set of experiments, the cabbage was grown in soil amended with an agronomic rate of biosolids from a local WWTP. The ambient concentration of PPCPs in the biosolids resulted in final soil concentrations of 93.1 ng g⁻¹ carbamazepine, 67.4 ng g⁻¹ sulfamethoxazole, 30.3 ng g⁻¹ salbutamol, 433.7 ng g⁻¹ triclosan, and 24.7 ng g⁻¹ trimethoprim. After growing to maturity, the aerials of the plants were separated from roots and the two tissue types were analyzed separately. All four human pharmaceuticals were detected in both tissues in the cabbage grown in the soil fortified with the four pharmaceuticals with median concentrations of 255.4 ng g⁻¹ aerials and 272.9 ng g⁻¹ roots carbamazepine; 222.8 ng g⁻¹ aerials and 260.3 ng g⁻¹ roots sulfamethoxazole; 108.3 ng g⁻¹ aerials and 140.6 ng g⁻¹ roots salbutamol; and 20.6 ng g⁻¹ aerials and 53.7 ng g⁻¹ roots trimethoprim. Although all study compounds were present in the biosolids-amended planting soil, only carbamazepine (317.6 ng g⁻¹ aerials and 416.2 ng g⁻¹ roots), salbutamol (21.2 ng g⁻¹ aerials and 187.6 ng g⁻¹ roots), and triclosan (22.9 ng g⁻¹ aerials and 1220.1 ng g⁻¹ roots) were detected in the aerials of the cabbage. In addition to the study compounds detected in the aerials, sulfamethoxazole was detected in the roots of one of the plants in the biosolid-amended soil. In comparison to many previous studies that have utilized PPCP concentration that exceed environmentally relevant concentrations, plants in this study were exposed to environmentally relevant concentrations of the PPCPs, yet resulted in uptake concentrations similar to or greater than those reported in comparable studies. We suggest that rhizosphere conditions, particularly the presence of dissolved organic matter in the planting matrix, might be one of the critical factors determining mobilization and bioavailability of xenobiotic compounds such as PPCPs.

Hope, B.K., L. Pillsbury, et al. (2012) "A state-wide survey in Oregon (USA) of trace metals and organic chemicals in municipal effluent." *Sci Total Environ* 417-418: 263-72.

Oregon's Senate Bill 737, enacted in 2007, required the state's 52 largest municipal wastewater treatment plants (WWTP) and water pollution control facilities (WPCF) to collect effluent samples in 2010 and analyze them for persistent organic pollutants. These facilities are located state-wide and represent a variety of treatment types, service population sizes, geographic areas, and flow conditions. Of the 406 chemicals ultimately analyzed, 114 were detected above the level of quantification (LOQ) in at least one sample. Few persistent pollutants were found possibly because of their diversion from effluent via sorption to sludge (solids phase) or high LOQs for certain chemicals. Several pesticides, as well as benzene and phenol degradation products, all previously unreported in effluent, were detected. Ten polychlorinated biphenyls (PCB) congeners were present at low concentrations in ≤ 10 samples, while polychlorinated naphthalenes and dioxins/furans were not detected at all. Twenty-one polybrominated diphenyl ether (PBDE) congeners were found, nine of which have been reported in Osprey eggs in Oregon and Washington. Methylmercury was present

in 65% of samples, with average and maximum concentrations of 0.18 and 1.36 ng/L, respectively. Although they are generally assumed to be innocuous by-products of sewage treatment, additional research is needed on potential impacts to aquatic ecosystems of high loadings of coprostanol and cholesterol. These results suggest that effluent, rather than just receiving waters, should itself be analyzed for a wide range of contaminants in order to understand how upstream sources, conveyed through WWTPs and WPCFs, could be impacting aquatic ecosystems.

James, M.O., C.J. Marth, et al. (2012) "Slow O-demethylation of methyl triclosan to triclosan, which is rapidly glucuronidated and sulfonated in channel catfish liver and intestine." *Aquat Toxicol* 124-125: 72-82.

The antibacterial personal care product triclosan is discharged in municipal waste, and converted in part by bacteria in sewage sludge and soil to its more lipid-soluble methyl ether, methyl triclosan. Triclosan and methyl triclosan have been detected in water, sediment, fish and invertebrates near sewage treatment facilities. Understanding the biotransformation of methyl triclosan and triclosan in a model food fish, the channel catfish, will be of value in assessing the likelihood that these compounds will bioaccumulate in exposed fish, and therefore potentially pass up the food chain. We hypothesize that cytochrome P450 will catalyze the O-demethylation of methyl triclosan to yield triclosan, which is likely to undergo glucuronidation or sulfonation of the phenolic hydroxyl group. Conversion of methyl triclosan to triclosan was measured by LC/MS/MS following aerobic incubation of varying concentrations of methyl triclosan with NADPH and hepatic and intestinal microsomes from untreated, 3-methylcholanthrene-treated (10 mg/kg, i.p.) or PCB-126-treated (0.1 mg/kg, i.p.) channel catfish (n=4 per treatment group). The $K(m)$ values for methyl triclosan were similar for untreated, 3-methylcholanthrene-treated and PCB-126-treated catfish liver microsomes, ranging from 80 to 250 μ M. $V(max)$ values for O-demethylation ranged from 30 to 150 pmol/min/mg protein, with no significant differences between controls, PCB-126-treated or 3-methylcholanthrene-treated fish, suggesting that methyl triclosan O-demethylation was not a CYP1-catalyzed reaction. Methyl triclosan O-demethylation activities in intestinal microsomes were similar to or lower than those found with liver microsomes. The calculated rate of O-demethylation of methyl triclosan in catfish liver at 1 μ M, a concentration reported in exposed fish, and 21°C, an early summer water temperature, is 0.10 pmol/min/mg protein. This slow rate of metabolism suggests that upon continued exposure, methyl triclosan may bioaccumulate in the channel catfish. Triclosan itself, however, was readily glucuronidated by hepatic and intestinal microsomes and sulfonated by hepatic and intestinal cytosol. Triclosan glucuronidation followed Michaelis-Menten kinetics when rates were measured across a concentration range of 5-1000 μ M, whereas triclosan sulfonation exhibited substrate inhibition at concentrations above 10-20 μ M in both intestinal and hepatic cytosol. Based on the enzyme kinetic constants measured in hepatic and intestinal fractions at 21°C, triclosan at 1 μ M could be glucuronidated at rates of 23 and 3.2 pmol/min/mg protein respectively in liver and intestine, and sulfonated at rates of 277 (liver) and 938 (intestine) pmol/min/mg protein. These rates are much higher than the rates of demethylation of methyl triclosan, and suggest that triclosan would be rapidly cleared and unlikely to bioaccumulate in catfish tissues.

Kim, B., M. Murayama, et al. (2012) "Characterization and environmental implications of nano- and larger TiO(2) particles in sewage sludge, and soils amended with sewage sludge." *J Environ Monit* **14**(4): 1129-37.

Titanium dioxide (TiO(2)) is the most extensively used engineered nanoparticle to date, yet its fate in the soil environment has been investigated only rarely and is poorly understood. In the present study, we conducted two field-scale investigations to better describe TiO(2) nano- and larger particles in their most likely route of entry into the environment, i.e., the application of biosolids to soils. We particularly concentrated on the particles in the nano-size regime due to their novel and commercially useful properties. First, we analyzed three sewage sludge products from the US EPA TNSSS sampling inventory for the occurrence, qualitative abundance, and nature of TiO(2) nano- and larger particles by using analytical scanning electron microscopy and analytical (scanning) transmission electron microscopy. Nano- and larger particles of TiO(2) were repeatedly identified across the sewage sludge types tested, providing strong evidence of their likely concentration in sewage sludge products. The TiO(2) particles identified were as small as 40 nm, and as large as 300 nm, having faceted shapes with the rutile crystal structure, and they typically formed small, loosely packed aggregates. Second, we examined surface soils in mesocosms that had been amended with Ag nanoparticle-spiked biosolids for the occurrence of TiO(2) particles. An aggregate of TiO(2) nanoparticles with the rutile structure was again identified, but this time TiO(2) nanoparticles were found to contain Ag on their surfaces. This suggests that TiO(2) nanoparticles from biosolids can interact with toxic trace metals that would then enter the environment as a soil amendment. Therefore, the long-term behavior of TiO(2) nano- and larger particles in sewage sludge materials as well as their impacts in the soil environment need to be carefully considered.

Kim, M., P. Guerra, et al. (2013) "Polybrominated diphenyl ethers in sewage sludge and treated biosolids: effect factors and mass balance." *Water Res* **47**(17): 6496-505.

