The Use of Biosolids in Maine: A Review.

Prepared By:

John M. Peckenham
Senior Research Scientist
Senator George J. Mitchell Center for Environmental and Watershed Research
University of Maine
Orono, Maine

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EXECUTIVE SUMMARY

The goal of this white paper is to review research on the environmental benefits and risks associated with the beneficial reuse of biosolids. This work examines two major questions:

1. Is the beneficial reuse of biosolids, as regulated and practiced in Maine, sufficiently safe and protective of public health and the environment, particularly soil and water quality?

2. Maine public policy since 1988 favors the beneficial use of biosolids over disposal options such as incineration or landfilling; is this beneficial use of biosolids supported by research?

Answers to these questions have been derived from numerous information sources: peer-reviewed research reports; conference proceedings; National Academy of Science Publications; and state and federal rulemaking documents and regulations. This white paper is intended to be a comprehensive and independent assessment of the beneficial reuse of biosolids as practiced in the state of Maine.

Overview

In Maine, the reuse of sewage sludge is regulated as a solid waste residual. The rules developed by the Maine Department of Environmental Protection (DEP) as 06-096 CMR Chapter 419 were authorized by the Legislature under statute 38 MRSA Sections 1304(1), (13), and (13-A). These statutes authorize the DEP to regulate solid waste to minimize pollution of the environment. The innovative reuse of wastes, explicitly the agronomic use of sludge by land application and similar uses, is supported by these statutes. Simplified, the Maine statutes direct the Maine DEP to support the highest value use for sewage sludge, to assure compliance with sludge quality standards, and to keep the public informed of sludge utilization activities and uses through various public informational processes.

The U.S. Environmental Protection Agency defines biosolids as, *"The primarily organic solid product yielded by municipal wastewater treatment processes that can be beneficially recycled"*. Biosolids are derived from sewage sludge that meet all the standards for reuse and that have been treated to reduce pathogen content. There are two standards for pathogen reduction: Class B (significant reduction) and Class A (reduction to background concentrations). Biosolids are considered beneficial because they contain essential plant nutrients such as nitrogen and phosphorous, as well as important trace metals. Biosolids may also contain trace concentrations of potentially harmful metals and organic compounds. The maximum acceptable concentrations of potentially harmful constituents are regulated. The majority of biosolids generated in Maine have metal and organic compound concentrations well below the maximums allowed.

According to Maine DEP records there are 200 licensed wastewater treatment facilities in the state. In 2002, approximately 154,923 cubic yards of sewage sludge were generated in the state. A majority (>75%) of the sewage sludge is processed into Class A or Class B biosolids each year for some form of beneficial reuse. This beneficial reuse may be the land application of Class B biosolids as a fertilizer on farmland, or as a Class A compost for use as a landscaping mulch.

Findings

Soil Quality. Biosolids are complex mixtures of organic matter that have agronomic value, as well as containing trace metals, such as cadmium, zinc, and copper. A substantial body of research indicates that biosolids provide a greater benefit through improved soil quality that exceeds the risks posed by added metals. Biosolids do pose some degree of risk to grazing animals and humans due to either plant incorporation of trace chemical constituents, or pathogen exposure from accidental ingestion of solids. There is some measurable transfer of metals from biosolids in soil to certain crops, but research shows that the amount of transfer up the food chain appears to be limited. Managing soil pH to be nearly neutral (pH~ 7) minimizes the loss of metals to either plant uptake, or leaching to groundwater. Epidemiological studies have not demonstrated systematic harmful effects to healthy people from direct or indirect exposure to soil at biosolids at land-application sites. Data collected in Maine suggest that risks to soil quality posed by trace metals at biosolids utilizations sites are negligible.

The land application of biosolids presents the following potential benefits and risks to soil quality.

Potential Benefits:

+ Inexpensive source of nitrogen.
+ Source of trace nutrients and phosphorous.
+ Biosolids increase soil organic matter and improve moisture regulation.
+ Concentrations of heavy metals in Maine's biosolids are well below the US EPA exceptional quality standard.
+ Transfer of metals to food crops is limited.
+ Organic matter in biosolids binds with metals and lowers their bioavailability.

Potential Risks:

– Biosolids contain some trace metals of concern, but nearly all in Maine are below regulatory risk thresholds.
– A small fraction of nutrients and metals may leach from biosolids into groundwater.
– Added metals may persist in soils for decades and slowly become bioavailable.
– Soil pH needs to be managed over long time periods to minimize metal losses.

Overall, Maine's Chapter 419, the agronomic use rules, provides adequate protection of Maine's soil quality. Long-term management of soil pH is an important point needing emphasis because the rules do not address future land uses. Since the rules include the importance of maintaining proper soil chemistry, the long-term risks from mismanagement are minimized.

Water Quality. Biosolids are managed by regulation to prevent any degradation of water quality. This is because biosolids have the potential to affect water quality through the leaching of at least two general kinds of contaminants: essential plant nutrients and trace metals. Biosolids contain some water soluble compounds that could affect water quality. It is important to stress that biosolids are composed of the least water-soluble components of the waste stream. Research shows that when utilized, biosolids decompose over a period of years to release nutrients, organic carbon, and metals. The slow release of these components of biosolids controls how both the beneficial and potentially harmful constituents become available to plants and animals. Under certain conditions water-soluble components can be carried into surface or ground waters. The use of good agricultural practices, including soil erosion control measures, minimizes the impact of biosolids, and other nutrient sources. The risks posed to surface and ground waters by spreading biosolids are probably small when appropriate setbacks are utilized. Uncovered stockpiles on bare ground will leach small volumes of concentrated liquid that can affect groundwater quality with elevated concentrations of nitrogen and trace metals.

The land application of biosolids presents the following potential benefits and risks to water quality.

Potential Benefits:

+ Required separation distances from surface water and biosolids protect water quality.
+ The thickness of soils and absorption onto soil particles protects groundwater below fields approved for land application of Class B biosolids.
+ Plant nutrients in biosolids are released slowly and are readily consumed by plants.
+ Metals contained in biosolids are retained by organic matter and minerals in near-neutral soils.

Potential Risks:

– Nutrients from biosolids stockpiles can be leached to groundwater or be too concentration for plant uptake.
– Soluble metals from biosolids may be transported to groundwater.
– Plants can incorporate potentially toxic metals from soil solutions.
– Long-term management of soil pH is needed to minimize metal loss.

Overall, Maine’s Chapter 419 provides adequate protection of Maine’s water quality. Land application rules, using good erosion-control practices, provide sufficient protection of surface waters. Groundwater quality may be impacted locally by allowing uncovered and unlined stockpiles of Class B biosolids. Composted biosolids are more stable and less likely to leach nutrients. Separation distances to ground water for Class B biosolids may not be sufficient to restrict movement of the most mobile components of biosolids into groundwater.

Pathogens and Odors. Biosolids are classified on the basis of pathogen reduction. Pathogens may include viable enteric bacteria and other organisms, such as bacteria, viruses, and parasites that have survived the treatment process. The goal for Class A pathogen reduction is to destroy or inactivate pathogens to a concentration equivalent to natural background content in soils. Class B biosolids must have a reduction in populations of pathogens by a factor of at least 100 times. Maine recognizes nine methods to produce Class A biosolids and six methods to produce Class B biosolids. The survival of pathogens during the production of biosolids and the ability of these organisms to be infectious is a fundamental public-health concern addressed by the state and federal rules. There is uncertainty in the understanding of how long pathogenic organisms can survive in biosolids and the associated risk of infections. Some of this uncertainty is addressed by state mandated site-specific licenses, mandatory setbacks, and restrictive site suitability criteria for the land-application of Class B biosolids.

Class B biosolids are processed to reduce significantly, but not eliminate, pathogen content and thus present some risk to humans due to direct exposure from accidental ingestion, or via inhalation of bioaerosols. These two routes of exposure require very close physical contact to cause exposure that may lead to illness. The small magnitude of an illness risk is supported by epidemiological studies of waste treatment facility workers and of healthy people having direct or indirect exposure to biosolids at land-application sites. Pathogen viability is affected by many environmental conditions; conditions that allow few organisms to persist. The current standards reduce risks to very small levels, but do not eliminate them. The combination of biosolids processing standards and site use restrictions appear to be effective at protecting public health.

Sewage sludges and biosolids have odors, some of which are considered offensive. Odors may also act as vector attractors (*e.g.* flies and rodents). The association of odors with a substance that may contain pathogens is a commonly cited trigger for community response to biosolids utilization. Setbacks from storage or application sites reduce the impact of odors. New methods of odor management are needed to reduce objections to biosolids reuse.

The land application of biosolids presents the following potential benefits and risks to public health.

Potential Benefits:

+ Class B biosolids protocols significantly reduce pathogen content to concentrations lower than detected in untreated animal manures.
+ Class A biosolids have a pathogen content equal to background soil concentrations.
+ Epidemiological studies show that risks of infection to a healthy population adjacent to properly managed biosolids facilities or Class B application sites are low.
+ Transport of viable pathogens to groundwater is strongly attenuated by soil processes.
+ Regulatory controls minimize public exposure (risks) to biosolids.
+ Class A biosolids have odors similar to organic soils.

Potential Risks:

– Class B biosolids contain some residual concentrations of viable pathogens.
– Pathogens may be infectious and mobile as bioaerosols close to Class B biosolids, but not Class A.
– Pathogenic organisms in Class B biosolids may remain dormant but potentially infectious in the soil (this is addressed by site access restrictions).
– Odors may act as irritants or trigger immune responses.
– Rapid identification of pathogenic organisms is not a mature technique and it is difficult to accurately document presence or absence.

Overall, Maine’s Chapter 419 provides protection of Maine’s public health. A better understanding of pathogens and risks of infection is needed. Odor control continues to be a challenge and it is a source of public concern. The detection of offensive odors is an important factor underlying complaints about biosolids reuse. Operational setbacks help to control odor complaints and reduce the chances of accidental exposure to residual pathogens.

Conclusions

Maine public policy since 1988 has favored the beneficial reuse of biosolids over disposal options such as incineration or landfilling. The reuse of biosolids, as practiced in Maine, is part of the concept of sustainability. Sewage sludge will be produced if we are to continue keeping untreated wastes out of our rivers and streams. Agronomic use of the resulting biosolids is a method to capture and reuse valuable nutrients and organic matter. Like animal manure, biosolids contain comparable nutrients and metals; but untreated animal manures contain more pathogens than biosolids. When managed properly, biosolids serve a useful function in agriculture by increasing soil fertility. Other uses of biosolids, such as forest fertilization and landscaping using Class A composted biosolids, have lessened the dependence on farm applications.

The removal of untreated wastes from our surface waters has resulted in a significant reduction of risks to the environment and human health. Massive outbreaks of diseases caused by polluted water are now uncommon. Ecosystems that were once destroyed by untreated wastes now show evidence of recovery. Relative to untreated wastes, biosolids present a manageable risk to human health and the environment. The continued and sustainable reuse of biosolids in Maine must be supported by research to identify and reduce potentially hazardous chemicals, odors, and pathogen. Regulations should be updated when research demonstrates a need to reduce unacceptable risks. Public policy needs to lead the process towards the reduction or elimination of harmful constituents in the waste stream so that they do not end up in biosolids. There is a need for greater effort to provide the public with a better overview of the benefits and risks of waste management and biosolids reuse in particular.

Section I. Introduction.

1.1 Biosolids Defined

The treatment of municipal wastewater produces solids that have traditionally been called sludge. These solids may include portions directly removed from the wastewater and biological matter (i.e. biomass) generated by microorganisms during processes to remove organic matter and nutrients. Solids recovered from industrial processes are also called sludge and the term is often associated with potentially hazardous industrial wastes. Industrial sludges may have little or no agronomic value, so it is important to distinguish those solids produced from municipal wastewater that have value as a fertilizer or soil amendment. Hence the term biosolids is applied to specifically processed materials that contain plant nutrients or high amounts of organic matter. Biosolids may contain traces of potentially hazardous substances in concentrations that are considered to be below dangerous limits. The Maine and Federal regulations do not explicitly refer to treated sewage sludge as biosolids; however, the EPA (1995) defines biosolids as:

> "*The primarily organic solid product yielded by municipal wastewater treatment processes that can be beneficially recycled*".

The term biosolids has become an accepted term for the usable matter recovered from the processing and treatment of sewage sludge. This acceptance is reflected in Webster's Collegiate Dictionary, 10th edition, which defines biosolids as:

> *"solid organic matter recovered from a sewage treatment process and used especially as fertilizer"*.

It is important to distinguish the meanings of sewage sludge from biosolids. Biosolids have been treated to meet specific land-application criteria in accordance with the US EPA 503 rules (40 CFR 503 (c)) developed in 1993 to ensure safe agronomic use. In particular, sewage sludge contains pathogens, microorganisms that can cause illness or disease; biosolids have been processed to reduce pathogen content. Also, biosolids have been processed to reduce the attraction of disease carrying organisms, such as flies or rodents. These disease carriers are called vectors. Two types of biosolids are recognized based on their potential to contain pathogenic organisms. Class A biosolids have been treated to reduce pathogens to natural background concentrations and vector attractiveness to very low values; much lower than would be found in manures. Class B biosolids have been treated to reduce both pathogens and vector attractiveness, and uses are restricted by well-defined site suitability and access control regulations. These classes and uses of biosolids are clearly defined in the Maine regulations.

1.2 Why Biosolids?

The land application of solids recovered from sewerage treatment process (biosolids) has benefits and risks. Rich in organic matter and containing nitrogen and phosphorous, these solids have value as a fertilizing soil amendment. Being derived from a waste product, biosolids contain traces of potentially hazardous metals, persistent organic compounds, and pathogenic organisms. The composition of the wastes generated by our society is a reflection of our consumption and disposal habits (Kroiss, 2004). Maine's reuse regulations seek to balance the risks to public health while protecting the environment. The benefits and risks of land-applying biosolids is the theme of this document.