Polybrominated diphenyl ether (PBDE) flame retardants have been consistently detected in sewage sludge and treated biosolids. Two hundred and eighty-eight samples including primary sludge (PS), waste biological sludge (WBS) and treated biosolids from fifteen wastewater treatment plants (WWTPs) in Canada were analyzed to investigate the factors affecting accumulation of PBDEs in sludge and biosolids. Factors examined included environmental/sewershed conditions and operational parameters of the WWTPs. PBDE concentrations in PS, WBS and treated biosolids were 230-82,000 ng/g, 530-8800 ng/g and 420-6000 ng/g, respectively; BDE-209, -99, and -47 were the predominant congeners. Concentrations were influenced by industrial input, leachate, and temperature. Several examinations including the measurement of BDE-202 indicated minimal debromination during wastewater treatment. Estimated solids-liquid distribution coefficients were moderately correlated to hydraulic retention time, solids loading rate, mixed liquor suspended solids, solids retention time, and removal of organic solids, indicating that PBDE partitioning to solids can be optimized by WWTPs' operational conditions. Solids treatment type strongly affected PBDE levels in biosolids: 1.5 times increase after solids digestion, therefore, digestion efficiency could be a potential factor for variability of PBDEs concentration. In contrast, alkaline treatment reduced PBDE concentrations in biosolids. Overall, mass balance approaches confirmed that PBDEs were removed from the liquid stream through partitioning to solids. Variability of PBDE levels in biosolids could result in

different PBDEs burdens to agricultural land, and different exposure levels to soil organisms.

Kwon, J.W. and K. Xia. (2012) "Fate of triclosan and triclocarban in soil columns with and without biosolids surface application." *Environ Toxicol Chem* **31**(2): 262-9.

The leaching and transformation behaviors of triclosan (TCS) and triclocarban (TCC) in soil columns (20 cm high, 4 cm in diameter) packed with an agricultural soil (Roxana very fine sandy loam) with and without biosolids surface application were investigated. The column leachates and soil samples were analyzed for TCS, TCC, and their transformation products. Significantly more TCS was transformed compared with TCC. Surface application of biosolids significantly retarded their transformation. Downward movement of TCS and TCC occurred within a 10-cm soil depth. Methyl-TCS was not detectable in the leachates but was detected in the top 5-cm soil layer, with more appearing in the biosolids-applied soil. At the end of the column study, carbanilide (CBA) was the only detectable TCC reductive dechlorination product in the soil. No TCC reductive dechlorination products were detectable in the leachates. Detection of 3,4-dichloroaniline (3,4-DCA) and 4-chloroaniline (4-CA) suggested the occurrence of TCC hydrolysis. Rapid leaching of 4-CA through the soil column was observed. The 3,4-DCA was detected throughout the entire 20-cm depth of the soil column but not in the leachates. The fact that only small percentages of the transformed TCS and TCC appeared, after a 101-d column study, in the forms of the products analyzed suggested that either the investigated transformation pathways were minor pathways or further rapid transformation of those products had occurred.

Lajeunesse, A., S.A. Smyth, et al. (2012) "Distribution of antidepressant residues in wastewater and biosolids following different treatment processes by municipal wastewater treatment plants in Canada." *Water Res* **46**(17): 5600-12.

The fate of 14 antidepressants along with their respective N-desmethyl metabolites and the anticonvulsive drug carbamazepine (CBZ) was studied in 5 different sewage treatment plants (STPs) across Canada. Using two validated LC-MS/MS analytical methods, the concentrations of the different compounds were determined in raw influent, final effluent and treated biosolids samples. Out of the 15 compounds investigated, 13 were positively detected in most 24-h composite raw influent samples. Analysis showed that venlafaxine (VEN), its metabolite O-desmethylvenlafaxine (DVEN), citalopram (CIT), and CBZ were detected at the highest concentrations in raw influent (up to 4.3 $\mu\text{g L}^{-1}$ for DVEN). Cumulated results showed strong evidence that primary treatment and trickling filter/solids contact has limited capacity to remove antidepressants from sewage, while activated sludge, biological aerated filter, and biological nutrient removal processes yielded moderate results (mean removal rates: 30%). The more recalcitrant compounds to be eliminated from secondary STPs were VEN, DVEN and CBZ with mean removal rates close to 12%. Parent compounds were removed to a greater degree than their metabolites. The highest mean concentrations in treated biosolids samples were found for CIT (1033 ng g^{-1}), amitriptyline (768 ng g^{-1}), and VEN (833 ng g^{-1}). Experimental sorption coefficients ($K(d)$) were also determined. The lowest $K(d)$ values were obtained with VEN, DVEN, and CBZ (67-490 L kg^{-1}). Sorption of these compounds on solids was assumed negligible ($\log K(d) \leq 2$). However, important sorption on solids was observed for sertraline, desmethylsertraline, paroxetine and fluoxetine ($\log K(d) > 4$).

Lee, H.B., J. Kohli, et al. (2014) "Selected chloro and bromo derivatives of triclosan--syntheses and their occurrence in Canadian sewage and biosolid samples." Environ Sci Pollut Res Int **21**(1): 314-24.

The occurrence of triclosan (TCS), a general purpose antibacterial agent contained in numerous consumer and personal-care products, in the aquatic environment is well known. To a lesser degree, the formation of chlorinated and brominated derivatives of TCS during the chlorination of the antibacterial has also been reported. Presumably due to the lack of authentic standards, very few reports have been published on the levels of these halogenated TCSs in the environment. For this purpose, we have synthesized six selected halogenated derivatives of TCS, namely, 3-Cl-, 5-Cl-, 3,5-Cl₂-, 3-Br-, 5-Br-, and 3,5-Br₂- TCSs, with supporting (1)H-NMR (nuclear magnetic resonance) and GC-MS (gas chromatography-mass spectrometry) data for their structural assignments. Using these model compounds together with sensitive analytical methods, we were able to identify and quantify the above compounds together with their precursor compound TCS in Canadian municipal wastewater and biosolid samples for the first time. While detected in all influent (range from 1.4 to 24.1 ng L⁻¹) and biosolid (range from 7.7 to 274 ng g⁻¹) samples, the concentrations of these chlorinated TCS were generally from 100- to 1,000-fold lower than TCS in the same sample. Even lower levels (<20 ng/g in 85% of the results) of brominated TCS were found in biosolids, and they were mostly undetected in sewage.

Li, H., M.W. Sumarah, et al. (2013) "Persistence and dissipation pathways of the antidepressant sertraline in agricultural soils." Sci Total Environ 452-453: 296-301.

Sertraline is a widely-used antidepressant that is one of the selective serotonin reuptake inhibitors. It has been detected in biosolids and effluents from sewage treatment plants. Since sertraline can reach agriculture land through the application of municipal biosolids or reclaimed water, the persistence and dissipation pathways of (3)H-sertraline were determined in laboratory incubations using three agriculture soils varying in textures and properties. The total solvent extractable radioactivity decreased in all three soils with times to dissipate 50% of material (DT50) ranging from 48.1±3.5 (loam soil) to 84.5±13.8 (clay soil) days. Two hydroxylated sertraline transformation products were identified in all three soils by high performance liquid chromatography with time-of-flight mass spectrometry (HPLC-TOF-MS), but the accumulation did not exceed 10% of the initial parent concentration. The addition of liquid municipal biosolids to the loam soil had no effect on the rate of sertraline dissipation, or production of transformation products. In summary, sertraline was persistent in agricultural soils with major dissipation pathways including the production of non-extractable soil-bound residues, and accumulation of hydroxylated transformation products. The biologically active sertraline transformation product norsesertraline was not detected in soil.

Li, H., M.W. Sumarah, et al. (2012) "Persistence of the tricyclic antidepressant drugs amitriptyline and nortriptyline in agriculture soils." Environ Toxicol Chem **32**(3): 509-16.

Amitriptyline and nortriptyline are widely used tricyclic antidepressant drugs. They have been detected in wastewater, surface runoff, and effluents from sewage treatment plants. As such, they could potentially reach agriculture land through the application of municipal biosolids or reclaimed water. In the absence of data on their fate in the environment, the persistence and dissipation pathways of radiolabeled amitriptyline were determined in three

agriculture soils varying widely in texture and chemical properties (loam soil, clay loam soil, and sandy loam soil). Tritiated amitriptyline was added to laboratory microcosms containing soils, and the metabolism of the extractable (3) H was monitored during incubation at 30°C. The total solvent extractable radioactivity decreased in all three soils with times to dissipate 50% of material (DT50) ranging from 34.1 ± 3.2 (loam soil) to 85.3 ± 3.2 d (sandy soil). Nortriptyline (N-desmethyl amitriptyline) and amitriptyline-N-oxide were identified as major transformation products in all three soils by high performance liquid chromatography with photodiode array detector and time-of-flight mass spectrometry (HPLC-TOF-MS/UV). The addition of liquid municipal biosolids to the loam soil had no effect on the dissipation of amitriptyline. The persistence of nortriptyline was evaluated in the loam soil. The DT50 of nortriptyline was 40.5 ± 3.2 d estimated with HPLC-TOF-MS/UV. Approximately 10% of added nortriptyline was converted to hydroxylated products after 50 d of incubation. In summary, amitriptyline persisted in agricultural soils with major dissipation mechanisms, including forming nonextractable residues and producing various transformation products including the psychoactive drug nortriptyline.

Li, J., L. Dodgen, et al. (2013) "Degradation kinetics and metabolites of carbamazepine in soil." *Environ Sci Technol* **47**(8): 3678-84.

The antiepileptic drug carbamazepine (CBZ) is one of the most frequently detected human pharmaceuticals in wastewater effluents and biosolids. Soil is a primary environmental compartment receiving CBZ through wastewater irrigation and biosolid application. In this study, we explored the transformation of CBZ to biologically active intermediates in soil. Both (14)C labeling and liquid chromatography-tandem mass spectrometry (LC-MS/MS) were used to track transformation kinetics and identify major degradation intermediates. Through 120 days of incubation under aerobic conditions, mineralization of CBZ did not exceed 2% of the spiked rate in different soils. Amendment of biosolids further suppressed mineralization. The fraction of non-extractable (i.e., bound) residue also remained negligible (<5%). On the other hand, CBZ was transformed to a range of degradation intermediates, including 10,11-dihydro-10-hydroxycarbamazepine, carbamazepine-10,11-epoxide, acridone-N-carbaldehyde, 4-aldehyde-9-acridone, and acridine, of which acridone-N-carbaldehyde was formed in a large fraction and appeared to be recalcitrant to further degradation. Electrocyclization, ring cleavage, hydrogen shift, carbonylation, and decarbonylation contributed to CBZ transformative reactions in soil, producing biologically active products. The persistence of the parent compound and formation of incomplete intermediates suggest that CBZ has a high risk for off-site transport from soil, such as accumulation into plants and contamination of groundwater.

Liao, C., S. Lee, et al. (2013) "Parabens in sediment and sewage sludge from the United States, Japan, and Korea: spatial distribution and temporal trends." *Environ Sci Technol* **47**(19): 10895-902.

Parabens (alkyl esters of p-hydroxybenzoic acid) are widely used in cosmetics, pharmaceuticals, and foodstuffs as broad-spectrum antimicrobial preservatives. Laboratory animal studies have shown that parabens possess weak estrogenic activity. Widespread exposure of humans to parabens has raised significant public health concerns. Despite such concern, little is known about the occurrence of parabens in the environment. In this study, six paraben analogues, methyl- (MeP), ethyl- (EtP), propyl- (PrP), butyl- (BuP), benzyl-

(BzP), and heptyl parabens (HepP), were determined in surface sediment and sediment core samples collected from several locations in the United States (U.S.), Japan, and Korea by high-performance liquid chromatography-tandem mass spectrometry (HPLC-MS/MS). Concentrations of parabens also were determined in sewage sludge collected from several wastewater treatment plants (WWTPs) in Korea. MeP was found in all samples, including surface sediment, sediment core, and sludge samples, at concentrations ranging from 0.312 to 540 ng/g dry weight (dw). PrP was detected in the majority of samples (79%), and the concentrations were, in general, 1-2 orders of magnitude lower than MeP concentrations. Significant positive correlations were found among the concentrations of paraben analogues in sediment and sludge, which suggested the existence of similar sources of origin for these compounds. The sum concentrations of six parabens (summation operatorPBs) in sludge (geometric mean: 66.3, median: 89.5 ng/g dw) were remarkably higher than those in sediment (5.48, 5.24 ng/g dw). Vertical profiles of parabens in sediment cores from the U.S. showed a gradual increase in concentrations in the past decade, although such a trend was not clear in sediment core from Tokyo Bay, Japan.

Lowman, A., M.A. McDonald, et al. (2013) "Land application of treated sewage sludge: community health and environmental justice." *Environ Health Perspect* **121**(5): 537-42.

BACKGROUND: In the United States, most of the treated sewage sludge (biosolids) is applied to farmland as a soil amendment. Critics suggest that rules regulating sewage sludge treatment and land application may be insufficient to protect public health and the environment. Neighbors of land application sites report illness following land application events. **OBJECTIVES:** We used qualitative research methods to evaluate health and quality of life near land application sites. **METHODS:** We conducted in-depth interviews with neighbors of land application sites and used qualitative analytic software and team-based methods to analyze interview transcripts and identify themes. **RESULTS:** Thirty-four people in North Carolina, South Carolina, and Virginia responded to interviews. Key themes were health impacts, environmental impacts, and environmental justice. Over half of the respondents attributed physical symptoms to application events. Most noted offensive sludge odors that interfere with daily activities and opportunities to socialize with family and friends. Several questioned the fairness of disposing of urban waste in rural neighborhoods. Although a few respondents were satisfied with the responsiveness of public officials regarding sludge, many reported a lack of public notification about land application in their neighborhoods, as well as difficulty reporting concerns to public officials and influencing decisions about how the practice is conducted where they live. **CONCLUSIONS:** Community members are key witnesses of land application events and their potential impacts on health, quality of life, and the environment. Meaningful involvement of community members in decision making about land application of sewage sludge will strengthen environmental health protections.

Lozano, N., C.P. Rice, et al. (2012) "Fate of Triclosan and Methyltriclosan in soil from biosolids application." *Environ Pollut* **160**(1): 103-8.

This study investigates the persistence of Triclosan (TCS), and its degradation product, Methyltriclosan (MeTCS), after land application of biosolids to an experimental agricultural plot under both till and no till. Surface soil samples (n = 40) were collected several times over a three years period and sieved to remove biosolids. Concentration of TCS in the soil

gradually increased with maximum levels of 63.7 ± 14.1 ng g⁻¹ dry wt., far below the predicted maximum concentration of 307.5 ng g⁻¹ dry wt. TCS disappearance corresponded with MeTCS appearance, suggesting in situ formation. Our results suggest that soil incorporation and degradation processes are taking place simultaneously and that TCS background levels are achieved within two years. TCS half-life (t(0.5)) was determined as 104 d and MeTCS t(0.5), which was more persistent than TCS, was estimated at 443 d.

Macherius, A., D.R. Lapen, et al. (2014) "Triclocarban, triclosan and its transformation product methyl triclosan in native earthworm species four years after a commercial-scale biosolids application." *Sci Total Environ* 472: 235-8.

Triclocarban (TCC), triclosan (TCS) and methyl triclosan (Me-TCS) were detected in soil and the native population of earthworms of an agricultural field in Ottawa, Canada, about four years after a commercial-scale application of biosolids. In soil that received biosolids, TCC and TCS were detected at median concentrations of 13.0 and 1.5 ng/g soil (d.w.), respectively, while Me-TCS, the transformation product of triclosan, was detected at a six-fold higher median concentration than its precursor. In earthworms collected at the biosolids-amended field-plot about four years post application, Me-TCS was also detected at higher concentrations (26 to 114 ng/g tissue d.w.) than TCS (16-51 ng/g) and TCC (4-53 ng/g). These data provide evidence that not only parent compounds but also their transformation products need to be considered in faunal bioaccumulation studies. Moreover, the preliminary results for pooled earthworm samples from different ecological groups suggest that the degree of bioaccumulation of biosolids-associated contaminants may depend on the habitat and feeding behavior of the organisms.

Magdouli, S., R. Daghrir, et al. (2013) "Di 2-ethylhexylphthalate in the aquatic and terrestrial environment: a critical review." *J Environ Manage* 127: 36-49.

Phthalates are being increasingly used as softeners-plasticizers to improve the plasticity and the flexibility of materials. Amongst the different plasticizers used, more attention is paid to di (2-ethylhexylphthalate) (DEHP), one of the most representative compounds as it exhibits predominant effects on environment and human health. Meanwhile, several questions related to its sources; toxicity, distribution and fate still remain unanswered. Most of the evidence until date suggests that DEHP is an omnipresent compound found in different ecological compartments and its higher hydrophobicity and low volatility have resulted in significant adsorption to solids matrix. In fact, there are important issues to be addressed with regard to the toxicity of this compound in both animals and humans, its behavior in different ecological systems, and the transformation products generated during different biological or advanced chemical treatments. This article presents detailed review of existing treatment schemes, research gaps and future trends related to DEHP.

McDaniel, J., M. Stromberger, et al. (2013) "Survival of *Aporrectodea caliginosa* and its effects on nutrient availability in biosolids amended soil." *Appl Soil Ecol* 71: 1-6.

Few earthworms are present in production agricultural fields in the semi-arid plains of Colorado, where earthworm populations may be constrained by limited water and/or organic matter resources. We conducted a 12-week laboratory incubation study to determine the potential of a non-native endogeic earthworm (*Aporrectodea caliginosa*) to survive in a low-organic matter Colorado soil (1.4% organic C content), supplemented with or without

biosolids, and to determine the effects of *A. caliginosa* on soil microbial biomass and soil nutrient availability. A factorial design with three main effects of *A. caliginosa*, biosolids addition, and time was used. Data was collected through destructively sampling at one, two, four, eight, and twelve weeks. During the 12-week study, 97.5% of the worms in the soil survived, and the survival of the earthworms was not significantly affected by the addition of biosolids. The addition of biosolids, however, did significantly reduce the gain in mass of the earthworms (8% mass gain compared to 18% in soil without biosolids). The presence of *A. caliginosa* significantly increased soil NH₄-N, and NO₃-N concentrations by 31% and 4%, respectively, which was less than the six fold increases in both soil NH₄-N, and NO₃-N concentrations supplied from biosolids. Microbial biomass carbon was not affected by *A. caliginosa*, but microbial biomass N was affected by an earthworm A biosolids interaction at week 1 and 12. We concluded that *A. caliginosa* can survive in a low-organic matter Colorado soil under optimal moisture content and that once established, *A. caliginosa* can provide modest increases in inorganic N availability to crops Colorado agroecosystems.

McFarland, M., K. Kumarsamy, et al. (2013) "Impact of Biosolids Recycling on Groundwater Resources." *Water Env Res* **85**(11): 2141-46.