Overall, the general public lacks extensive knowledge of where their wastes go and how they are recycled. The beneficial re-use of wastewater treatment plant solids are not typically a major public concern. There have been exceptions where the public has felt that both the regulatory agencies and waste treatment plant operators have disregarded concerns about their health and the environment. This has led to the unfortunate situation of having communities divided by whether they support or object to the land application of biosolids. The social issues associated with waste management are beyond the scope of this review. The purpose of this paper is to summarize how the State of Maine regulates the beneficial utilization of biosolids through land application and to review relevant scientific research (210 recent publications). The intent is to provide a technical summary about how the use of sewage sludge (biosolids) is controlled to keep our waters clean and our environment safe.

The use of waste products, especially those that have strong odors, or come from an objectionable source, invariably causes public concerns. These concerns underlie a community's desire to protect public health and safety, and so merit a serious public discourse. The gains and losses due to utilizing wastewater solids in Maine need to be examined using an analytical approach. The beneficial use of biosolids is not strictly an issue of right or wrong, or even good or bad, but an issue of balancing risks and benefits.

Human society cannot exist without a continuous process of determining acceptable risks. Just like driving a car, a reasonable adult will balance the benefits of getting to work on time with road conditions and the risks of having a traffic accident. In the case of wastewater treatment, there are the benefits of cleaner surface waters and an agronomic value derived from reusing biosolids balanced by the risks of metals in biosolids and the risks of public exposure to potentially hazardous substances. This paper will outline the benefits and risks of using biosolids as a fertilizer or soil amendment as derived from the scientific literature. A comparison of the risks of biosolids to manure or fertilizer will not be discussed in detail. Several comprehensive studies about the environmental effects of manure and fertilizer are available (see citations in Moss et al, 2002).

1.3 Why A Biosolids White Paper?

Goal. The goal of this paper is to review research on the environmental benefits and liabilities of using biosolids for agronomic benefit as the basis for assessing how well Maine's laws and regulations protect environmental quality. This effort includes a summary of the current status of biosolids utilization in Maine, with an emphasis on land application regulated under 06-096 CMR 419. The Maine land-application rules are compliant with existing federal rules (40 CFR Part 503). This work addresses two major themes:

1. Is the land application of biosolids, as regulated and practiced in Maine, sufficiently safe and protective of public health and the environment, particularly soil and water quality?

2. Maine public policy since 1988 favors beneficial use of biosolids over disposal options such as incineration or landfilling; is this beneficial use of biosolids supported by research?

Background: There is a perception in the wastewater treatment field that the general public misunderstands the environmental and human health effects of biosolids utilization in any form (Beecher et al., 2005; O'Connor et al., 2005). The existence of local opposition to utilization can be cited as the basis of this impression. This difference arises in part because opponents of biosolids use perceive a greater risk than the wastewater treatment plant operators. The perception of a greater risk, even if that perception is difficult to substantiate, is just as real in the minds of those opposed to biosolids reuse as any factual documentation of risks (Daughton, 2004; Beecher et al., 2005). This review provides a summary of research that can be used as a point of departure for discussions. Another aim of this paper is to help provide a broader background on the impact of biosolids utilization. As part of the continuing public debate, there is a need to have the arguments based on factual data that can help to define problems, answer questions, and aid in the interpretation of anecdotal information. The educational efforts of the wastewater industry and regulatory agencies, although technically complete and factual, made be viewed as agenda driven or unbalanced. Information sources that are considered biased often are rejected and ignored. If there is to be any progress made in determining how we balance the protection of public health with maintaining a clean environment, there must be effective and informed dialogue.

Needs: The wastewater treatment plant managers, concerned citizens, and others have requested a review of environmental and public health research relative to biosolids. The primary focus has been on the land application of biosolids because this is the area of greatest concern for potentially harmful impacts. The design of the analysis is based on the interpretation of more than 200 reports and peer-reviewed scientific papers. The peer-review process assures that the studies followed scientifically accepted methods of data collection and analysis. Using this protocol means that independent researchers should reach similar conclusions when analyzing the results of the same study. There is a wealth of research on how biosolids affect soil and water quality, as well as how pathogens from the waste treatment process are controlled or inhibited. The scientific studies are diverse and the results are not always accessible to the average citizen.

1.4 Biosolids White Paper Organization

The paper is divided into five sections.

Section I provides a brief background on why we have the whole issue of utilizing biosolids, including an outline of how biosolids are regulated in Maine. The regulations should direct the management of biosolids based on the scientific research.

Section II addresses how biosolids affect soil quality by drawing from a substantial body of research.

Section III analyzes how biosolids affect water quality, both surface and ground, since a primary aim of the regulation is to protect water quality.

Section IV summarizes the current research on odors and pathogens in biosolids.

Section V takes the research studies and assesses whether the Maine regulations work to protect the environment and public health.

What occurs in Maine is important in the context of the whole country. The generation and management of biosolids has been the focus of national studies (NRC, 1996 and 2002) and efforts have been made to target key issues such as the Water Environment Research Foundation's Biosolids Summit (Dixon and Field, 2004). This paper will help to relate national issues to Maine.

1.5 Background

The federal Clean Water Act (33 USC 1251 et seq.) was enacted in 1972 and it initiated a process to make our rivers, lakes, and streams cleaner. This process continues and many areas are once again enjoying the benefits of having water that has been restored to be swimable, fishable, and drinkable. As a society, we place a high value on our water resources, while at the same time we place high demands on these same resources (Bergstrom et al., 2001). These water quality gains come at a cost, and part of the cost has been removing sewage wastes from our waters.

Waterways have been used for waste disposal for centuries; even the ancient Romans had sophisticated systems of aqueducts and sewers to keep their urban areas healthy and clean. The Clean Water Act went beyond sewer systems to developing technologies to remove the chemical and biological burden that wastes place on water. This meant that cities and towns had to remove solids and soluble nutrients from the wastes in order to lower the burden. For areas without much industry, the wastes come predominantly from domestic sources such as toilets, sinks, showers, and washing machines. Industrial sources are strictly regulated under the National Pretreatment Program (www.epa.gov/npdes) to prevent discharges that would adversely affect effluent quality and ultimately biosolids quality. This program has helped to reduce the metal content in biosolids over the last decade.

Through a series of treatment steps that screen and settle out the solids and use bacteria to consume the nutrients, sewage treatment plants discharge clear, practically potable, water. The solids produced at the treatment plant are an integral part of making the wastewater cleaner. Production of the solids is impossible to avoid. These solids contain the nutrients removed from the wastewater, along with other components that adhere to the solids. There are only a few acceptable methods for dealing with these materials: 1) disposal in a landfill; 2) incineration and disposal of the ash in a landfill; or 3) utilization of the solids as a fertilizer or soil-building material (Overcash, 2004; Overcash et al., 2005). Each of these sewage sludge disposal options is worthy of a detailed analysis and Krogmann et al. (1999) present a detailed summary of each. In this paper the third option, utilization, and particularly as Class B biosolids, will be assessed. Class A biosolids differ from Class B in terms of pathogen content and character of its organic matter, but the broader range of research on Class B biosolids allows for a more rigorous analysis.

1.6 Maine's Regulations

In Maine, sewage sludge used in land application is regulated as a solid-waste residual. The rules developed by the Maine Department of Environmental Protection (DEP) were authorized by the Legislature under statute 38 MRSA Sections 1304(1), (13), and (13-A). These statutes authorize the DEP to regulate solid wastes to minimize pollution of the environment. The innovative re-use of wastes, explicitly sludge land-application, is supported by statute. The statutes also state that the public must be notified of sludge utilization sites. Simplified, the *Maine statutes direct the Maine DEP to support the highest value use for sewage sludge and direct the DEP to keep the public informed of utilization sites*.

Under these legislative statutes, the Maine DEP has developed rules within its solid waste responsibilities for the Agronomic Utilization of Residuals (06-096 CMR, Chapter 419). Copies of the rules are available in most public libraries in Maine and all of the rules can be viewed online at the Maine DEP web page, http://www.maine.gov/dep/environlrr.htm. The Maine rules conform to the US EPA rules for the land application of sewage sludge (40 CFR Part 503). Maine's minimum quality standard for sewage sludge is equal to the EPA's exceptional quality standard. The Maine DEP regulates the land application of sewage sludge (biosolids) using standards that meet or are more stringent than the US EPA requirements. This increases the level of protection to the environment and public health in Maine as compared to what is mandated by the federal government.

The Maine rules refer to sewage sludge that is acceptable for land application and the term "biosolids" is not used explicitly in the regulations. In the following discussion "biosolids" always refers to a sewage sludge that meets land application standards. In later sections of this report, research completed before the acceptance of the term "biosolids" uses the term "sewage sludge". It is not usually clear if the sewage sludges applied before 1993 met today's quality standards. The land application of septage wastes is not included in this summary.

The Maine rules for agronomic utilization of Class B residuals are comprised of several parts that cover:

- Licensing of generators and utilization sites,
- siting of utilization sites,
- operating standards including biosolids quality and composition,
- suspension of utilization sites,
- record keeping and reporting, and
- oversight.

First and foremost, the utilization of biosolids must be licensed by the Maine DEP (Chapter 419, Section 2). Program and site licenses are needed to store and apply biosolids. Public notice of license application is required and public comment regarding the application to the Maine DEP is invited (Chapter 419, Section 2(G), and Chapter 2). Typically notice is made as a legal notice in a local newspaper and at the town office, plus mailing to utilization-site abutters.

Siting. There are specific rules for the licensing of Class B biosolids land-spreading sites that include both material quality and site suitability (Chapter 419, Section 3(B)). The siting standard establishes quality guidelines for a maximum acceptable concentration of specific trace metals in the biosolids (Table I) and pathogen content. Any leachable residual, including biosolids, must be used with setback from wells, property lines, bedrock outcroppings, dwellings, and surface water features and be used over a soil of sufficient thickness to protect ground water (Chapter 419, Section 3(A)). Site suitability is defined to minimize erosion and loss of biosolids into surface and ground waters. Ideal locations are flat with a thick layer of fairly dense soils.

Setbacks from surface water features (drainage ditches, streams, lakes, etc.) vary depending upon the land slope and vegetation type, such as wooded or open (Chapter 419, Section 3(B)(2)). These setbacks protect surface waters from direct transport of biosolids across the ground surface during a rainstorm. Neighboring properties are protected with setbacks from boundary lines. (Chapter 419, Section 3 (C)).

Agronomic Value. Biosolids must be used for a defined agronomic benefit (Chapter 419, Section 4(B)). This benefit may be from nutrients, such as nitrogen or phosphorous, or as a liming agent. The amount of biosolids utilized must be calculated based upon soil testing and crop requirements. This is a very important concept, because biosolids contain several nutrients and utilization must not exceed any crop or soil nutrient need.

Environmental Protection. The Maine DEP is charged to protect the waters of the state, and utilization of Class B biosolids must not pollute any water by direct application, surface runoff, or leaching to ground water (Chapter 419, Section 4(E)). To protect water resources, biosolids may not be applied to frozen or snow covered ground, or during periods when the ground is saturated with water. Biosolids must be spread evenly at agronomic rates and utilization rates must account for crop harvest or fallowing. Vegetation must be maintained to minimize erosion losses. Buffer zones must be maintained to prevent the washing of biosolids into surface waters. Hydric soils are not suitable for land spreading and their use is prohibited. Hydric soils are defined to be saturated with water long enough during the growing season to favor the growth of wetland plants.

Class B biosolids in Maine typically have carbon to nitrogen ratios less than 25:1. This implies that excess nitrogen may be leached from the biosolids into groundwater. In addition to requiring agronomic application rates, the Maine DEP has additional standards to protect groundwater quality (Chapter 419, Section (4)(L)). These standards define suitable soils to minimize leaching, establish a separation distance to groundwater or bedrock, and limit the window for spreading (no spreading on frozen, snow-covered, or water-saturated soil).

Pathogen Control. Biosolids, because they contain human pathogens, have additional operational standards (Chapter 419, Section 4(I)). The Maine DEP classifies any residual that may contain human pathogens as a Type II residual. These residuals can be utilized only after they are treated to reduce the pathogen content and vector attraction potential. Two pathogen reduction standards are recognized: Class A and Class B. Class A biosolids have been processed to reduce pathogens to very low concentrations, equivalent to background values, based upon *Salmonella* and fecal coliform assays. Common methods used in Maine to make Class A biosolids are composting and advanced alkaline stabilization with supplemental drying. Processing sewage sludge to the Class B standard reduces pathogens, but not to as low a concentration as required for Class A. Common methods employed in Maine are lime stabilization, composting, and thermophilic aerobic digestion. Vector reduction techniques are employed to minimize biological contact with disease spreading organisms. Vector attraction reduction for Class B biosolids can also be attained by direct injection into the soil or tilling after application.

The potential risks of biosolids components entering the food chain through crops, livestock, or direct human contact is a public health concern. In order to minimize health risks, the Maine

DEP places restrictions on the use of agricultural land that has received Class B biosolids, but not Class A (Chapter 419, Section (4) (I) (2)). These restrictions apply to when:

- crops can be grown and harvested;
- animals can be grazed;
- turf can be grown;
- topsoil harvested; and
- public access must be controlled.

Metals. There are heavy metals in biosolids that are characteristic of the region's water supply and the diet of the source community. Heavy metals concentrations are monitored in biosolids and soils because some are plant or animal toxins (Chapter 419, Section (4)(J)). Additional setbacks are required when metals exceed the screening concentrations (Table I). Maine allows for certain maximum concentrations in biosolids that may be allowed is special one-time application (second column of Table I). Regardless of how much is applied, Maine has strict annual and cumulative metal loading limits (Chapter 419, Section (4)(J)(5)). All land utilization of biosolids must cease if metal loadings reach the cumulative limit in soil (fourth column of Table I) as determined from soil tests, regardless of agronomic requirements.

TABLE I. Maine standards for metal content in sewage sludge, soil loading limits, and maximum acceptable metal content in soils at utilization site.

Trace Metal	Screening Concentration in Sewage Sludge (mg/kg)	Maximum Concentration in Sewage Sludge (mg/kg)	Maximum Annual Loading to Soil (kg/ha)	Cumulative Maximum Loading to Soil (kg/ha)	Maximum Concentration in Soil (mg/kg)
Aluminum					100,000
Arsenic	10	41	0.5	10	73
Barium					1,500
Beryllium					7
Cadmium	10	39	1.9	39	39
Chromium	1,000	3,000			3,000
Cobalt					70
Copper	1,000	1,500	75	1,500	1,500
Lead	300	300	15	300	300
Mercury	6	10	0.3	6	6
Molybdenum	75	75			15
Nickel	200	420	20	420	420
Selenium	100	100	5	100	100
Silver					34
Vanadium					300
Zinc	2,000	2,800	140	2,800	2,800

Note: blank cells have no standard, mg/kg = ppm, values are on a dry weight basis.