Using the United States Environmental Protection Agency's (U.S. EPA) Multimedia, Multi-pathway, Multi-receptor Exposure and Risk Assessment (3MRA) technology, a computer-based biosolids groundwater risk characterization screening tool (RCST) was developed. The objective of this study was to apply the RCST to characterize the potential human health risks associated with exposure to biosolid pollutants. RCST application to two Virginia biosolids land application sites predicted that pollutant concentrations as large as ten times the current regulatory limit could be safely applied to land with no apparent human health effects associated with groundwater consumption. Only under unrealistically high biosolids application rates and pollutant concentrations were the public health risks associated with groundwater impairment characterized as significant (hazard quotient greater than or equal to 1.0). For example, when the biosolids land application rate was increased to 900 Mg/ha and the pollutant concentrations were increased to ten times the legal limit, the hazard quotient value ranged from 1.27 (zinc) to 248.19 (selenium).

McFarland, M.J., K. Kumarasamy, et al. (2013) "Protecting groundwater resources at biosolids recycling sites." *J Environ Qual* **42**(3): 660-5.

In developing the national biosolids recycling rule (Title 40 of the Code of Federal Regulation Part 503 or Part 503), the USEPA conducted deterministic risk assessments whose results indicated that the probability of groundwater impairment associated with biosolids recycling was insignificant. Unfortunately, the computational capabilities available for performing risk assessments of pollutant fate and transport at that time were limited. Using recent advances in USEPA risk assessment methodology, the present study evaluates whether the current national biosolids pollutant limits remain protective of groundwater quality. To take advantage of new risk assessment approaches, a computer-based groundwater risk characterization screening tool (RCST) was developed using USEPA's Multimedia, Multi-pathway, Multi-receptor Exposure and Risk Assessment program. The RCST, which generates a noncarcinogenic human health risk estimate (i.e., hazard quotient [HQ] value), has the ability to conduct screening-level risk characterizations. The regulated heavy metals modeled in this study were As, Cd, Ni, Se, and Zn. Results from RCST

application to biosolids recycling sites located in Yakima County, Washington, indicated that biosolids could be recycled at rates as high as 90 Mg ha, with no negative human health effects associated with groundwater consumption. Only under unrealistically high biosolids land application rates were public health risks characterized as significant ($HQ \geq 1.0$). For example, by increasing the biosolids application rate and pollutant concentrations to 900 Mg ha and 10 times the regulatory limit, respectively, the HQ values varied from 1.4 (Zn) to 324.0 (Se). Since promulgation of Part 503, no verifiable cases of groundwater contamination by regulated biosolids pollutants have been reported.

McFarland, M.J., K. Kumarsamy, et al. (2012) "Groundwater quality protection at biosolids land application sites." *Water Res* **46**(18): 5963-9.

Using the United States (US) Environmental Protection Agency's (EPA) Multimedia, Multi-pathway, Multi-receptor Exposure and Risk Assessment (3MRA) technology, a computer-based biosolids groundwater risk characterization screening tool (RCST) was developed. The RCST, which generates a non-carcinogenic human health risk estimate (i.e., hazard quotient or HQ value), has the ability to conduct screening-level risk-based characterization of potential human risks associated with pollutants released from biosolids land application sites. The HQ is a human health indicator that is equal to the ratio of the pollutant dose (mass of pollutant per unit body weight per time) to the specific pollutant reference dose (R(f)d) which, in turn, is a human health benchmark defined by the EPA as a scientific estimate of the daily exposure level. A HQ value equal to or greater than one (1) suggests that the resulting conditions pose an unacceptable risk to human health. The focus of the current study was to evaluate whether the present regulatory limits established for biosolids pollutants (e.g., heavy metals) were sufficiently protective of human health associated with potential groundwater consumption using a new EPA risk assessment tool. Application of the RCST to two biosolids land application sites located near Columbus, Georgia predicted that, when the depth to groundwater was maintained at a distance of at least 2 m, regulated pollutant concentrations as large as ten (10) times the current regulatory limit (i.e., Title 40 of the US Code of Federal Regulations Part 503 - Ceiling Concentration Limit) could be safely land applied at rates as high as ninety (90) Megagrams per hectare (Mg ha(-1)) with no apparent non-carcinogenic human health effects associated with groundwater consumption. At these pollutant concentrations, the HQ ranged from 1.79×10^{-9} for cadmium to 3.03×10^{-3} for selenium. Only under unrealistically high biosolids application rates were the public health risks associated with groundwater impairment characterized as significant ($HQ \geq 1.0$). For example, when the biosolids application rate was increased to 450 Megagrams per hectare (Mg ha(-1)) and the pollutant concentrations were increased to ten times the 40 CFR Part 503 Ceiling Concentration Limit, a HQ value of 2.23 was estimated (selenium). Similarly, when the biosolids application rate was increased to 900 Mg ha(-1) and the pollutant concentrations were increased to ten times the regulatory limit, the HQ ranged varied from 1.4 (for zinc) to 324.0 (for selenium).

McNamara, P.J., C.A. Wilson, et al. (2012) "The effect of thermal hydrolysis pretreatment on the anaerobic degradation of nonylphenol and short-chain nonylphenol ethoxylates in digested biosolids." *Water Res* **46**(9): 2937-46.

The presence of micropollutants can be a concern for land application of biosolids. Of particular interest are nonylphenol diethoxylate (NP(2)EO), nonylphenol monoethoxylate

(NP(1)EO), and nonylphenol (NP), collectively referred to as NPE, which accumulate in anaerobically digested biosolids and are subject to regulation based on the environmental risks associated with them. Because biosolids are a valuable nutrient resource, it is essential that we understand how various treatment processes impact the fate of NPE in biosolids. Thermal hydrolysis (TH) coupled with mesophilic anaerobic digestion (MAD) is an advanced digestion process that destroys pathogens in biosolids and increases methane yields and volatile solids destruction. We investigated the impact of thermal hydrolysis pretreatment on the subsequent biodegradation of NPE in digested biosolids. Biosolids were treated with TH, anaerobic digestion, and aerobic digestion in laboratory-scale reactors, and NPE were analyzed in the influent and effluent of the digesters. NP(2)EO and NP(1)EO have been observed to degrade to the more estrogenic NP under anaerobic conditions; therefore, changes in the ratio of NP:NPE were of interest. The increase in NP:NPE following MAD was 56%; the average increase of this ratio in four sets of TH-MAD samples, however, was only $24.6 \pm 3.1\%$. In addition, TH experiments performed in pure water verified that, during TH, the high temperature and pressure alone did not directly destroy NPE; TH experiments with NP added to sludge also showed that NP was not destroyed by the high temperature and pressure of TH when in a more complex sludge matrix. The post-aerobic digestion phases removed NPE, regardless of whether TH pretreatment occurred. This research indicates that changes in biosolids processing can have impacts beyond just gas production and solids destruction.

Misiti, T.M., M.G. Hajaya, et al. (2011) "Nitrate reduction in a simulated free-water surface wetland system." *Water Res* **45**(17): 5587-98.

The feasibility of using a constructed wetland for treatment of nitrate-contaminated groundwater resulting from the land application of biosolids was investigated for a site in the southeastern United States. Biosolids degradation led to the release of ammonia, which upon oxidation resulted in nitrate concentrations in the upper aquifer in the range of 65-400 mg N/L. A laboratory-scale system was constructed in support of a pilot-scale project to investigate the effect of temperature, hydraulic retention time (HRT) and nitrate and carbon loading on denitrification using soil and groundwater from the biosolids application site. The maximum specific reduction rates (MSRR), measured in batch assays conducted with an open to the atmosphere reactor at four initial nitrate concentrations from 70 to 400 mg N/L, showed that the nitrate reduction rate was not affected by the initial nitrate concentration. The MSRR values at 22 degrees C for nitrate and nitrite were 1.2 ± 0.2 and 0.7 ± 0.1 mg N/mg VSS(COD)-day, respectively. MSRR values were also measured at 5, 10, 15 and 22 degrees C and the temperature coefficient for nitrate reduction was estimated at 1.13. Based on the performance of laboratory-scale continuous-flow reactors and model simulations, wetland performance can be maintained at high nitrogen removal efficiency (>90%) with an HRT of 3 days or higher and at temperature values as low as 5 degrees C, as long as there is sufficient biodegradable carbon available to achieve complete denitrification. The results of this study show that based on the climate in the southeastern United States, a constructed wetland can be used for the treatment of nitrate-contaminated groundwater to low, acceptable nitrate levels.

Navab Daneshmand, T., R. Beton, et al. (2012) "Inactivation mechanisms of bacterial pathogen indicators during electro-dewatering of activated sludge biosolids." *Wat Res* **46**(13): 3999-4008.