Hazardous Substances. The biosolids must be tested for the presence of numerous hazardous organic compounds (Chapters 405 and 418) including dioxins (Chapter 419, Section (4)(K)).

Typically, biosolids contain few, if any, hazardous organic compounds or dioxins. The Maine DEP evaluates hazardous organic compounds on a case-by-case basis and has set a maximum acceptable concentration of 250 parts-per-trillion (ppt) limit for dioxins (expressed as the 1987 factors for toxic equivalents to 2,3,7,8 TCDD; tetra-chloro-dibenzo-dioxin).

Odors. Biosolids have the potential to generate nuisance odors. Under Chapter 400 (Section (4) (G) (1)), utilization must produce no unreasonable change in air quality. This is managed in Chapter 419 Section (4) (H) through three performance criteria. These criteria apply only to putrescible materials. All Class A biosolids and most Class B biosolids that meet the vector attractiveness reduction criteria should fall below the applicable threshold. The first performance criterion is requiring a 300 foot setback from occupied buildings; a greater setback may be needed if odors are unusually intense. The second is a site specific odor control plan to be implemented by the generator. The third standard is a requirement to notify the Department at least one day prior to site utilization.

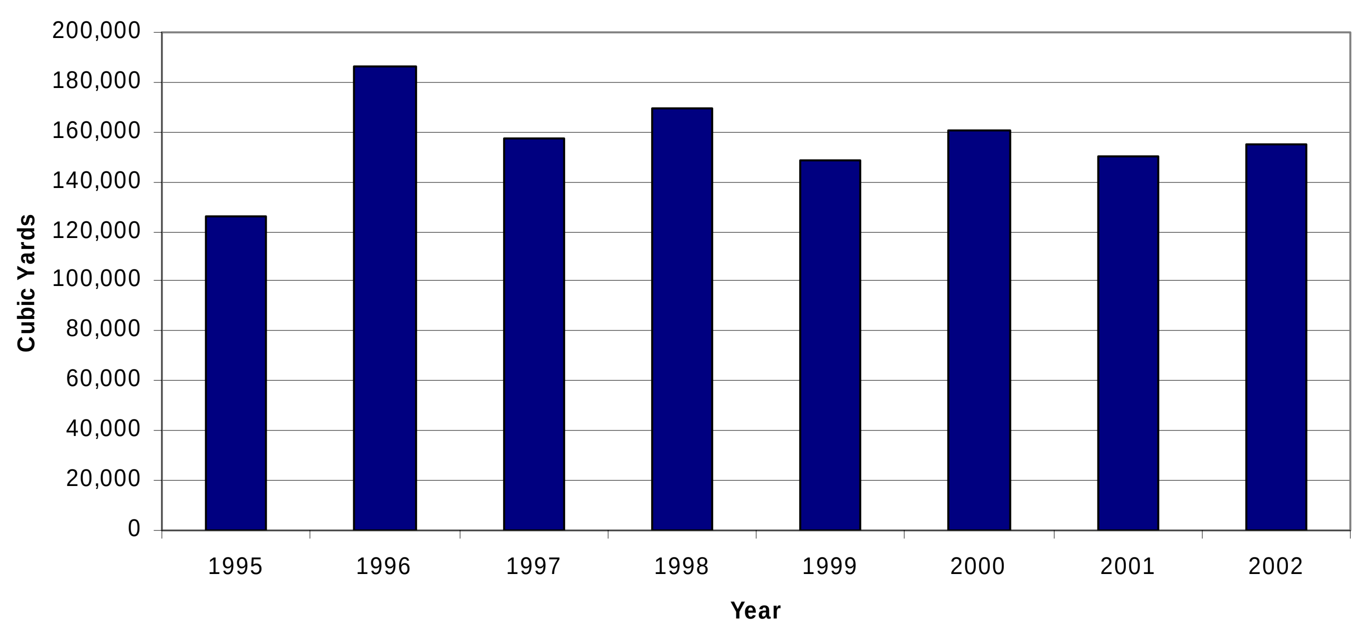
Storage. The generation of biosolids occurs year-round, but spreading on agricultural land is limited by the cropping cycle. Typically, biosolids are spread in the late-spring during planting, after mid-summer croppings, or in the fall after harvest. In order to accommodate farm management, biosolids must be stored before application. The storage of biosolids is regulated because they can have a high moisture content and leachate can drain from stockpiles. The Maine DEP has extensive rules for stockpiling (Chapter 419, Sections (10) (11) (12)). The rules are different for covered storage and field stacking.

In general, biosolids storage must be sited away from dwellings, roads, water supplies, and floodplains (Chapter 419, Section (10)(A)). In particular, field storage sites must not contaminate the waters of the state. This mandate is met by limiting storage in a field to the agronomic amount needed and storing biosolids on flat ground. In addition, soils below the stockpile must be relatively dense with low permeabilities (< 2-inches per hour) in the C horizon (Chapter 419, Section (10)(C)). In order to protect surface and ground waters, soils must be 30 to 40 inches thick and the seasonal high-water table must be greater than 24 inches below the surface. Any leachate developed by the stockpile must be contained within the utilization area. Biosolids are not to be stockpiled within 250 feet of large water bodies such a great ponds, rivers, and perennial streams (Chapter 419, Section (10)(D)).

1.7 Characterization of Biosolids in Maine

How Much is Produced? According to Maine DEP records there are 200 licensed wastewater treatment facilities in the state. These facilities vary in size from small towns to large cities; some of which may also receive industrial inputs. A smaller number of facilities (120) are listed as generating sewage sludge. The sewage sludge may not necessarily be treated to produce biosolids. Common management alternatives are land application, composting, or landfilling. In 2002, approximately 154,923 cubic yards of sewage sludge was generated in the state. Note that wastewater treatment plants record volumes in either cubic yards or gallons or pounds. To convert between these different units of measure the Maine DEP assumes that sewage sludge weighs 1700 pounds per cubic yard. The amount of sewage sludge generated each year varies by

Figure 1. Annual Sludge Production in Maine 1995-2002 (Figure modified from Maine DEP).



10 to 20 per cent (Figure 1). This variability is due in part to lagoon storage facilities at some wastewater treatment plants and the plant operators' ability to dewater the sludges.

How Much is Reused? Just as the amount of sewage sludge generated each year varies, the ultimate disposition of the sludges each year is also variable (Figure 2). A majority (>75%) of the sewage sludge is processed into Class A or Class B biosolids each year. Disposal in landfills accounts for 10 to 25 per cent of the sludge each year. The remainder of the annual production goes to different uses: landfills, storage, and transport out of state. In 2002, 35,738 cubic yards (23%) were processed to the Class B standard and reused in land applications. Another 46,581 cubic yards (30%) were processed to the Class A standard and 18,946 cubic yards (12%) were utilized in Maine; the remainder of the Class A biosolids were exported.

There are some important trends in sewage sludge disposition between 1995 and 2002 that reflect trends in management and utilization. The amount of Class A biosolids produced each year has been increasing consistently and now is the destination for more than half of all the sewage sludge produced. The land application of Class B biosolids has steadily declined over this period of eight years and in 2002 it accounted for less than 25 per cent of all the sewage sludge produced. It is important to note that both Class A and Class B biosolids can be applied to land. Class B biosolids use is restricted to agronomic applications while Class A biosolids, such as compost, have many more potential applications. Composted biosolids have been employed in diverse uses such as: road bank stabilization, landscaping around parking lots, playing fields, and land restoration projects.

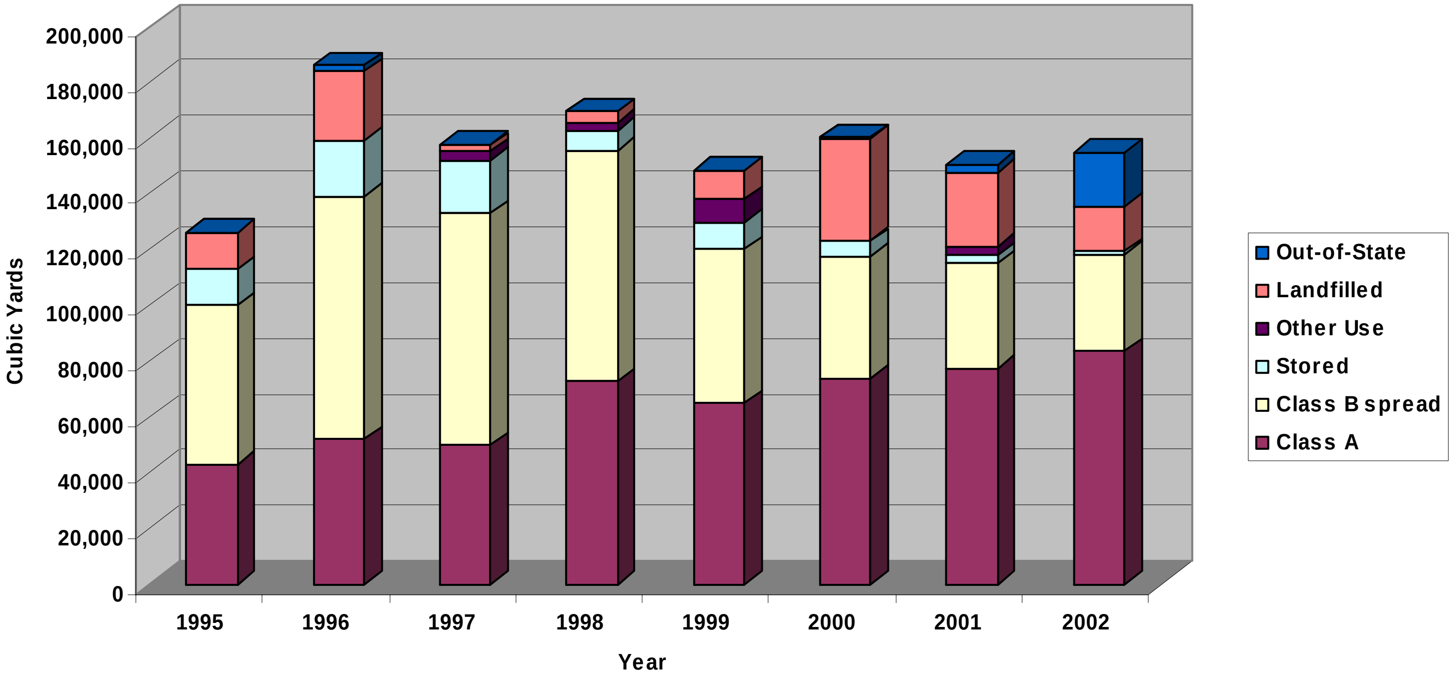
The amount of sewage sludge sent to landfills varies each year. The landfilled amount varies due to sludge quality, economic incentives, or material designated for land application that could not be delivered because of weather conditions or limited storage. Landfilling is relatively expensive; the long-term outlook for landfills is a growing demand for the space and higher tipping fees.

Not all sewage sludge generated in Maine is utilized in the state. Some is shipped out of state to other processing facilities, utilization sites, or landfills. The amount leaving the state is dependent upon demand by processors and disposal fees.

What is the Composition of Biosolids? Biosolids are produced from the solids collected at wastewater treatment plants and their composition depends upon what gets sent to the treatment plant. For many towns in Maine, the input is coming from homes and contains all the substances that we send down our drains. Large industries usually have their own dedicated wastewater treatment plants. Small industries will typically discharge wastes to municipal treatment systems after some amount of pre-treatment. The US EPA initiated pre-treatment of industrial wastes in 1978 under amendments to the Clean Water Act (40 CFR Part 403). Under the pre-treatment program industries must remove hazardous wastes from their sewage discharge. This program has helped to reduce the amount of hazardous chemicals that once ended up in sewage sludge (Krogmann and Chiang, 2002).

In Maine, the quality of the wastes, and ultimately the biosolids, are tested or monitored at multiple locations in the process. All testing is approved and reviewed by the DEP- the agency responsible for protecting the state's water, air, and soil. Raw sewage is tested as it comes into the wastewater treatment plant. The biosolids product is tested on a routine and regular basis, semi-annually to monthly as determined by produced volumes. The characteristics of biosolids

Figure 2. Utilization of Sewage Sludge in Maine 1995-2002 (Data from Maine DEP).



do not vary markedly over time and testing every few hundred cubic yards is considered to be sufficient. Any material can be selected by the Maine DEP for a spot test, anywhere, anytime. All testing must be performed using standard protocols, EPA analytical methods and in a timetable set by the regulators (06-096 CMR Chapter 405, Sampling and Analytical Plan Requirements). Manures and even commercial fertilizers are not subject to this amount of testing.

Biosolids have agronomic value because they contain measurable quantities of needed plant nutrients, especially: nitrogen, calcium, magnesium, potassium, sodium, phosphorous, and carbon. These nutrients may constitute up to several percent of the total mass. Micronutrients provided by biosolids are chloride and iron, plus some trace metals. Micronutrients usually are contained in the part-per-million (ppm) range. Some of these nutrients are readily available to plants while others are released more slowly. Each type of biosolids will have its own characteristic nutrient value.

Biosolids are mostly water: Class B has 20% to 30% total solids; Class A has 40% to 50% total solids. The water in biosolids is slowly released. The high organic matter content of biosolids makes it a valuable amendment for improving water retention capacity in soils. Lime-stabilized biosolids have a high pH and can be used as liming materials as well as a fertilizer. Since soils in Maine are naturally acidic, crops grow better in soils that have been limed to reduce acidity. Some typical ranges for the nutrient content of Class B biosolids in Maine are presented in Table II. Some of the biosolids have had lime added prior to analysis and this contributes to the broad range of calcium concentrations.

Table II. Typical Plant Nutrient Concentrations in Class B Biosolids in Maine.

	Total Nitrogen	**Phosphorous**	**Potassium**	**Carbon**	**Calcium**	**Sodium**	**Iron**
Class B	***%***	***%***	***%***	***%***	***ppm***	***ppm***	***ppm***
Minimum	0.14	0.1	0.0	14.0	1500	294	580
Maximum	7.78	3.2	0.8	52.6	325000	6700	75000
Mean	4.46	1.0	0.2	37.8	44993	2686	13922

Data from Maine DEP and New England Organics: 239 analyses from 22 facilities collected between 2001 and 2003.

Biosolids also contain metals in trace concentrations. Some metals are also plant nutrients when present in very low concentrations. However, in high concentrations some metals can impair plant growth (phytotoxicity) or degrade the quality of the crops. Maine has maximum ceiling concentrations for 16 different, and naturally occurring, metals in soils at utilization sites. Biosolids are required to be analyzed for the presence of 19 metals that have maximum acceptable concentrations in soils: aluminum, arsenic, barium, beryllium, cadmium, calcium, chromium, cobalt, copper, iron, lead, mercury, molybdenum, nickel, selenium, silver, sodium, vanadium, and zinc. The Maine screening standards for 10 metals are presented in Table I. The screening standards are equivalent to the US EPA’s Exceptional Quality standard for two metals and more restrictive for six others.

The actual concentrations of trace metals in biosolids in Maine vary considerably across the state. In general, nearly all of the sewage sludges produced in Maine have metal concentrations well below the screening limit. This implies that when sludges are applied at agronomic rates, the input of metals to the soil is small. The actual ranges of metals found in sewage sludge, including those processed into biosolids, are depicted in Figure 3. The data are plotted as cumulative frequency diagrams. Maine's screening standard is shown as a vertical line in each plot. The curve depicts the portion of the data that fall below a certain value. For example, 100 per cent of the arsenic concentrations are less than 39 mg/kg and half of all concentrations are less than 6 mg/kg. The cumulative frequency plots show the variability of the concentrations better than a table of ranges. Steep curves imply that the concentrations have small variations and shallow curves have wide variations. This analysis is based on 182 samples reported from 51 sewage treatment plants in Maine during 2002.

Following is a summary of the trace metal concentrations detected in Maine sewage sludges that were processed into Class A or B biosolids during 2002. The concentrations are compared to the Maine screening standard which represents exceptional quality. The median is the value for the middle of the population (geometric mean); half of the samples are larger and half are smaller.

Although there are trace metals in sewage sludges generated in Maine, very few have concentrations that exceed the screening limits. The median concentrations for all metals are substantially below the screening limits, usually 50 per cent or less.

Figure 3. Cumulative Frequencies of Trace Metals in Maine Sewage Sludge. Data from Maine DEP for 2002.

Note: Figure is continued on the succeeding three pages.

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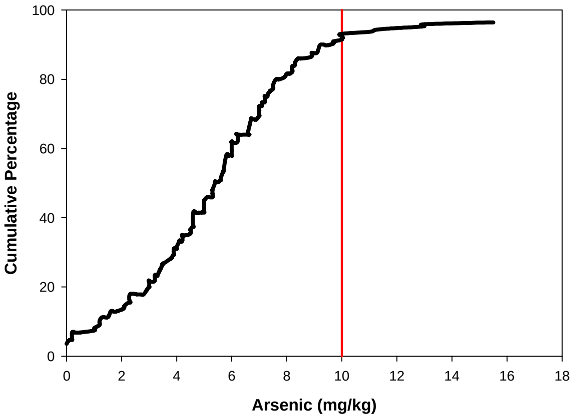
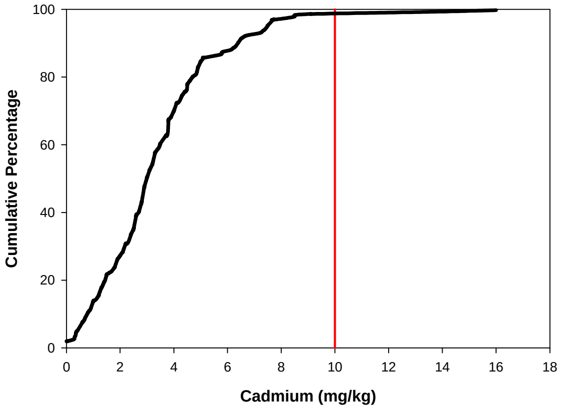
Arsenic. Arsenic occurs in concentrations up to 39 mg/kg in Maine sewage sludges. More than 90 per cent of all these sludges have concentrations below the Maine screening standard of 10 mg/kg. The median concentration is approximately 6 mg/kg, nearly half of the screening standard

Figure 3-A. Arsenic.



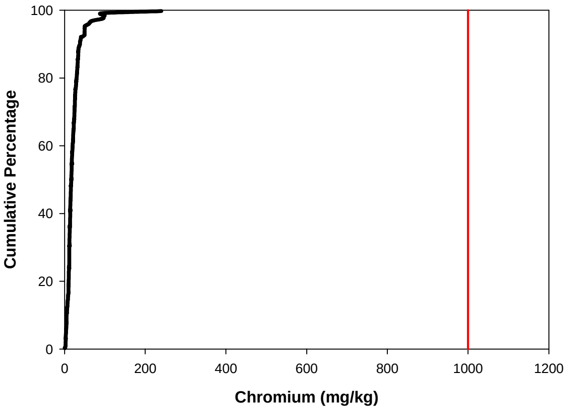
Cadmium. Cadmium occurs in concentrations up to 16 mg/kg in Maine sewage sludges. More than 99 per cent of all these sludges have concentrations below the Maine screening standard of 10 mg/kg. The median concentration is approximately 3 mg/kg, nearly one-third of the screening standard

Figure 3-B. Cadmium.



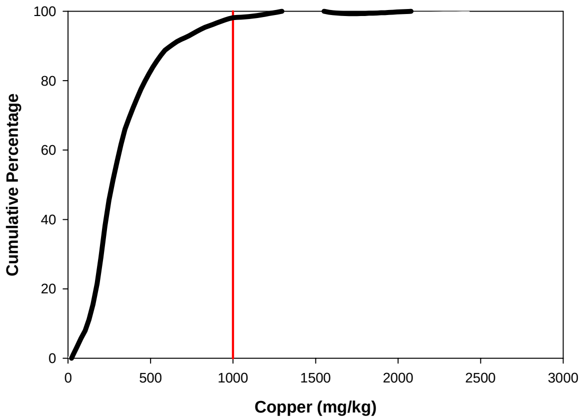
Chromium. Chromium occurs in concentrations up to 240 mg/kg in Maine sewage sludges. All these sludges (100%) have concentrations below the Maine screening standard of 1000 mg/kg. The median concentration is approximately 17 mg/kg, less than 2 per cent of the screening standard.

Figure 3-C. Chromium.



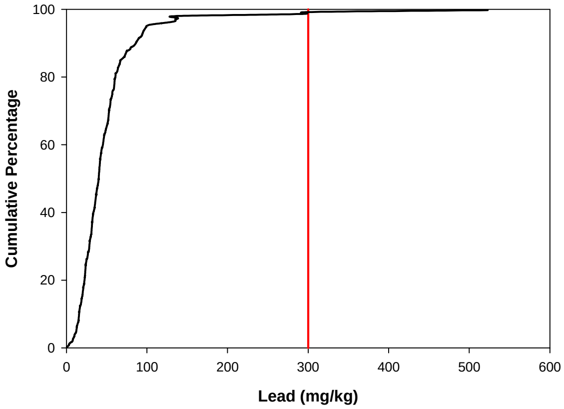
Copper. Copper occurs in concentrations up to 2429 mg/kg in Maine sewage sludges. More than 98 per cent of all these sludges have concentrations below the Maine screening standard of 1000 mg/kg. The median concentration is approximately 260 mg/kg, slightly less than one-third of the screening standard.

Figure 3-D. Copper.



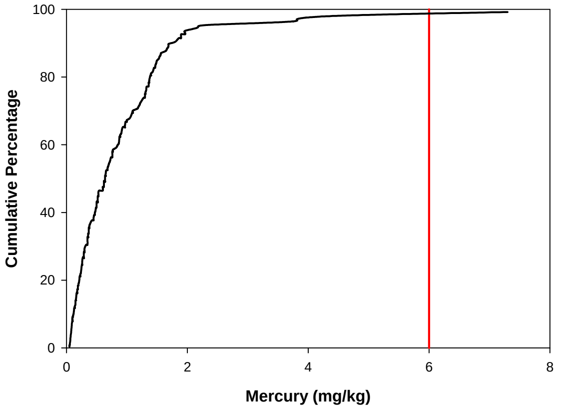
Lead. Lead occurs in concentrations up to 523 mg/kg in Maine sewage sludges. More than 99 per cent of all these sludges have concentrations below the Maine screening standard of 300 mg/kg. The median concentration is approximately 40 mg/kg, nearly one-tenth of the screening standard.

Figure 3-E. Lead.



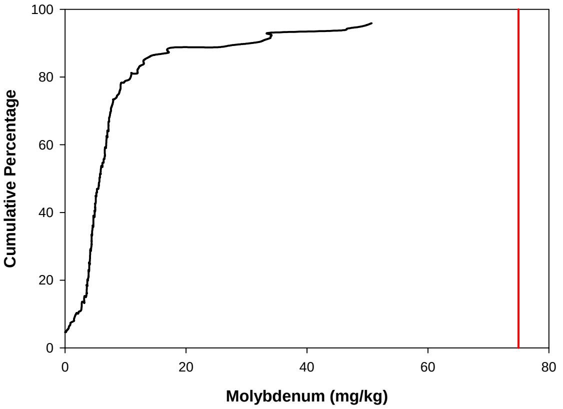
Mercury. Mercury occurs in concentrations up to 10 mg/kg in Maine sewage sludges. More than 99 per cent of the sludges have concentrations below the Maine screening standard of 6 mg/kg. The median concentration is approximately 0.6 mg/kg, one-tenth of the screening standard.

Figure 3-F. Mercury.



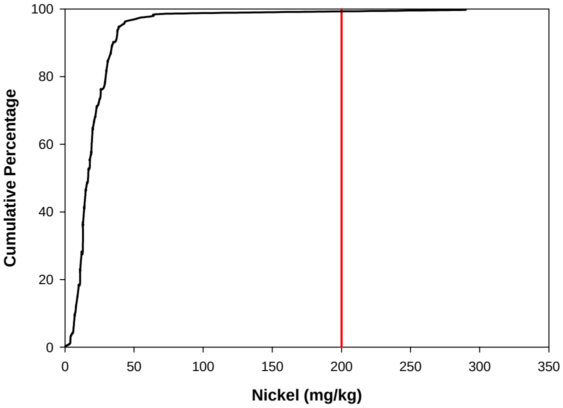
Molybdenum. Molybdenum occurs in concentrations up to 72 mg/kg in Maine sewage sludges. All these sludges (100%) have concentrations below the Maine screening standard of 75 mg/kg. The median concentration is approximately 6 mg/kg, less than one-tenth of the screening standard.

Molybdenum



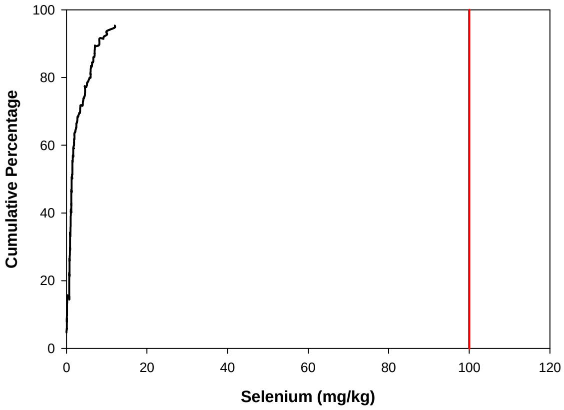
Nickel. Nickel occurs in concentrations up to 290 mg/kg in Maine sewage sludges. More than 99 per cent of all these sludges have concentrations below the Maine screening standard of 200 mg/kg. The median concentration is approximately 17 mg/kg, less than one-tenth of the screening standard.

Figure 3-H. Nickel.



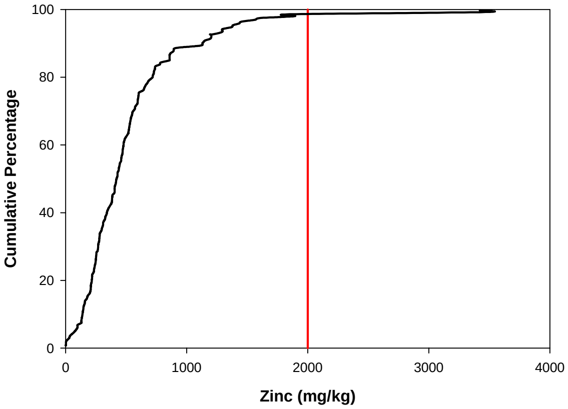
Selenium. Selenium occurs in concentrations up to 52 mg/kg in sewage sludges. All sludges (100%) have concentrations below the Maine screening standard of 100 mg/kg. The median concentration is approximately 1.5 mg/kg, nearly 2 per cent of the screening standard.

Figure 3-I. Selenium.



Zinc. Zinc occurs in concentrations up to 3422 mg/kg in sewage sludges. More than 98 per cent of all sludges have concentrations below the Maine screening standard of 2000 mg/kg. The median concentration is approximately 420 mg/kg, nearly one-fifth of the screening standard.

Figure 3-J. Zinc.



Are There Hazardous Substances in Biosolids? The composition of biosolids depends upon the wastes sent to the wastewater treatment plant. Aggressive pollution-prevention programs that have targeted industries and household hazardous wastes have reduced the amount of hazardous substances entering the waste stream over the last decade. Since industries have reduced the amount of hazardous wastes that could end up in biosolids, Maine has been able to maintain its quality standards. The biosolids are screened for 148 different hazardous organic compounds. Some of the potentially hazardous organic compounds detected come from innocuous or unavoidable sources such as drinking water supplies, plastic pipes, or the action of bacteria during the waste treatment process. The presence of pesticides or poly-chlorinated biphenyls (PCBs) at concentrations above detection limits is almost nonexistent in biosolids. Concentrations of dioxins below the Maine limit of 250 ppt have been detected in some biosolids. Unfortunately, dioxins can be detected in almost everything from sewage sludge to soil. Much effort has been spent to identify and control sources of dioxin. Organic compounds that may be detected in some Maine biosolids are characterized below:

Acetone and 2-Butanone. These are common industrial chemicals and are found as solvents in paints, adhesives, and nail polish remover. A more likely source in biosolids is the formation of acetone or 2-butanone through bacterial fermentation of organic matter.