Electro-dewatering is an energy-efficient technology in which an electric field can increase the dryness of biosolids from secondary wastewater treatment from 15% w/w to 30-50% w/w. Here, we address bacterial pathogen indicators inactivation (total coliforms, *Escherichia coli* and aerobic endospores) during electro-dewatering, investigating the roles of electrochemically generated oxidants, extreme pH, and high temperature (from Joule heating). Our results demonstrate that temperature is the primary factor affecting total coliforms and *E. coli* inactivation. First, several electro-dewatering cycles were used to increase sludge temperature to about 100 degree C after 6 min, during which time the average pH decreased from 7 to 3.6 after 10 min. Total coliforms and *E. coli* MPNs reached their detection limits after 6 min (with 4-5 logs of inactivation for total coliforms and 3-4 logs for *E. coli*). In contrast, aerobic endospores were not inactivated under these conditions; rather, their germination appeared to be stimulated by 6-8 min of electro-dewatering. Second, the dewatering cake was separated into four horizontal layers. After 8 min of electro-dewatering, the pH in the top layers decreased to 3, whereas the pH in the bottom layers increased to 8. Inactivation of total coliforms and *E. coli* in the sludge cake was similar in all layers, increasing with time, suggesting that oxidants and extreme pH are secondary inactivation factors. Finally, electrodes were cooled to maintain a temperature less than 34 degree C. Although pH decreased significantly after 12 min of electro-dewatering, there was no significant bacterial pathogen indicator inactivation at low temperature.

Niemi, L.M., K.A. Stencel, et al. (2013) "Quantitative determination of antidepressants and their select degradates by liquid chromatography/electrospray ionization tandem mass spectrometry in biosolids destined for land application." *Anal Chem* **85**(15): 7279-86.

Antidepressants are one of the most widely dispensed classes of pharmaceuticals in the United States. As wastewater treatment plants are a primary source of pharmaceuticals in the environment, the use of biosolids as fertilizer is a potential route for antidepressants to enter the terrestrial environment. A microsolvant extraction method, utilizing green chemistry, was developed for extraction of the target antidepressants and degradation products from biosolids, or more specifically lagoon biosolids. Liquid chromatography/tandem mass spectrometry was used for quantitative determination of antidepressants in the lagoon biosolid extracts. Recoveries from matrix spiking experiments for the individual antidepressants had an average of 96%. The limits of detection for antidepressant pharmaceuticals and degradates ranged from 0.36 to 8.0 ng/kg wet weight. The method was applied to biosolids destined for land application. A suite of antidepressants was consistently detected in the lagoon biosolid samples, and thus antidepressants are being introduced to terrestrial environments through the land application of these biosolids. Sertraline and norsertraline were the most abundant antidepressant and degradation product detected in the biosolid samples. Detected, individual antidepressant concentrations ranged from 8.5 ng/kg (norfluoxetine) to 420 ng/kg wet weight (norsertraline).

Pannu, M.W., G.A. O'Connor, et al. (2012) "Toxicity and bioaccumulation of biosolids-borne triclosan in terrestrial organisms." *Environ Toxicol Chem* **31**(3): 646-53.

Triclosan (TCS) is a common constituent of personal care products and is frequently present in biosolids. Application of biosolids to land transfers significant amounts of TCS to soils.

Because TCS is an antimicrobial and is toxic to some aquatic organisms, concern has arisen that TCS may adversely affect soil organisms. The objective of the present study was to investigate the toxicity and bioaccumulation potential of biosolids-borne TCS in terrestrial micro- and macro-organisms (earthworms). Studies were conducted in two biosolids-amended soils (sand, silty clay loam), following U.S. Environmental Protection Agency (U.S. EPA) guidelines. At the concentrations tested herein, microbial toxicity tests suggested no adverse effects of TCS on microbial respiration, ammonification, and nitrification. The no observed effect concentration for TCS for microbial processes was 10 mg/kg soil. Earthworm subchronic toxicity tests showed that biosolids-borne TCS was not toxic to earthworms at the concentrations tested herein. The estimated TCS earthworm lethal concentration (LC50) was greater than 1 mg/kg soil. Greater TCS accumulation was observed in earthworms incubated in a silty clay loam soil (bioaccumulation factor [BAF] = 12 +/- 3.1) than in a sand (BAF = 6.5 +/- 0.84). Field-collected earthworms had a significantly smaller BAF value (4.3 +/- 0.7) than our laboratory values (6.5-12.0). The BAF values varied significantly with exposure conditions (e.g., soil characteristics, laboratory vs field conditions); however, a value of 10 represents a reasonable first approximation for risk assessment purposes.

Pannu, M.W., G.S. Toor, et al. (2012) "Toxicity and bioaccumulation of biosolids-borne triclosan in food crops." *Environ Toxicol Chem* **31**(9): 2130-7.

Triclosan (TCS) is an antimicrobial compound commonly found in biosolids. Thus, plants grown in biosolids-amended soil may be exposed to TCS. We evaluated the plant toxicity and accumulation potential of biosolids-borne TCS in two vegetables (lettuce and radish) and a pasture grass (bahia grass). Vegetables were grown in growth chambers and grass in a greenhouse. Biosolids-amended soil had TCS concentrations of 0.99, 5.9, and 11 mg/kg amended soil. These TCS concentrations represent typical biosolids containing concentrations of 16 mg TCS/kg applied at agronomic rates for 6 to 70 consecutive years, assuming no TCS loss. Plant yields (dry wt) were not reduced at any TCS concentration and the no observed effect concentration was 11 mg TCS/kg soil for all plants. Significantly greater TCS accumulated in the below-ground biomass than in the above-ground biomass. The average bioaccumulation factors (BAFs) were 0.43 ± 0.38 in radish root, 0.04 ± 0.04 in lettuce leaves, 0.004 ± 0.002 in radish leaves, and <0.001 in bahia grass. Soybean (grain) and corn (leaves) grown in our previous field study where soil TCS concentrations were lower (0.04-0.1 mg/kg) had BAF values of 0.06 to 0.16. Based on the data, we suggest a conservative first approximate BAF value of 0.4 for risk assessment in plants.

Peak, D., G. Kar, et al. (2012) "Kinetics and Mechanisms of Phosphorus Release in a Soil Amended With Biosolids or Inorganic Fertilizer." *Soil Sci* **177**(3): 183-187.

Desorption and dissolution often control the mobility and availability of phosphorus (P) in the natural environment. In this study, P desorption was compared from a soil receiving either long-term inorganic or biosolid fertilization as a part of a long-term field scale research project. A continuous-flow desorption method was used to measure cumulative P desorption over time, and P K-edge X-ray absorption near edge structure spectroscopy was used to determine the chemical species removed from the soil samples by desorption. The cumulative amount of P released in the inorganic fertilizer-amended soil was higher (895 vs. 573 mg kg⁻¹), and the rate of P release was much faster ($k = 0.012$ vs. 0.005 m⁻¹) than that of the biosolids-amended soil. The kinetics data were best described by the parabolic

diffusion equation ($r^2 = 0.98-0.99$), suggesting that P desorption was mass-transfer limited or that intraparticle diffusion could be the rate-limiting step. The X-ray absorption near edge structure results indicated that dissolution of calcium and iron phosphate minerals occurs in addition to desorption of P from the exchangeable sites. These observations suggest that the redistribution between aqueous, adsorbed, and precipitated phosphate (PO₄³⁻) species occurs rapidly when solution P concentrations are depleted.

Robinson, K.G., C.H. Robinson, et al. (2012) "Public attitudes and risk perception toward land application of biosolids within the south-eastern United States." *J Environ Manage* 98: 29-36.

A descriptive-correlational study of biosolids recycling was conducted in the south-eastern United States to assess current knowledge, attitudes and risk perceptions of participants in two communities that land apply biosolids as part of their waste management programs. One community, Amelia County VA, has been outspoken against biosolids recycling in the past, whereas the second community, Knoxville, TN region, has voiced few concerns about biosolids recycling. Additionally, gender differences within the entire study population were assessed. A 45-question telephone survey, utilizing a 4-point Likert scale, was developed and administered to 311 randomly selected adults in the two regions. Commonalities identified during the study revealed key risk perceptions by the public regarding biosolids regulations, treatment, and application. Given current perceptions and knowledge, respondents felt that the benefits derived from biosolids recycling do not offset the perceived health and safety risks. However, as distance between application and personal property increased, a decrease in opposition of biosolids reuse became evident for all respondents. Survey participants were dissatisfied with the level of stakeholder involvement in research and decision-making processes concerning biosolids. The outspoken Amelia County residents perceived greater health risks due to inadequate treatment of biosolids and odorous emissions during the application process than the less engaged Knox Metro respondents. Significant gender differences were observed with sampled females perceiving greater risks to health and safety from biosolids recycling than males. There was also indication that decisions and risks were not sufficiently communicated to the public, leading to respondents being inadequately informed about biosolids land application in both communities. Community-specific outreach programs must address these public risk perceptions and the differences in perception caused by gender and issue awareness to assist solid waste managers in developing and implementing successful biosolids land application systems that are acceptable to the public.

Sabourin, L., P. Duenk, et al. (2012) "Uptake of pharmaceuticals, hormones and parabens into vegetables grown in soil fertilized with municipal biosolids." *Sci Total Environ* 431: 233-6.

Several recent greenhouse studies have established the potential for uptake of human pharmaceuticals from soil fertilized with municipal biosolids into a variety of crops. In the present study, a field experiment was undertaken to evaluate the uptake of organic micropollutants from soil fertilized with municipal biosolids at a regulated application rate into tomatoes, carrots, potatoes and sweet corn produced under normal farming conditions. The vegetables were grown according to farming practices mandated by the province of Ontario Canada, the key feature being a one-year offset between biosolid application and the harvest of crops for human consumption. Biosolids at application, and crop samples following harvest were analyzed for 118 pharmaceuticals and transformation products, 17

hormones or hormone transformation products, and 6 parabens. Analyte concentrations in the biosolids were consistent with those detected in other surveys. Eight of the 141 analytes were detected in one or two crop replicates at concentrations ranging from 0.33 to 6.25 ng/g dry weight, but no analytes were consistently detected above the detection limit in all triplicate treated plots. Overall, this study suggests that the potential for micropollutant uptake into crops under normal farming conditions is low.

Saez, J.A., T.C. Harmon, et al. (2012) "Seasonal ammonia losses from spray-irrigation with secondary-treated recycled water." Water Sci Technol **65**(4): 676-82.

This work examines ammonia volatilization associated with agricultural irrigation employing recycled water. Effluent from a secondary wastewater treatment plant was applied using a center pivot irrigation system on a 12 ha agricultural site in Palmdale, California. Irrigation water was captured in shallow pans and ammonia concentrations were quantified in four seasonal events. The average ammonia loss ranged from 15 to 35% (averaging 22%) over 2-h periods. Temporal mass losses were well-fit using a first-order model. The resulting rate constants correlated primarily with temperature and secondarily with wind speed. The observed application rates and timing were projected over an entire irrigation season using meteorological time series data from the site, which yielded volatilization estimates of 0.03 to 0.09 metric tons NH(3)-N/ha per year. These rates are consistent with average rates (0.04 to 0.08 MT NH(3)-N/ha per year) based on 10 to 20 mg NH(3)-N/L effluent concentrations and a 22% average removal. As less than 10% of the treated effluent in California is currently reused, there is potential for this source to increase, but the increase may be offset by a corresponding reduction in synthetic fertilizers usage. This point is a factor for consideration with respect to nutrient management using recycled water.

Shoults-Wilson, W.A., B.C. Reinsch, et al. (2011) "Effect of silver nanoparticle surface coating on bioaccumulation and reproductive toxicity in earthworms (*Eisenia fetida*)." Nanotoxicology **5**(3): 432-44.

The purpose of this study was to investigate the effect of surface coating on the toxicity of silver nanoparticles (Ag NPs) soil. Earthworms (*Eisenia fetida*) were exposed to AgNO₃ and Ag NPs with similar size ranges coated with either polyvinylpyrrolidone (hydrophilic) or oleic acid (amphiphilic) during a standard sub-chronic reproduction toxicity test. No significant effects on growth or mortality were observed within any of the test treatments. Significant decreases in reproduction were seen in earthworms exposed to AgNO₃, (94.21 mg kg⁻¹) as well as earthworms exposed to Ag NPs with either coating (727.6 mg kg⁻¹) for oleic acid and 773.3 mg kg⁻¹) for polyvinylpyrrolidone). The concentrations of Ag NPs at which effects were observed are much higher than predicted concentrations of Ag NPs in sewage sludge amended soils; however, the concentrations at which adverse effects of AgNO₃ were observed are similar to the highest concentrations of Ag presently observed in sewage sludge in the United States. Earthworms accumulated Ag in a concentration-dependent manner from all Ag sources, with more Ag accumulating in tissues from AgNO₃ compared to earthworms exposed to equivalent concentrations of Ag NPs. No differences were observed in Ag accumulation or toxicity between earthworms exposed to Ag NPs with polyvinylpyrrolidone or oleic acid coatings.

Siddiquee, M.N. and S. Rohani. (2011) "Experimental analysis of lipid extraction and biodiesel production from wastewater sludge." *Fuel Proces Tech* **92**(12): 2241-51.

The most promising renewable alternative fuel, biodiesel, is produced from various lipid sources. Primary and secondary sludge of municipal wastewater treatment facilities are potential sources of lipids. In this study, factorial experimental analyses were used to study the influence of different variables on the lipid extraction and biodiesel production from dried municipal primary and secondary sludge (Adelaide Pollution Control Plant, London, ON, Canada). The empirical models were developed for each factorial analysis. The temperature turned out to be the most significant variable for lipid extraction by using methanol and hexane as solvents. Extraction using methanol resulted in a maximum of 14.46 (wt/wt) % and 10.04 (wt/wt) % lipid (on the basis of dry sludge), from the primary and secondary sludge sources respectively. A maximum of 11.16 (wt/wt) % and 3.04 wt/wt% lipid (on the basis of dry sludge) were extracted from the primary and secondary sludge sources, respectively, using hexane as a solvent. The FAME (fatty acid methyl ester) yield of the H sub(2)SO sub(4) catalyzed esterification-transesterification of the hexane and methanol extracted lipids were 41.25 (wt/wt) % and 38.94(wt/wt) % (on the basis of lipid) for the primary sludge, and 26.89 (wt/wt) % and 30.28 (wt/wt) % (on the basis of lipid) for the secondary sludge. The use of natural zeolite as a dehydrating agent was increased the biodiesel yield by approximately 18 (wt/wt) % (on the basis of lipid). The effect of temperature and time was also investigated for biodiesel production from the lipid of wastewater sludge. The yield and quality of the FAME were determined by gas chromatography.

Sivapatham, P., M.C. Potts, et al. (2012) "Evaluation of wastewater treatment by-products as soil amendment: Growth of sorghum-sudan grass and trace elements concentrations." *J Environ Sci Health A Tox Hazard Subst Environ Eng* **47**(11): 1678-86.

Wastewater treatment by-products (WTBP), such as sewage sludge (SS) may be used to enhance soil chemical, physical, and biological properties. These enhanced soil properties, in turn, could from its source of production to its site of application. These concerns may be mitigated by incineration of the SS to produce ash (SSA) and dissolved in water and stored in ponds as contribute to an increase in plant growth, production, mineral nutrition. Some SS is difficult to handle due to bad odor in its raw state and has large mass, hence expensive for transportation weathered SSA (WSSA). A greenhouse study was conducted using Candler fine sand CFS; (CFS; pH = 6.8) and Ogeechee loamy sand OLS; (pH = 5.2) with application of either 0, 24.7, 49.4, 98.8, or 148.2 Mg ha(-1) as either SS, SSA, or WSSA to evaluate the biomass production and elemental composition responses of sorghum-sudan grass (*Sorghum vulgare* var. Sudanese hitche). Shoot and root biomass were 2 to 3 fold greater in the soil amended with SS, than either SSA or WSSA. Concentrations of nutrient and trace elements in the shoots and roots increased with increasing rates of amendments. Application of these by-products up to 98.8 Mg ha(-1) rate did not adversely affect growth or accumulation of trace elements in sorghum-sudan grass. Long-term field studies are recommended to investigate the potential leaching of various elements from the amended soils in addition to evaluation of plant growth and production responses to determine the acceptable rates of these by-products as amendments to agricultural soils.

Snyder, E.H. and G.A. O'Connor. (2013) "Risk assessment of land-applied biosolids-borne triclocarban (TCC)." *Sci Total Environ* 442: 437-44.

Triclocarban (TCC) is monitored under the USEPA High Production Volume (HPV) chemical program and is predominantly used as the active ingredient in select antibacterial bar soaps and other personal care products. The compound commonly occurs at parts-per-million concentrations in processed wastewater treatment residuals (i.e. biosolids), which are frequently land-applied as fertilizers and soil conditioners. Human and ecological risk assessment parameters measured by the authors in previous studies were integrated with existing data to perform a two-tiered human health and ecological risk assessment of land-applied biosolids-borne TCC. The 14 exposure pathways identified in the Part 503 Biosolids Rule were expanded, and conservative screening-level hazard quotients (HQ values) were first calculated to estimate risk to humans and a variety of terrestrial and aquatic organisms (Tier 1). The majority of biosolids-borne TCC exposure pathways resulted in no screening-level HQ values indicative of significant risks to exposed organisms (including humans), even under worst-case land application scenarios. The two pathways for which the conservative screening-level HQ values exceeded one (i.e. Pathway 10: biosolids→soil→soil organism→predator, and Pathway 16: biosolids→soil→surface water→aquatic organism) were then reexamined using modified parameters and scenarios (Tier 2). Adjusted HQ values remained greater than one for Exposure Pathway 10, with the exception of the final adjusted HQ values under a one-time 5 Mg ha⁻¹ (agronomic) biosolids loading rate scenario for the American woodcock (*Scolopax minor*) and short-tailed shrew (*Blarina brevicauda*). Results were used to prioritize recommendations for future biosolids-borne TCC research, which include additional measurements of toxicological effects and TCC concentrations in environmental matrices at the field level.

Velicogna, J., E. Ritchie, et al. (2012) "Ecotoxicity of siloxane D5 in soil." *Chemosphere* 87(1): 77-83.