Bis (2-ethylhexyl) Phthalate. This compound is found anywhere plastic pipes are used. It is part of a family of compounds known as plasticizers; compounds that make plastics flexible. Similar compounds that may also be detected are butylbenzylphthalate and di-n-octylphthalate.

Chloroform. Chloroform is a disinfection by-product produced when drinking water is treated with chlorine to control pathogens. The chlorine reacts with natural organic matter in the source water to form chloroform. Chloroform is common to many public water supplies that use chlorine as a disinfectant.

Phenol. The occurrence of phenol in biosolids is due to several sources. Phenol can come from: its use as a sterilizing agent, chemical feedstock, plastics, or as a product of bacterial metabolism.

1.8 How Do Biosolids Compare to Manures?

Manures are the raw wastes from farm animals; in Maine, sources can be cows, chickens, or pigs. There is a long tradition of using manure for a fertilizer. The nutrient value of biosolids tends to be comparable to manures for nitrogen and phosphorus, while the potassium content of biosolids is lower than manures. The trace metal content of biosolids is also comparable to biosolids. The trace metal concentration of biosolids is plotted in Figure 4 using the same data as shown in Figure 3. In Figure 4, the concentration ranges are depicted as boxes. The box itself shows the range of 75 percent of the samples, the line in the box is the mean value. The whiskers outside the box show the range of 90 percent of the samples and the dots are samples that lie outside of that 90 percent. The concentration scale is logarithmic in order to show all of the trace metals simultaneously.

Figure 4. Trace Metals In Biosolids.

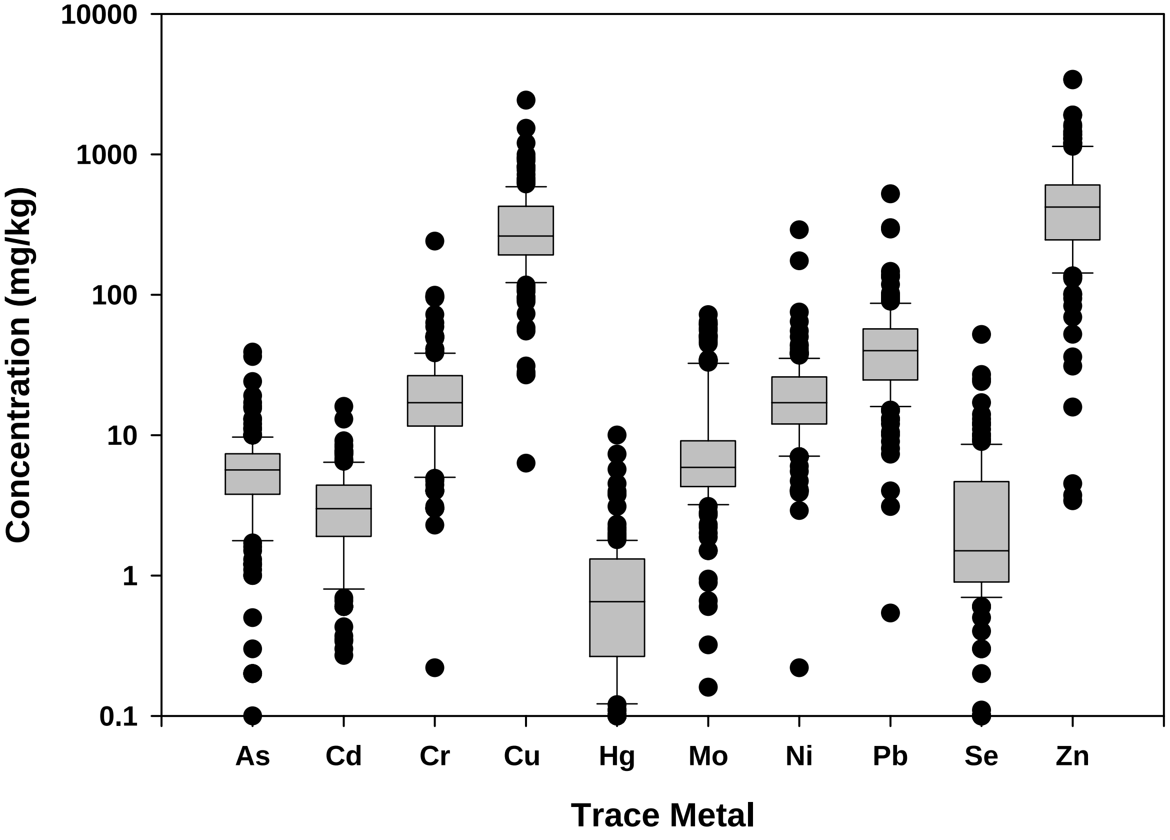
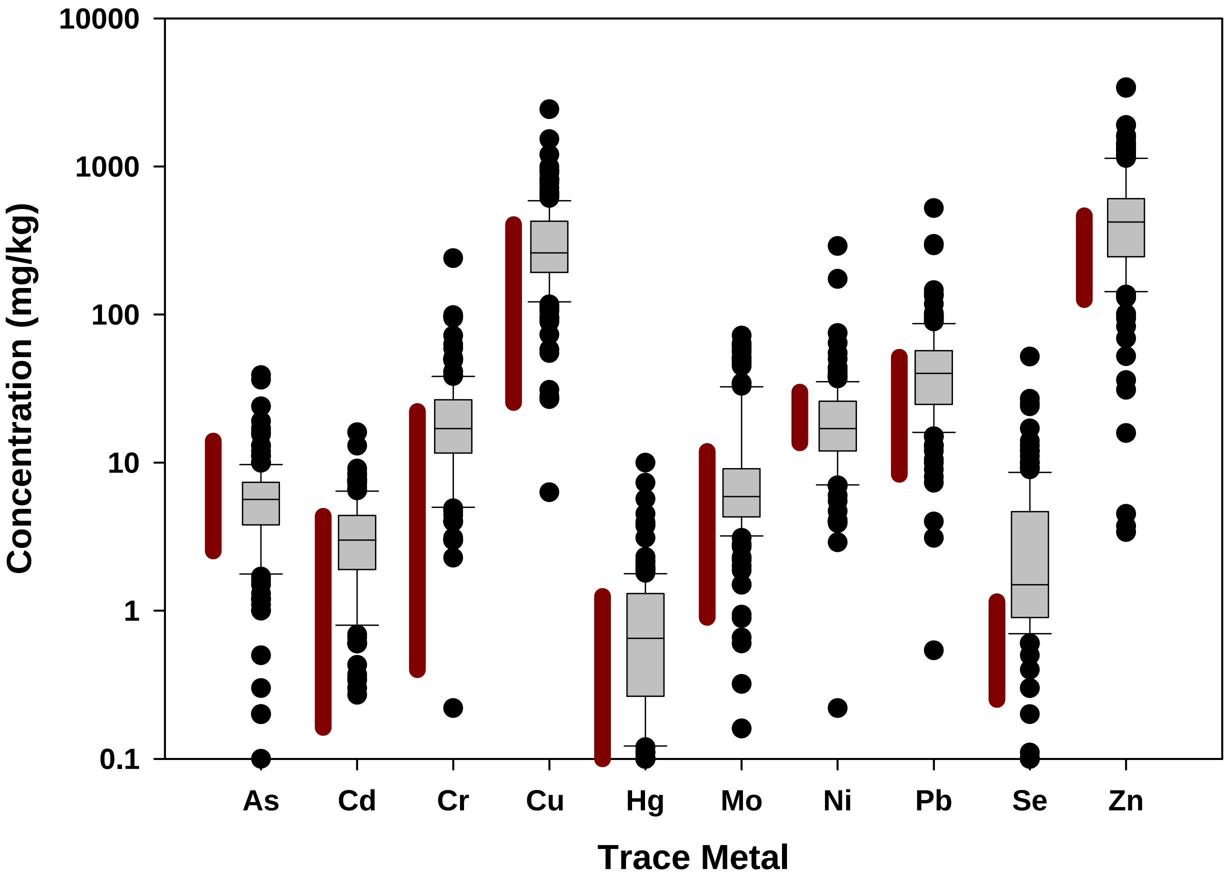


Figure 5. Trace Metals In Biosolids Compared To Manures.

Box plots are biosolids and red lines are manure ranges.



The trace metal concentrations for animal manures are compared to biosolids in Figure 5. The manure values are ranges only (solid vertical lines next to the boxes). Trace metals concentrations in manures are taken from several sources including Maine DEP (unpublished), national studies (Moss et al., 2002), and European studies (Eriksson, 2001; Moreno-Caselles et al., 2002). The ranges of trace metal concentrations in manures overlap the values for biosolids, with the exception of selenium. In terms of nutrients and trace metals, biosolids are very similar to common manures. In terms of pathogens, farm manures are not subject to any pathogen reduction or pathogen control processes.

1.9 What Are The Trends In Maine?

In Maine, the relative disposition of biosolids has changed during the last few years. The uses have not changed and the overall end points continue to be: Class B land applied, Class A land applied, landfilling, export out-of-state, and Class B for other uses. These trends are visible in Figure 2. Land application of Class B biosolids is a declining part of the mix. These changes in how biosolids are managed underscore the challenges faced by the waste-water treatment plants. In particular, the treatment works must make sewage sludge in order to keep surface water clean and managing this sludge (biosolids) is an essential part of the overall process. When the wastewater treatment plant options are reduced to only landfills or Class A biosolids, costs increase. These costs are ultimately paid for by the community through higher fees or taxes. The future use of biosolids, as either Class A or B, will depend upon how current policy is implemented and how new policies are structured.

1.10 What Are The Concerns?

The improvement of surface water quality accomplished through wastewater treatment is highly valued by the public. The production of sewage sludge and biosolids are therefore necessary products of the treatment process. The agronomic use of biosolids represents a progression from treating the residuals as waste products to treating them as recyclable commodities. Reuse leads towards a sustainable system. Reusing biosolids is not a universally accepted practice (Tyson, 2002). In fact some would argue that the practice is not sustainable because of the eventual build-up of metals in soil (Orlando, 2001). There is the counter-argument that the practice is sustainable because sludge quality is continually being improved and biosolids utilization is an essential part of managing our society's wastes (Krogman et al., 1999 and 2001; Kroiss, 2004). Groups, such as organic farmers, have expressed reservations about using a waste product to produce food crops. Animal manures are given a different type of acceptance even though manures pose similar potentials for adverse effects (Krogman et al., 2001; Tyson, 2002). In general, the concerns about biosolids have been grouped into two general categories: (1) Environment- soil and water quality; and (2) Human Health- risks of illness.

Environmental Effects-

- Groundwater or surface water contamination by metals, nutrients, or pathogens.
- Soil contamination by metals, persistent organic compounds, or pathogens.

Health Risks-

- Pathogens causing infection by direct exposure or bioaerosols.
- Metal accumulation into food crops or grazing animals.
- Potential exposure to trace organic compounds.

The following sections will summarize research centered on these concerns and will evaluate the effectiveness of Maine's regulation of biosolids.

Section II. The Effect of Biosolids on Soil Quality and Crops.

2.1 Introduction.

The following summary emphasizes recent studies that are based upon several years of elapsed time for field and laboratory studies. The land-application of biosolids is generally condoned because of its nutrient content and soil-conditioning properties. This has been repeatedly demonstrated and a short review is provided in Section 2.2. Here the emphasis will be on the associated risks and the management of those risks. Particular attention is placed on evaluating the effects of heavy metals in biosolids. These heavy metals come from human wastes, corrosion of metal pipes in plumbing systems, and since the advent of pre-treatment technologies, declining inputs from industrial sources. Therefore, biosolids will have some measurable content of heavy metals that could pose a health risk via multiple pathways if *directly ingested* in unsafe quantities. Under certain conditions the long-term addition of heavy metals from manures, biosolids, and other soil amendments can accumulate in soils with possible environmental consequences. These trace metals may enter the food chain via uptake by plants used for food or fodder, or via grazing animals. Finally, these heavy metals may be leached from soils and could affect water quality. Persistent organic compounds can exhibit similar types of behaviors in crops, soil, and water.

Biosolids are land applied primarily for their plant-nutrient value provided by nitrogen, the primary controlling nutrient. Maine's rules also have provisions to monitor phosphorous loadings in sensitive watersheds. In addition, biosolids are screened on a regular basis for trace metal content. This screening is mandated to limit the amount of metal that is added to the soil in both single applications and cumulative from multiple applications at the same location. Trace organic compounds in biosolids are regulated in Maine, as are dioxins. The Maine DEP has established screening concentrations limits in 06-096 CMR, Chapter 418, for 579 hazardous substances that include inorganic and organic compounds. As a result of this substantial pre-screening requirement, more is known about the chemical content of biosolids than any other soil amendment.

In Maine, for nearly all biosolids applied to land, trace metal loading is not a limiting factor for biosolids utilization. As described in ***Section 1.6***, almost all biosolids in Maine have metal concentrations well below the maximum allowable. The fate of trace metals in biosolids is of interest to scientists trying to understand whether metals could enter the food chain or just remain inert in soil. This has been the focus of research for many years and there are numerous relevant publications cited in this paper. The scientific interpretation of these studies can be summarized into two generalizations:

(1) metal loading by biosolids is strictly regulated by state and federal regulations and it is not a significant concern because there is a soil-plant barrier that limits metals uptake by plants and even if metals accumulate in soils, the general food chain is protected, and
(2) metals accumulate in the soil, bound to solid matter, but certain metals could become mobile or plant-available over time as they are released from binding sites.

In general, there is ample evidence for the agronomic value of biosolids as a soil amendment or fertilizer. The Maine regulations use nutritive chemistry of biosolids as the basis for setting the amount of biosolids that may per applied to land. This nutritive content of biosolids is orders of magnitude greater (1,000 to 10,000 times) than the quantities of trace metals and persistent organic compounds. The risks posed by these other components are the crux of some objections to land applying biosolids. In particular, do these trace components accumulate in crops, accumulate in the soil, or leach into water supplies?

2.2 Agronomic Value.

Some of the earlier studies of land applying sewage sludge supported the procedure because the nitrogen content was considered to be free fertilizer. Sewage sludge was treated as being directly analogous to animal manure. Biosolids, like animal manures, are rich in both organic matter and nitrogen, making them desirable amendments for agricultural fields (Hall and Williams, 1984; Stukenberg et al., 1993; Kellog et al., 2000). The agronomic value of such amendments was confirmed with field testing that reported increases in soil humic matter, cation exchange capacity, and nitrogen after repeated applications (Stadelman and Furrer, 1985; Estes and Buob, 2001; Shober et al., 2002). Biosolids are not a total replacement of fertilizers and although they have fertilizer value, they do not provide a balance of nutrients and need to be managed as part of a farm nutrient management plan. In a well-managed setting with appropriate timing of applications, biosolids provide a significant nutrient gain for farmers (Pierzynski, 1994; Oberle and Keeney, 1994). Beyond any fertilizer value the addition of biosolids to soil lowers bulk density, and increases porosity, moisture retention, and organic carbon (Lindsay and Logan, 1998). The application of biosolids to an apple orchard improved soil physical properties and increased crop yield (Neilsen et al., 2003). Roka et al. (2004) determined that limed biosolids had an agronomic value of $5.90 per ton. There is a substantial body of research available on the agronomic value of biosolids that is not reviewed here (e.g. Larson et al., 1994). The 1993 conference sponsored by the Soil Science Society of America (Clapp et al., 1994) and the National Research Council (1996) report on sludge and food crops contain many papers and citations relevant to beneficial use. Biosolids compare favorably with manures (see Figure 5) and provide similar fertilizing properties (Moss et al., 2002). As a point of comparison, the trace metal and organic chemical composition of manures and fertilizers are not regulated as strictly as are biosolids.

2.3 Metal Mobility.

An early focus of research was on the presence of trace metals and the leaching of metals from soil. As a result, applied research was directed toward metals in biosolids, much more so than organic chemicals and pathogens. Current regulations draw heavily from this research. It should be stressed that some of the sewage sludges studied more than 20 years ago were of lower quality than what is allowed for land application under current regulations (Issac and Boothroyd, 1996).

One of the first steps was to determine if metals in sludges (pre-biosolids) were mobile. Gerritse et al. (1982) determined that some metals were mobile, the three most mobile being manganese, strontium, and antimony; all other metals were sorbed onto soil particles at pH >6. It is assumed that plants can uptake only the soluble metals. Andersson (1984) found that sewage sludges had a different soluble metal fraction with decreasing solubilities starting with the most soluble: cadmium > zinc > nickel > cobalt > copper> manganese > lead > chromium. When the same sludges were composted the order of solubility changed to: zinc > cadmium > manganese > lead

>nickel > cobalt > copper> chromium. Composting changed the way some metals were bound in the sludge. According to Andersson (1984) and Speir et al. (2003), although several metals are soluble, zinc is most likely to be incorporated by plants. Zinc is not a great concern because it has a relatively low toxicity. Plant uptake of cadmium has been a focus of additional research because of its potential toxicity in the food chain.

Metal solubility does not necessarily mean that transport into plants or groundwater is occurring. Soluble metals may be loosely held onto the surface of soil particles. For example, cadmium concentrations in soil following seven years of sludge application (initial Cd loading = 3.2 kg/ha) at the Askov site in Denmark were detectable only in the first 25 centimeters and none was detected in the shallow groundwater (Larsen, 1984). This and other early studies indicate that metals in biosolids may be mobile, but for most metals plant-uptake or transport downward in soil is limited.

The work completed during the 1980’s was useful to set the direction for following research. In particular, the fate of metals in soils was not thoroughly understood. Some questions remained:

- Do any metals in biosolids enter the food chain via plant uptake?
- Does plant uptake of metals from soil follow a linear dose-response relationship?
- Do metals from biosolids that are bound in organic matter become mobile over time?
- Can metals be leached into groundwater?

These questions continue to drive some of the metals research that continues today.

2.4 Trace Metal Uptake By Plants.

Some trace metals in biosolids may function as micro-nutrients in plants and animals. Micronutrient metals include: copper, iron, manganese, molybdenum, and zinc. However, the same, or other, trace metals may accumulate up the food chain via plants and thus could present a health risk to grazing animals and humans. Metals must occur in relatively high availabilities in soils to represent a risk of transfer to plants. The uptake of cadmium and zinc by plants at some biosolids utilization sites has been documented (Stukenberg et al., 1993). Cadmium has been studied more closely because is appears to be the most toxic heavy metal that is likely to accumulate in plants and so serves as a useful indicator, while the imbalance of copper and zinc may affect health in some grazing animals (Muchi et al., 1987; Chaney, 1994; Smith, 1994).

Excessive concentrations of some metals will inhibit crop growth, or even kill crops, and this effect is called phytotoxicity. Even the chemical form of the metal is important. Field and laboratory studies by Chaney (1994) showed that experiments using metal salts generated different results from actual biosolids. This difference is attributed to using metal salts in the experiments that are highly soluble and release the metals easily into solutions. This is in contrast to the strong metal-organic complexes that form in the biosolids and that are much less soluble, and thus the metals are less available. The understanding of the cause-and-effect relationships and dosing experiments are further complicated by the mechanisms that control how metals are incorporated into plant tissues.

The essential problem is discovering if metals stay in the soil, are incorporated into plants (bioavailability), or are leached deep into soil or ground water (leachability). The public health risks come from metals entering the food chain or dissolving into drinking water. The research shows this problem to be difficult to answer.

Plant uptake of metals, regardless of source, is not a linear dose-response, but a complex curve with an uptake plateau at elevated soil concentrations. This means that small increases in metal concentrations in soils having low background concentrations may cause small increases of metal concentrations in plants. When background concentrations are greater, increasing the content of metal in soil will eventually cause no additional increase in metal concentrations in plants. In a sense, plants can filter out metals and limit how much enters via their roots.

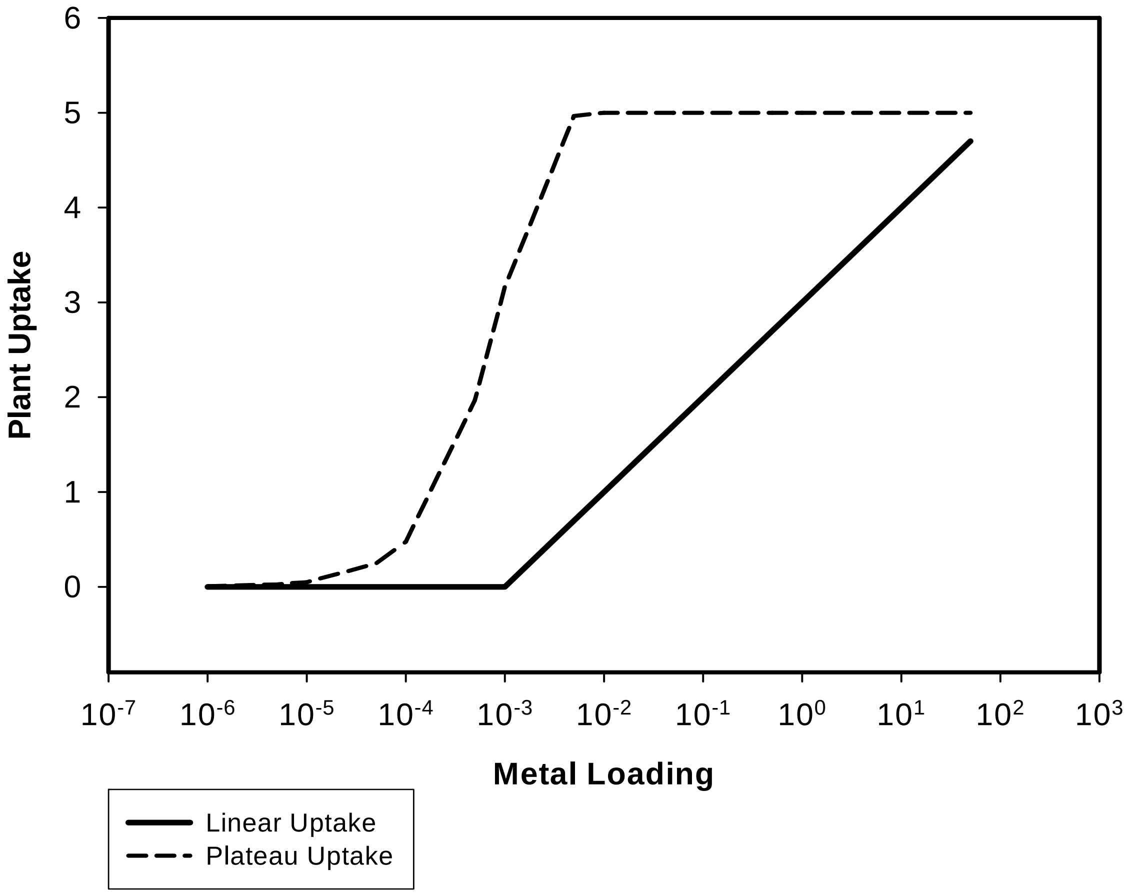
The metal-uptake-plateau theory is the basis for Chaney (1994) and Chaney et al. (2004) to state that plants can act as a bio-barrier for metals. Other interpretations of similar data exist, including an exception for cadmium (Dudka and Miller, 1999). Brown et al. (1996) have a contrary interpretation of soil-plant relationships and determined that uptake follows a log-linear relationship. This model defines the metal loading to soil as the dose and the plant uptake is a function of the logarithm of the dose. They suggest that crops can be indexed by their relative metal uptake. The soil-metal-plant relationships defy simple conclusions. For instance, Logan et al. (1997) presented a different interpretation of similar experimental results; a linear dose-response of metal uptake in crops for up to two years after biosolids application, followed by a plateau. Plant uptake was linear with biosolids application rates for the period studied. Clearly, these different experiments did not replicate the identical conditions; another possibility is that the data reflect different parts of similar dose-response curves.

Organic-matter and minerals in soil and biosolids mediate complex interactions that minimize the uptake of metals such as cadmium. This indicates that for most high-quality biosolids, plant uptake of cadmium is not a concern (Chaney, 1996; Brown et al., 1998; Speir et al., 2003). The authors imply that total metal loading may not be the limiting factor in assessing risks because the solubility, or plant-availability, of the metals was over-estimated in the regulations.

A comparison of these different soil-plant relationships is shown in Figure 6. The key difference is that in the linear model, plants take up more metal directly in proportion to the amount added above some threshold value. In the plateau model, plant uptake is similar to the linear model at low loadings. However, the plateau model includes an absolute maximum capacity for metal uptake. Metal loading to soil beyond a certain value will not increase plant uptake. The two types of metal-uptake relationships plotted in Figure 6 are offset for clarity. At low metal loadings, the plant uptake rates are similar for both models (both curves have the same slope). In the plateau model, when plant uptake reaches a specific limit, uptake slows or stops. The plateau model implies that as soils accumulate metals, plants can actually dilute metals entering the food chain (Chaney, 1996). It is possible for the differences between the two models to be very slight below the plateau concentration. In such a situation, the data of Chaney et al. (2004) may cover the whole plateau curve, while Logan et al. (1997) assessed the early and linear region, and Brown et al. (1998) collected data on the portion of the curve approaching the plateau. The protection offered by the plateau is important, but plant-specific constants are lacking.

The plant-availability of trace metals from biosolids is controlled by the chemistries of both the biosolids and the soils; principally defined by the organic matter of the biosolids and the sorptive capacity of the soil (Basta, 2004; Basta et al., 2005). The pH of the biosolids and soils is the chemical variable with the single greatest control over the availability of trace metals (Heckman et al., 1987; Mulchi et al., 1987; Chaney, 1994; Basta and Sloan, 1999; Basta et al., 2005). These factors must be considered when interpreting trace metal uptake experiments. The plateau effect could be a function of soil pH conditions that cause trace metals to be held by organic matter or adsorbed to minerals. At soil pH >6, the total metal content can be high, while the plant-available concentration is much smaller (e.g. McBride et al., 2004). This may explain why Chang et al. (1997) analyzed 15 years of land-application data and found neither a plateau nor a re-release of metals. This is possible if plant-available metal loadings were at low concentrations and plant uptake was in the linear range.

Figure 6. Comparison of Metal Loading and Plant Uptake.



Although many of these studies attribute the availability of trace metals solely to soil chemistry, there are other possible controls on metal uptake by plants. Trace metal uptake is modulated by plant physiology and it is the plants themselves that control the presence or absence of a plateau (Hamon et al., 1999; Maisonnave et al., 2001). It is well established that plant species have different nutrient needs, including functional differences relative to metal uptake. This suggests three master variables interact to define the availability of trace metals in soil and the rate of uptake by plants:

A. Soil chemistry, especially soil pH,
B. Biosolids composition, and
C. Type of plant.

Even though potentially toxic metals such as cadmium may enter into plant crops, the actual concentrations in plants appear to be below harmful limits (Brown, et al., 1998; O'Connor and McDowell, 1999). Estes and Buob (2001) found no differences in metal content in corn grown with or without biosolids. The US EPA risk assessment used referenced studies to establish maximum loading rates for metals in biosolids and is rated as being very conservative (Ryan and Chaney, 1993; Logan et a;., 1999). The term conservative means that the greatest plant uptake rates were used to complete the risk assessment and real risks are likely to be orders of magnitude lower. However, McBride (1998) believes that the model used by the EPA employed uptake coefficients that were too low because the data were generated using optimal soil acidities (pH >6) studies and most natural soils in the northeastern United States are more acidic. Under more acidic conditions the metals would be more mobile and bioavailable and uptake rates could be higher. Good agricultural practices require soil pH to be managed close to pH 6.

McBride (1998), McBride et al. (2004) and several other researchers (Chaney, 1994 and 2004; Smith, 1994; Speir et al., 2003) raise the important issue of soil pH management on fields receiving biosolids. In addition to pH, the presence of soil amendments containing high concentrations of iron, manganese, or phosphorous reduce the bioavailability of heavy metals such as lead, zinc, and cadmium (Brown et al., 2003; Brown, et al., 2004). This means that a fraction of the trace metals are likely bound in forms (organic or oxy-hydroxide complexes) that may be less sensitive to soil pH. In Maine, where soils are naturally acidic, the re-mobilization of trace metals is possible if soils are not managed to maintain optimal soil pH. Maintenance of soil to near neutral pH must be a long-term objective for land application sites.