Decamethylcyclopentasiloxane (D5) is a cyclic volatile methyl siloxane (cVMS) commonly found in commercially available products. D5 is expected to enter the terrestrial environment through the deposit of biosolids from sewage treatment plants onto agricultural fields for nutrient enrichment. Little to no information currently exists as to the risks of D5 to the terrestrial environment. In order to evaluate the potential risk to terrestrial organisms, the toxicity of a D5 contaminated biosolid in an agricultural soil was assessed with a battery of standardized soil toxicity tests. D5 was spiked into a surrogate biosolid and then mixed with a sandy loam soil to create test concentrations ranging from 0 to 4074 mg kg⁻¹. Plant (*Hordeum vulgare* (barley) and *Trifolium pratense* (red clover)) and soil invertebrates (*Eisenia andrei* (earthworm) and *Folsomia candida* (springtail)) toxicity tests were completed to assess for lethal and sub-lethal effects. Plant testing evaluated the effects on seedling emergence, shoot and root length, and shoot and root dry mass. Invertebrate test endpoints included adult lethality, juvenile production, and individual juvenile dry mass (earthworms only). Soil samples were collected over time to confirm test concentrations and evaluate the loss of chemical over the duration of a test. The toxicity of the D5 was species and endpoint dependent, such that no significant adverse effects were observed for *T. pratense* or *E. andrei* test endpoints, however, toxicity was observed for *H. vulgare* plant growth and *F. candida* survival and reproduction. Chemical losses of up to 50% were observed throughout the tests, most significantly at high concentrations.

Venkatesan, A.K. and R.U. Halden. (2013) "National inventory of alkylphenol ethoxylate compounds in U.S. sewage sludges and chemical fate in outdoor soil mesocosms." Environ Pollut 174: 189-93.

We determined the first nationwide inventories of alkylphenol surfactants in U.S. sewage sludges (SS) using samples from the U.S. Environmental Protection Agency's 2001 national SS survey. Additionally, analysis of archived 3-year outdoor mesocosm samples served to determine chemical fates in SS-amended soil. Nonylphenol (NP) was the most abundant analyte (534 +/- 192 mg/kg) in SS composites, followed by its mono- and di-ethoxylates (62.1 +/- 28 and 59.5 +/- 52 mg/kg, respectively). The mean annual load of NP and its ethoxylates in SS was estimated at 2408-7149 metric tonnes, of which 1204-4289 is applied on U.S. land. NP compounds showed observable loss from SS/soil mixtures (1:2), with mean half-lives ranging from 301 to 495 days. Surfactant levels in U.S. SS ten-times in excess of European regulations, substantial releases to U.S. soils, and prolonged half-lives found under field conditions, all argue for the U.S. to follow Europe's move from 20 years ago to regulate these chemicals.

Venkatesan, A.K. and R.U. Halden. (2013) "National inventory of perfluoroalkyl substances in archived U.S. biosolids from the 2001 EPA National Sewage Sludge Survey." J Hazard Mater 252-253: 413-8.

Using liquid chromatography tandem mass spectrometry, we determined the first nationwide inventories of 13 perfluoroalkyl substances (PFASs) in U.S. biosolids via analysis of samples collected by the U.S. Environmental Protection Agency in the 2001 National Sewage Sludge Survey. Perfluorooctane sulfonate [PFOS; 403 +/- 127 ng/g dry weight (dw)] was the most abundant PFAS detected in biosolids composites representing 32 U.S. states and the District of Columbia, followed by perfluorooctanoate [PFOA; 34 +/- 22 ng/g dw] and perfluorodecanoate [PFDA; 26 +/- 20 ng/g dw]. Mean concentrations in U.S. biosolids of the remaining ten PFASs ranged between 2 and 21 ng/g dw. Interestingly, concentrations of PFOS determined here in biosolids collected prior to the phase-out period (2002) were similar to levels reported in the literature for recent years. The mean load of summation operator PFASs in U.S. biosolids was estimated at 2749-3450 kg/year, of which about 1375-2070 kg is applied on agricultural land and 467-587 kg goes to landfills as an alternative disposal route. This study informs the risk assessment of PFASs by furnishing national inventories of PFASs occurrence and environmental release via biosolids application on land.

Wang, D.G., H. Steer, et al. (2013) "Concentrations of cyclic volatile methylsiloxanes in biosolid amended soil, influent, effluent, receiving water, and sediment of wastewater treatment plants in Canada." Chemosphere 93(5): 766-73.

A comprehensive surveillance program was conducted to determine the occurrence of three cyclic volatile methylsiloxanes (cVMS) octamethylcyclotetrasiloxane (D4), decamethylcyclopentasiloxane (D5), and dodecamethylcyclohexasiloxane (D6) in environmental compartments impacted by wastewater effluent discharges. Eleven wastewater treatment plants (WWTPs), representative of those found in Southern Ontario and Southern Quebec, Canada, were investigated to determine levels of cVMS in their influents and effluents. In addition, receiving water and sediment impacted by WWTP effluents, and biosolid-amended soil from agricultural fields were also analyzed for a preliminary evaluation of the environmental exposure of cVMS in media impacted by wastewater

effluent and solids. A newly-developed large volume injection (septumless head adapter and cooled injection system) gas chromatography - mass spectrometry method was used to avoid contamination originating from instrumental analysis. Concentrations of D4, D5, and D6 in influents to the 11 WWTPs were in the range 0.282-6.69µg/L(-1), 7.75-135µg/L(-1), and 1.53-26.9µg/L(-1), respectively. In general, wastewater treatment showed cVMS removal rates of greater than 92%, regardless of treatment type. The D4, D5, and D6 concentration ranges in effluent were <0.009-0.045µg/L(-1), <0.027-1.56µg/L(-1), and <0.022-0.093µg/L(-1), respectively. The concentrations in receiving water influenced by effluent, were lower compared to those in effluent in most cases, with the ranges <0.009-0.023µg/L(-1), <0.027-1.48µg/L(-1), and <0.022-0.151µg/L(-1) for D4, D5, and D6, respectively. Sediment concentrations ranged from <0.003-0.049µg/g(-1)dw, 0.011-5.84µg/g(-1)dw, and 0.004-0.371µg/g(-1)dw for D4, D5, and D6, respectively. The concentrations in biosolid-amended soil, having values of <0.008-0.017µg/g(-1)dw, <0.007-0.221µg/g(-1)dw, and <0.009-0.711µg/g(-1)dw for D4, D5, and D6, respectively, were lower than those in sediment impacted by wastewater effluent in most cases. In comparison with the no-observed-effect concentrations (NOEC) and IC50 (concentration that causes 50% inhibition of the response) values, the potential risks to aquatic, sediment-dwelling, and terrestrial organisms from these reported concentrations are low.

Wang, D.G., W. Norwood, et al. (2013) "Review of recent advances in research on the toxicity, detection, occurrence and fate of cyclic volatile methyl siloxanes in the environment." *Chemosphere* **93**(5): 711-25.

The fate and behavior of cyclic volatile methylsiloxanes (cVMS) octamethylcyclotetrasiloxane (D4), decamethylcyclopentasiloxane (D5), and dodecamethylcyclohexasiloxane (D6) in the environment were reviewed. We evaluated their usage data and patterns, physico-chemical properties, toxicology, partitioning and degradation, methods of detection, and concentrations. The use of cVMS as an intermediate in the formation of silicone polymers, personal care and household products has resulted in their widespread environmental exposure; they have been detected in biogas, air, water, soil, biosolid sediment, and biota samples. Modeled and experimental results suggest that cVMS may be subject to long-range atmospheric transport, but have low potential to contaminate the Arctic. For D4 and D5, there was no evidence of trophic biomagnification in aquatic food webs, while some aquatic organisms demonstrated a high degree of bioconcentration and bioaccumulation. High concentrations of cVMS observed in indoor air and biosolids resulted from point sources. Concentrations of cVMS in water, sediment, and soil were all below their no-observed-effect-concentrations.

Waria, M., G.A. O'Connor, et al. (2011) "Biodegradation of triclosan in biosolids-amended soils." *Environ Toxicol Chem* **30**(11): 2488-96.

Land application of biosolids can constitute an important source of triclosan (TCS) input to soils, with uncertain effects. Several studies have investigated the degradation potential of TCS in biosolids-amended soils, but the results vary widely. We conducted a laboratory degradation study by mixing biosolids spiked with [¹⁴C]-TCS (final concentration = 40 mg/kg) with Immokalee fine sand and Ashkum silty clay loam soils at an agronomic application rate (22 Mg/ha). Biosolids-amended soils were aerobically incubated in biotic and inhibited conditions for 18 weeks. Subsamples removed at 0, 2, 4, 6, 9, 12, 15,

and 18 weeks were sequentially extracted with an operationally defined extraction scheme to determine labile and nonlabile TCS fractions. Over the 18-week incubation, the proportion of [^{14}C] in the nonlabile fraction increased and the labile fraction decreased, suggesting decreasing availability to biota. Partitioning of TCS into labile and nonlabile fractions depended on soil characteristics. Less than 0.5% of [^{14}C]-TCS was mineralized to carbon dioxide ($^{14}\text{CO}_2$) in both soils and all treatments. A degradation metabolite, methyl triclosan (Me-TCS), was identified in both soils only in the biotic treatment, and increased in concentration over time. Even under biotic conditions, biosolids-borne TCS is persistent, with a primary degradation (TCS to Me-TCS) half-life of 78 d in the silty clay loam and 421 d in the fine sand. A half-life of approximately 100 d would be a conservative first approximation of TCS half-life in biosolids-amended soils for risk estimation.

Whitley, A.R., C. Levard, et al. (2013) "Behavior of Ag nanoparticles in soil: effects of particle surface coating, aging and sewage sludge amendment." *Environ Pollut* 182: 141-9.