2.5 Metal Accumulation in Soil.

If plants only take up a small fraction of the metals added to soils from biosolids, then the metals could be accumulating in the soil. The fate of metals from biosolids is directly addressed for long-term management of utilization sites under Maine law. Accumulation of metals is the reason for having annual and cumulative loading limits. It has been recognized for many years that metals from sewage sludge accumulate soils having pH values of 6 to 8 units (Gerritse et al., 1982). It is a well-understood geochemical principle that under oxidizing and non-acidic conditions, most metals tend to form oxides or hydroxides that are sparingly soluble. Compounds of iron hydroxide or phosphorus can also bind trace metals. The exceptions are molybdenum, vanadium, uranium, and selenium (Levinson, 1974), all of which occur in low concentrations in Maine's biosolids.

If metals accumulate in oxidized soils at a nearly neutral pH, then it should be possible to account for the trace metals added from biosolids and removed by plants. Several studies of long-term utilization sites have attempted to perform mass balances for metals. Stukenberg et al. (1993) reported that metal accumulation was mostly limited to the top 12 inches of soil. McBride et al. (1997) re-tested a utilization site 15 years after application and found elements added from biosolids were lost: 100 per cent for sodium, sulfur, calcium, and strontium; 40 per cent for zinc and copper; and less than 30 per cent for cadmium and phosphorous. Water-soluble copper, nickel, and zinc concentrations in the treated soil were ten times greater than the control soil. Surprisingly, these soluble metals had not been leached from the soil, but soil solutions in the treated soil had higher concentrations than a control field (McBride et al., 1999). Berti and Jacobs (1998) evaluated metal accumulation at a site with 10 years of biosolids application history. They found that metal recovery ranged from 45 to 155 per cent of loading; how metals could accumulate post-application is difficult to explain but probably reflects natural variability. In their mass balance they found that losses accounted for 20 per cent of all the chromium and nickel, 30 per cent of the cadmium, and 40 per cent of the lead and copper; zinc was essentially unchanged (zero loss). At another site with repeated applications of biosolids over a period of 11 years, Babarick et al. (1998) reported statistically significant metal accumulations relative to control soils. The metal loading was confined to within the plow layer (< 30 cm) with slight evidence of metals moving deeper into the soil. Estes and Buob (2001) reported no significant increases in trace metals in soils due to biosolids applications at study sites in New Hampshire. Sloan et al. (1998) found very high metal recovery rates (100 % ±) at the Rosemount site after 16 years of biosolids spreading. Long-term monitoring, 23 years post-application, was conducted by Sloan et al. (2000) and they found that after the first two years cadmium and zinc remained nearly unchanged. They indicated that the organic matter holding the metals is mineralizing very slowly and is expected to persist for more than 100 years. Some of the variation in mass loading can be attributed to uncertainties in actual loading rates due to analytical limitations.

Molybdenum has gained additional scrutiny recently because of its phytotoxicity and unique geochemical properties (O'Connor and McDowell, 1999). Field studies conducted by Brinton and O'Connor (2003) suggest that the presence of iron and aluminum greatly reduce the bioavailability and mobility of molybdenum. However, as with other trace metals, the soil pH remains the most important control.

The scientific literature presents data that appear to be contradictory regarding metal accumulation and loss. These differences are probably due to the use of different biosolids in different soils in different climate regimes. The importance of high soil pH as an inhibitor to metal mobility (Gerritse et al., 1982; Basta and Sloan, 1999; Speir et al., 2003; Basta, 2004; Basta et al., 2005) and the metal-binding capacity of organic matter (Sloan et al., 1998; McGrath et al., 2000; DeVolder et al., 2003) have been amply demonstrated. More recent work has demonstrated the importance of metal-binding oxides in soils (Basta et al., 2004 and 2005). The chemical controls are in turn a function of the soil that results from the effects of climate on the local geology. Climate drives soil thermal regimes and moisture content; two factors that will affect biosolids decomposition rate and the release of trace metals. Another source of variability is the composition of the original sludge. Stehouwer et al. (2000) found that the metal content of sewage sludges in Pennsylvania could vary by factors of 10 to 50 per cent. They also reported that the quality of the sludges improved in the 1990's to have less variability and, in many cases, lower metal content.

The fate of metals in soil at biosolids utilization sites is difficult to predict without site-specific data, hence Maine's regulations err on the side of being conservative and assume greater mobility. This in turn means that acceptable metal loadings have a margin-of-error built in. In general, a small portion (<1%) of trace metals are bioavailable and incorporated into crops (Berti and Jacobs, 1998; Shober et al., 2002; Chaney, 2004). A much larger portion remains (> 50%) in the soil either bound to organic matter or to soil particles (Bell et al., 1991; Basta, 2004 and 2005). Some fraction of a few metals, like selenium and mercury, may be lost via volatilization (Capon et al., 1984). McBride et al. (2004) report that the bioavailability of zinc and copper can be elevated for many years. Although most of the research finds metal accumulation within 30 centimeters of the surface, up to 30 per cent of some trace metals may be transported to greater depths, including to ground water (Camobreco et al., 1996; McBride et al., 1997; Richards et al., 1998). The compositions of the starting materials (biosolids *and* soil) are key to initial bioavailability of metals and their subsequent mobility (Richards et al., 2000; Merrington et al., 2003; Speir et al., 2003). Soil and plant analyses in Maine show no evidence of significant plant uptake of metals (Houtman et al., 1995).

2.6 Organic Compounds.

There are numerous organic compounds in biosolids that come from diverse sources such as the organic wastes (fecal matter) and products that are used at home that end up in the waste stream, including pharmaceuticals and personal care products (Daughton and Ternes, 1999). Many of these compounds are water soluble (i.e. polar) and partition into water rather than solids during the waste treatment process (Heberer et al., 2002). Thus relatively few pharmaceuticals accumulate in sewage sludge. In addition, some organic compounds are destroyed during the treatment process. Thus, chemical principles predict that few organic compounds can persist through the waste treatment and biosolids processes to enter the food chain (Wild and Jones, 1992). This principle is supported by a recent survey of 39 wastewater treatment plant sludges in Canada that found no organic contaminants in environmentally relevant concentrations except for seemingly ubiquitous heavy petroleum hydrocarbons and some PAH compounds (Bright and Healy, 2003). Some of these organic compounds come from plastic pipes or stormwater runoff from roadways. Much of the organic matter, including trace organic chemicals, will be mineralized (decayed). Only a very small number of organic compounds do not decay over human-relevant timescales. As with the fate of trace metals, the research does not indicate a large potential threat from organic compounds in most biosolids. The trace organic compounds detected usually occur in concentrations below accepted regulatory action limits (for instance, Maine DEP Risk Assessment for Direct Contact, http://www.maine.gov/dep/rwm/rem/documents/fed-dod/rags.htm, and Chapter 405).

There is growing attention being paid to biological active chemicals in wastes. These are pharmaceuticals and personal care products (PPCP) that have human and veterinary uses or otherwise affect the endocrine system. Because many PPCPs are used for therapeutic reasons, they can pass through humans or animals unchanged and end up in the waste stream as active compounds, even at very low concentrations (Daughton and Ternes, 1999). These compounds were detected in 80 percent of 139 streams sampled by the U.S. Geological Survey in 1999 and 2000 (Kolpin et al., 2002). The most frequently detected compounds in this stream survey were: coprostanol, cholesterol, N,N-diethyltoluamide, caffeine, triclosan, tri(2-chloroethyl)phosphate and 4-nonylphenol. Little is known of the fate of these compounds in the environment and the synergistic effects when combined in exposed populations. Available studies suggest that these compounds may not be significantly accumulated in biosolids. Many of the compounds are water soluble and partition into water rather than solids during the waste treatment process (Heberer et al., 2002).

Ongreth and Khan (2004) report that only three pharmaceuticals of 24 examined exhibited significant concentration into sewage sludge (gemfibrozil, eryhthromycin, and carbamazeprine). All of these compounds were detectable in the low ppb range and other pharmaceuticals may partition into sewage sludge in much lower concentrations (Khan and Ongreth, 2002). These studies suggest that the risks posed by pharmaceuticals in sewage sludge are small because they occur in concentrations well below their intended therapeutic range.

Several researchers have found that some organic compounds of potential concern do not persist in biosolids, or at land-application sites. Wang et al. (1995) evaluated chlorobenzene in soils from the Woburn, England site that had 25 sludge applications between 1942 and 1961. They determined that only 10 per cent of the added chlorobenzene remained in the soil. Analysis of archived soils suggested that most of the chlorobenzene was lost through volatilization. Alexander (2000) presents an argument that the bioavailability of organic compounds naturally decline over time. Compounds that exhibit this effect are some polynuclear aromatic hydrocarbons (PAHs)- naphthalene, phenathrene, anthracene, fluoranthene, pyrene; the herbicide atrazine, and 4-nitrophenol.

Bright and Healey (2003) reported that many toxic organic compounds that were once found in sludges just are not detected in modern sludges. Chlorophenols, poly-chlorinated biphenyls (PCBs) and chlorinated pesticides are typically below detection limits. However, some aromatic compounds, p-cresol and phenol; polynuclear aromatic hydrocarbons (PAHs) such as phenanthrene, pyrene, naphthalene; and long-chained hydrocarbons in the C19 to C34 range were detected. Overall the loading of PAHs to soil is far below the level of toxicological concern. Topp and Colucci (2004) provided evidence that estrogen-like compounds (or endocrine disrupters) dissipate rapidly from soil, often in hours to days. This dissipation is hastened by oxidation, a process favored by surface application of biosolids.

It needs to be stressed that trace organic compounds are part of the biosolids organic matter. The distribution coefficient, K_d is a measure of the ratio of the compound that binds onto the organic mass relative to the concentration in the surrounding liquid. These trace organic compounds are naturally and strongly sorbed to the whole organic mass with K_d's much greater than 10^6 (Jones and Evans, 2004). In this case the concentration on the solid is more than one million times more concentrated than in water. These authors all suggest that trace organic compounds either disappear, degrade, or become biologically irrelevant within months of contact with the soil.

Some researchers have found that some persistent organic compounds are associated with biosolids. Wilds et al. (1991) indicate that PAHs can be detectable for many years in soils. They have determined half-lives for PAH compounds in the range of 2 to 9 years. Wang et al. (1995) stated that although much chlorobenzene dissipates, 10 per cent remains 42 years after application. Listed organic compounds are found only occasionally in Maine's biosolids. A common trace organic contaminant is the phthalate ester di-(2-ethylhexyl) phthalate (DEHP) that adds flexibility to innumerable plastics, including the common PVC drain pipes. Considered a non-toxic compound, its metabolites may have estrogenic effects and it may persist for many years (Madsen et al., 1999). The available research has not indicated any effect on human health. Another commonly encountered trace organic compound is alkylphenolethoxylate. This compound degrades to octylphenol, nonylphenol, nonylphenol mono-ethoxylate, and nonylphenol di-ethoxylate in concentrations sufficient to be a potential risk in surface waters, although there is no evidence that biosolids are a significant source (LaGuardia et al., 2001). Hale et al. (2002) have detected the fire retardants bromo-diphenyl ethers that are similar to polybrominated biphenyls. The occurrence rate is higher for urbanized areas and may affect urban sewage sludge quality.

The methods of analysis and toxicity risk-assessment tend to overstate risks (conservative models). Like some trace metals that may not be present in biologically significant concentrations, many organic compounds occur in biosolids at low concentrations. Data for Maine's biosolids show that the types of organic compounds discussed here are relatively rare.

Organic matter, in its most general sense, in biosolids is persistent and only slowly mineralizes, including the trace organic compounds (Jones and Evans, 2004). This is a desirable quality that improves soil quality. The compound specific data available to evaluate the risks posed by these compounds is limited, but the majority of the compounds are likely to be benign (Daughton and Ternes, 1999; Kester et al., 2004 and 2005). The risks posed by many organic compounds in waste streams appear to be small because they either: 1) do not partition into sewage solids, 2) are degraded during the treatment process, or 3) decay when exposed to sunlight. Data from Maine indicates that the content of hazardous organic compounds in biosolids is generally quite small and restricted to a small number of compounds.

2.7 Summary

Biosolids are complex mixtures of organic matter that have agronomic value, as well as containing trace metals, such as cadmium, zinc, and copper. Survey data of application sites suggest that the benefits greatly exceed the deficits (Houtman et al., 1995; Shober et al., 2002). Biosolids also present some risk to grazing animals and humans due to plant incorporation of chemical constituents or exposure from accidental ingestion of solids. The latter route requires very close physical contact. The risk posed to crops fertilized with biosolids is difficult to determine because soils are heterogeneous and crop responses are subject to numerous environmental variables. There is some measurable transfer of metals from biosolids in soil to certain crops, but the amount of transfer up the food chain appears to be small. Managing soil pH to be circum-neutral minimizes the loss of metals to plant uptake or leaching to groundwater. Data collected in Maine suggest that risks posed by trace metals at biosolids utilizations sites are negligible.

The NRC (2002) study recommended performing an updated survey of biosolids quality to determine how metal content has changed and to inventory other potentially hazardous substances. In addition, the study identified the need for field-based studies to evaluate the effectiveness of setbacks and operational oversight. This includes performance standards for the production of Class A and B biosolids. The Biosolids Summit (Dixon and Field, 2004) reiterated many of these same recommendations as well as the need for new protocols to characterize the fate and transport of chemicals of concern.

Following is a summary of the benefits and risks of using biosolids as a fertilizer.

Potential Benefits:

+ Inexpensive source of nitrogen.
+ Source of trace nutrients and phosphorous.
+ Biosolids increase soil organic matter and improve moisture regulation.
+ Concentrations of heavy metals in Maine's biosolids are well below the US EPA exceptional quality standard.
+ Transfer of metals to food crops is limited.
+ Organic matter in biosolids binds with metals and lowers their bioavailability.