This study addressed the relative importance of particle coating, sewage sludge amendment, and aging on aggregation and dissolution of manufactured Ag nanoparticles (Ag MNPs) in soil pore water. Ag MNPs with citrate (CIT) or polyvinylpyrrolidone (PVP) coatings were incubated with soil or municipal sewage sludge which was then amended to soil (1% or 3% sludge (w/w)). Pore waters were extracted after 1 week and 2 and 6 months and analyzed for chemical speciation, aggregation state and dissolution. Ag MNP coating had profound effects on aggregation state and partitioning to pore water in the absence of sewage sludge, but pre-incubation with sewage sludge negated these effects. This suggests that Ag MNP coating does not need to be taken into account to understand fate of AgMNPs applied to soil through biosolids amendment. Aging of soil also had profound effects that depended on Ag MNP coating and sludge amendment.

Wong, K., T. Harrigan, et al. (2012) "Leaching and ponding of viral contaminants following land application of biosolids on sandy-loam soil." *J Environ Manage* 112: 79-86.

Much of the land available for application of biosolids is cropland near urban areas. Biosolids are often applied on hay or grassland during the growing season or on corn ground before planting or after harvest in the fall. In this study, mesophilic anaerobic digested (MAD) biosolids were applied at 56,000 L/ha on a sandy-loam soil over large containment lysimeters seeded to perennial covers of orchardgrass (*Dactylis glomerata* L.), switchgrass (*Panicum virgatum*), or planted annually to maize (*Zea mays* L.). Portable rainfall simulators were to maintain the lysimeters under a nearly saturated (90%, volumetric basis) conditions. Lysimeter leachate and surface ponded water samples were collected and analyzed for somatic phage, adenoviruses, and anionic (chloride) and microbial (P-22 bacteriophage) tracers. Neither adenovirus nor somatic phage was recovered from the leachate samples. P-22 bacteriophage was found in the leachate of three lysimeters (removal rates ranged from 1.8 to 3.2 log₁₀/m). Although the peak of the anionic tracer breakthrough occurred at a similar pore volume in each lysimeter (around 0.3 pore volume) the peak of P-22 breakthrough varied between lysimeters (<0.1, 0.3 and 0.7 pore volume). The early time to peak breakthrough of anionic and microbial tracers indicated preferential flow paths, presumably from soil cracks, root channels, worm holes or other natural phenomena. The concentration of viral contaminants collected in ponded surface water ranged from 1 to 10% of the initial concentration in the applied biosolids. The die off of somatic phage and P-22 in the surface

water was fit to a first order decay model and somatic phage reached background level at about day ten. In conclusion, sandy-loam soils can effectively remove/adsorb the indigenous viruses leached from the land-applied biosolids, but there is a potential of viral pollution from runoff following significant rainfall events when biosolids remain on the soil surface.

Wu, C., A.L. Spongberg, et al. (2012) "Transfer of wastewater associated pharmaceuticals and personal care products to crop plants from biosolids treated soil." *Ecotoxicol Environ Saf* 85: 104-9.

The plant uptake of emerging organic contaminants such as pharmaceuticals and personal care products (PPCPs) is receiving increased attention. Biosolids from municipal wastewater treatment have been previously identified as a major source for PPCPs. Thus, plant uptake of PPCPs from biosolids applied soils needs to be understood. In the present study, the uptake of carbamazepine, diphenhydramine, and triclocarban by five vegetable crop plants was examined in a field experiment. At the time of harvest, three compounds were detected in all plants grown in biosolids-treated soils. Calculated root concentration factor (RCF) and shoot concentration factor (SCF) are the highest for carbamazepine followed by triclocarban and diphenhydramine. Positive correlation between RCF and root lipid content was observed for carbamazepine but not for diphenhydramine and triclocarban. The results demonstrate the ability of crop plants to accumulate PPCPs from contaminated soils. The plant uptake processes of PPCPs are likely affected by their physico-chemical properties, and their interaction with soil. The difference uptake behavior between plant species could not solely be attributed to the root lipid content.

Yu, Y., L. Wu, et al. (2013) "Seasonal variation of endocrine disrupting compounds, pharmaceuticals and personal care products in wastewater treatment plants." *Sci Total Environ* 442: 310-6.

The occurrence of 14 endocrine disrupting compounds (EDCs), pharmaceuticals and personal care products (PPCPs) in influents, effluents and sludge from five wastewater treatment plants (WWTPs) in southern California was studied in winter and summer. All 14 compounds were detected in influent samples from the five WWTPs except for estrone. Paracetamol, naproxen and ibuprofen were the dominant compounds, with mean concentrations of 41.7, 35.7 and 22.3 µg/L, respectively. The treatment removal efficiency for most compounds was more than 90% and concentrations in the effluents were relatively low. Seasonal variation of the compounds' concentration in the wastewater was significant: the total concentration of each compound in the wastewater was higher in winter than in summer, which is attributed to more human consumption of pharmaceuticals during winter and faster degradation of the compounds in summer. The highest concentrations of triclosan and octylphenol were detected in sewage sludge, with mean concentrations of 1505 and 1179 ng/g, respectively. Risk quotients (RQs), expressed as the ratios of environmental concentrations and the predicted no-effect concentrations (PNEC), were less than unity for all the compounds except for estrone in the effluents, indicating no immediate ecological risk is expected. However, RQs were higher than unity for 2 EDCs (estrone and octylphenol) and carbamazepine in sludge samples, indicating a significant ecotoxicological risk to human health. Therefore, appropriate treatment of sewage sludge is required before its application.

Ziemba, C. and J. Peccia. (2011) "Net energy production associated with pathogen inactivation during mesophilic and thermophilic anaerobic digestion of sewage sludge." *Water Res* **45**(16): 4758-68.

The potential for anaerobic digester energy production must be balanced with the sustainability of reusing the resultant biosolids for land application. Mesophilic, thermophilic, temperature-phased, and high temperature (60 or 70 degrees C) batch pre-treatment digester configurations have been systematically evaluated for net energy production and pathogen inactivation potential. Energy input requirements and net energy production were modeled for each digester scheme. First-order inactivation rate coefficients for *Escherichia coli*, *Enterococcus faecalis* and bacteriophage MS-2 were measured at each digester temperature and full-scale pathogen inactivation performance was estimated for each indicator organism and each digester configuration. Inactivation rates were found to increase dramatically at temperatures above 55 degrees C. Modeling full-scale performance using retention times based on U.S. EPA time and temperature constraints predicts a 1-2 log inactivation in mesophilic treatment, and a 2-5 log inactivation in 50-55 degrees C thermophilic and temperature-phased treatments. Incorporating a 60 or 70 degrees C batch pre-treatment phase resulted in dramatically higher potency, achieving MS-2 inactivation of 14 and 16 logs respectively, and complete inactivation (over 100 log reduction) of *E. coli* and *E. faecalis*. For temperatures less than 70 degrees C, viability staining of thermally-treated *E. coli* showed significantly reduced inactivation relative to standard culture enumeration. Due to shorter residence times in thermophilic reactors, the net energy production for all digesters was similar (less than 20% difference) with the 60 or 70 degrees C batch treatment configurations producing the most net energy and the mesophilic treatment producing the least. Incorporating a 60 or 70 degrees C pre-treatment phase can dramatically increase pathogen inactivation performance without decreasing net energy capture from anaerobic digestion. Energy consumption is not a significant barrier against improving the pathogen quality of biosolids.

Ziemba, C., W. Yang, et al. (2013) "Modeling human off-site aerosol exposures to polybrominated flame retardants emitted during the land application of sewage sludge." *Environ Int* **60**: 232-41.

Elevated sewage sludge concentrations of polybrominated diphenyl ethers (PBDEs) are due to their broad utilization in textiles and polymers, their resistance to biological degradation, and also their hydrophobic nature-which drives partitioning into wastewater solids. This study estimated the total U.S. emissions of PBDE due to sewage sludge land application and then determined the human inhalation exposure to sludge-associated PBDEs as a function meteorological conditions and downwind distances from an application site. These aerosol exposures have also been incorporated into pharmacokinetic models to predict contributions to steady-state body burden. Our results suggest that while the amount of PBDEs aerosolized during the land application process is small compared to aerosol emissions associated with product use, the application of sludges onto U.S. soils constitutes a major source of PBDEs entering the outdoor environment. Regarding aerosol exposure to nearby residents, the maximum daily inhalation dosages from a common land application scenario occur immediately after sewage sludges are applied and were 137, 27, 1.9, and 81pg/day for significant congeners PBDE-47, -99, -153 and 209 respectively. These doses are 1-2 orders of magnitude less than the standard daily inhalation exposure to the same PBDEs associated with home indoor air and are

similar to doses from inhalation of urban and rural outdoor air. Under the worst-case atmospheric transport scenario, the dosages are reduced by approximately 1 order of magnitude when the setback distance between the sludge aerosolization source and human receptor is increased to 200m. Though the health implications of low-level exposures are not well-understood, these sludge-derived PBDE dosages contribute less than a tenth of 1% to the estimated total body burden of PBDE produced from inhalation of indoor and outdoor air, exposure to house dust, and exposure to PBDE from food and water intake. Overall, the inhalation of PBDE aerosols from sludge-applied fields does not represent a significant contribution to human exposure compared to other common indoor exposures. However, land application is a major environmental source of PBDEs and sludge health impact analyses should focus on the practice's impacts on other exposures, such as biomagnification in aquatic and terrestrial food webs.