Potential Risks:

– Biosolids contain some trace metals of concern, but nearly all in Maine are below regulatory risk thresholds.
– A small fraction of nutrients and metals may leach from biosolids into groundwater.
– Added metals may persist in soils for decades and slowly become bioavailable.
– Soil pH needs to be managed over long time periods to minimize metal losses.

Following is a relative assessment of how Maine's rules protect soil quality.

Chapter 419 Management Goal	**Rules Commentary**	**Possible Deficiencies**
Nutrient Management	Appropriate within active agronomic plan.	Excessive historical fertilization due to agricultural practices such as over-manuring. More accurate mineralization rates are needed.
Single Application Metal Loading	Loading by application rate is adequate. Maine biosolids exceed US EPA EQ standard. Large conservative margin of error.	Soil and biosolids are compositionally variable. Few plant uptake studies in Maine to reflect current agronomic practices.
Cumulative Metal Loading	Cumulative Loading assumes a 20 year application cycle. Conservative margin for error based on recent land use trends.	Uncertainties in metal mobility and transport between plants, soil, and groundwater are small but finite. Site management requires operational continuity. Need for long-term soil pH management.
Hazardous Substances	Field utilization restrictions protect food-chain transfer.	Long-term fate is uncertain for some very persistent chemical species.

Section III The Effect of Biosolids on Water Quality

3.1 Introduction.

Biosolids are managed by regulation to prevent any degradation of water quality. This is because biosolids have the potential to affect water quality through the leaching of at least two general kinds of contaminants: essential plant nutrients and trace metals. Ironically, these are the same components that were removed from waste water to clean up discharges. The plant nutrients nitrogen and phosphorous, when added to water, can cause algae blooms that may lead to a degradation of quality. Excess nitrogen in drinking water is a potential health hazard and the US EPA has established maximum concentration limits for consumption of nitrate and nitrite. Trace metals in water are of concern only when they are mobile and occur in amounts above safe concentrations.

The US EPA and Maine DEP have definitive standards for selected compounds in drinking water, but the ambient standards for groundwater are less clear. The ambient standards are more subjective, depending upon uses. The standard for groundwater of highest quality (GW-A) is specified as being potable and suitable for public water supplies. This implies that water quality must meet state and federal quality guidelines established in the Safe Drinking Water Act. The secondary standard (GW-B) states only that the water be suitable for other uses. Clearly, the groundwater below agricultural fields would not be used solely for public water supplies. The lack of a numerical water quality standard for GW-B generates confusion about the potential effects of biosolids on water quality. The default comparison may be with the drinking water standards, an inappropriate comparison. The impact analysis is made more difficult by the presence of other agricultural chemicals associated with manures and chemical fertilizers. A better method to index impact is to compare changes in nutrients and metals in water before and after land applications.

The goal of all land application programs is to add nutrients equal to crop requirements and to prevent over-applications that could lead to a potential loss of excess nutrients (USEPA, 2002). Sewage sludges in Maine contain, on average, more than 4 per cent nitrogen. The average nitrate plus nitrite concentration is less than 0.2 per cent and average ammonium is less than 0.6 per cent. Nitrogen as nitrate or ammonia is very water soluble and it is readily available to plants. Movement of ammonia is slower than for nitrate or nitrite because it can be adsorbed onto clay particles in soil. Being soluble, these forms of nitrogen can be removed to varying degrees in surface flow, or by transport down into ground water. Nitrate in ground water is a ubiquitous problem in agricultural areas (Kellog et al. 2000; Nolan, 2001). The Maine regulations are built on the assumption that most of the nitrogen in the Maine sewage sludges is bound in organic matter (~80%) and it is not immediately plant available. The rate at which the organic matter decomposes (mineralizes) and releases nitrogen is important for reducing water quality impacts compared to inorganic fertilizers. A slow release of nutrients provides tangible benefits to crops that need nitrogen in steady doses. In general, nutrient release from biosolids is slower than for chemical fertilizers or green manures.

3.2 Nutrient Loading.

Biosolids have been land applied successfully for many years because they have fertilizer value (Hall and Williams, 1984). Studies of nitrogen loss from field applications report that only 20 per cent of nitrate is lost after several rain events (McLeod and Hegg, 1984). It appears that most biosolids have a small amount of soluble nitrate that is released at initial application and then the slow decay of organic matter releases nitrogen in quantities that is quickly scavenged by crops (Chaney, 1990; Gilmour et al., 2000). At a monitored biosolids spreading site in Colorado, nitrate in groundwater was found to have no net change; modest increases or decreases in concentrations over time balanced out (Stevens et al., 2003). In New Hampshire, Estes and Zhao (1996) determined that biosolids applied to cropland had a minimal effect on groundwater quality because of the slow nitrogen release. McDowell and Chestnut (2002) studied nitrogen loading at a topsoil manufacturing site where biosolids were used. The only effect on groundwater quality was detected near biosolids stockpiling locations. In Pennsylvania, Shober et al. (2002) found that long-term biosolids application to cropland increased soil nitrogen, implying that loss of nitrogen by leaching was slight.

Higher amounts of plant-available nitrogen in soil are beneficial to increase fertility for crops. Biosolids release nitrogen more slowly than chemical fertilizers, so nutrient flushing is less of a significant concern (Pierzynski, 1994). An extreme case of biosolids use at high-application rates, at 1.5 to 5 times the agronomic rates, at a gravel pit reclamation site, caused a quick flush of nitrate at 50 mg/L into ground water followed by a lower but steady input of 2 mg/L (Daniels et al., 2002). Gravel pits have very porous soils and water movement can be relatively fast. In agronomic applications of biosolids, excessive nitrogen addition is neither allowed nor good farming practice.

If nitrogen from biosolids is not to affect groundwater quality, the agronomic demand must be matched to the plant-available nitrogen (Kellog et al., 2000; USEPA, 2003). Unlike manure or chemical fertilizers, biosolids can only be applied in accordance with a written nutrient management plan. There has been a considerable effort expended to estimate the appropriate loading rate for initial nitrogen utilization and subsequent releases of nitrogen during mineralization. The amount of nitrogen available to plants will be specific to each type of biosolids and the mineralization rates will be controlled by site specific conditions (Gilmour and Skinner, 1999; Gilmour et al., 2000). The mineralization rate may have half-lives ranging from hours to thousands of days (Overcash, 2004; Overcash et al., 2005). Mineralization half life is the amount of time needed for half of the starting material to be converted. Estimating the amount of nitrogen that will become available to plants is further complicated by the loss of some nitrogen as ammonia gas (Pierzynski and Gehl, 2004). If nitrogen is to be managed on a fine scale, the land application process will need to have accurate loading calculations based upon soil chemistry, crops, and biosolids. If application rates are too high, excess available-nitrogen will be lost. For example, data from forested sites indicated that nitrate loss to surface waters occurs after biosolids are applied (increased over background by a factor of 2), but ammonia export appeared to be constant (Grey and Henry, 1998). A nitrogen mass balance was not reported in the study so nitrogen loss may not be due solely to nitrogen applied in biosolids.

It is important for the nitrogen loading to match the character of a particular biosolids. In Maine, as elsewhere, the problem of nitrogen mineralization has been managed by the DEP using fixed

TABLE IV. Mineralization of Organic Nitrogen From Sewage Sludge. Values are per cent mineralized from initial application.

Years After Sludge Application	Type of Sewage Sludge			
	Primary & Activated	Aerobically Digested	Anaerobically Digested	Composted
0-1	40	30	20	10
1-2	20	15	10	5
2-3	10	8	5	3
3-4	5	4	3	3

Table adapted from 06-096 CMR Chapter 419, Appendix A.

mineralization rates (Chapter 419, Appendix A). The mineralization rate is based upon the type of sewage sludge, previous site applications, and mode of use (topdressed or incorporated). The Maine rules use a set amount of organic nitrogen that is mineralized over several years as shown in Table IV. Reference guidelines for Maine are based on *Best Management Practices for Biosolids* developed by the University of New Hampshire Cooperative Extension (Boub et al., 1995) and the US EPA (1983 and 1994). The formula involves calculating the available nitrogen, and making allowances for volatilization loss of ammonia if topdressed, and then correcting for the nitrogen added by previous applications. This is a common method for calculating loading rates.

Nitrogen mineralization rates determine how much nitrogen becomes soluble and plant available. Crop demand varies during the growing season and the timing of application is important in order to match the release of nitrogen with the uptake by plants. Rodriguez et al. (2003) reported on biosolids providing adequate nitrogen for maize, and mineralization provided 35 per cent of the nitrogen needed during the following year. Biosolids mineralization rates were found to be 20 to 50 per cent in a 36-week greenhouse study, consistent with Maine's rules (Adegbidi and Briggs, 2003). An analysis of mineralization studies found that the biosolids application rate, biosolids C:N ratio, and temperature were the master variables (Er et al., 2004). These studies reflect the importance of characterizing the applied biosolids and utilization site conditions to manage nitrogen for crops.

One extreme example of nitrogen loss can occur when biosolids are stockpiled prior to land spreading. In 2002 and 2003, research was conducted in Maine to measure the loss of nitrogen from Class B biosolids stockpiles (Peckenham, 2004). Stockpiles are a much more concentrated source compared to spread biosolids and Class B biosolids are expected to have a larger moisture content than Class A. The stockpile experiment used plastic-lined cells to collect the liquid running over or through stockpiles. Even though leachate may contain an elevated concentration of nitrogen measured as total Kjeldahl nitrogen (TKN), loadings were dependent upon leachate flow rates. Loadings were calculated to be between 0.008 and 0.028 kilograms TKN/meter^3/day (0.013 to 0.047 pounds TKN/yard^3/day) in the footprint of the stockpile.

The loading of TKN gradually increased over the first month of stockpiling and reached a relative maximum at six to eight weeks. Loadings decreased markedly after two months because leachate flow decreased, even though concentrations of TKN in the leachate increased. Although biosolids can show elevated concentrations of nutrients and metals in leachate or run-off from a stockpile, they also have a large capacity to retain moisture and reduce run-off compared to soil (Glanville et al., 2004).

The loss of nitrogen from an unlined stockpile can have an impact on soil and groundwater below the footprint. For example, assume a field received a delivery of 100 cubic meters of biosolids for land-spreading and this stockpile sat for 30 days. Based on the nitrogen fluxes from the stockpile experiment, between 24 and 84 kilograms of nitrogen (as TKN) would be leached from the pile. Most of the nitrogen is in the form of ammonia and this may become converted to nitrate in the soil. This is enough nitrogen as nitrate-N for 0.4 to 1.3 acres of hay, but being concentrated in one small area could be lost to deeper soils or ground water. This represents a concentration of nitrate to ground water beneath the stockpile in the range of 240 to 840 mg/L. This concentration is consistent with the data from New Hampshire where McDowell and Chestnut (2002) found mean concentrations of nitrate in groundwater wells below stockpile sites approaching 60 mg/L and soil solutions had concentrations of 100 to 800 mg/L nitrate.

There is no absolute method to compare nitrogen species concentrations in biosolids with concentrations in groundwater (Oertel and Nicklow, 2003). This is because the process of nitrification (conversion from ammonia to nitrate) is mediated by microbes and rates depend upon soil conditions, as is denitrification (conversion from nitrate to nitrogen gas). However, high nitrogen loadings, such as under stockpiles, may increase nitrate-nitrogen in groundwater. Similar nitrogen enrichment has been reported for manure lagoons (Gooddy et al., 2002).

Biosolids contain phosphorous, but much of it is believed to be contained in sparingly soluble forms (Coker and Carlton-Smith, 1986; Elliot et al., 2002). According to Brandt et al. (2004) biosolids contain water-extractable phosphorous, but in concentrations far below chemical fertilizers or manures (USEPA, 2003). They report phosphorous concentrations that range from 0.5 to 14 per cent of the total mass. The limited mobility of phosphorous combined with its varying content means that biosolids should be managed for phosphorous on a case-by-case basis (Maguire et al. 2000). This conclusion was substantiated by field studies over sandy soil (worst-case scenario) that found no significant changes of phosphorus concentrations in groundwater after sludge applications (Shepherd and Withers, 2001). The evidence from agricultural regions is that nutrients- *from any source*- are prone to be exported in streams draining fields after excessive and multiple applications (Pyke et al., 2003; USEPA, 2003; Richards et al., 2004).

3.3 Organic Compounds and Trace Metals.

There are two important points to be considered in relation to organic compounds in biosolids- one has to do with the nature of the compound and the other is how organic compounds interact with metals. A few of the organic compounds detected in biosolids are biologically active (act as hormones) or may be suspected of having toxic effects. For instance, pharmaceuticals that enter into soil and water have been shown to affect plant growth in laboratory studies conducted at high concentrations (Jjemba, 2002). In general, organic compounds that end up in sewage solids are sparingly soluble (hydrophobic). This physical attribute acts to keep these compounds from dissolving back into water. This means that the organic compounds are not likely to end up moving into water. However, organic matter can undergo chemical or biological processes that can change the solubilities of daughter compounds.

The second aspect of organic compounds is that they may have the ability to bind with metals. Stable organic compounds can serve as a repository of metals that keeps them out of solution and otherwise immobile. The long-term stability of organic compounds that bind metals controls the release of many trace metals. The types of wastewater treatment and biosolids formed, Class A or B, will determine the characteristics of the organic constituents; factors that may control metal mobility as organic matter decays (Stacey et al., 2001). Antoniadis and Alloway (2002) determined that the leachability of cadmium, nickel, and zinc were strongly affected by organic matter derived from the parent biosolids to the point that enhanced transport caused by soluble organic matter doubled the distance these metals were leached through a soil column.

Several studies have investigated the fate of specific organic compounds known to be from the land application of biosolids (Chaney et al., 1996). Wang et al. (1995) tested a site that received 25 applications of sludge over 20 years. They determined that 90 percent of the chlorobenzene applied was gone and 10 percent was detectable as a residual in the soil. Loss from the soil was believed to be by volatilization and not leaching to ground water. Loss from the soil was related to solubility as defined by the octanol-water coefficient. Organic compounds that have high octanol-water coefficients are less likely to enter into the ground water. Wilds et al. (1991) found that polynuclear aromatic hydrocarbons (PAHs) in biosolids persisted in soils for many years (half life 2 to 9 years). The key control on how much organic material could leach into groundwater is the rate of mineralization (Jones and Evans, 2004). Some studies find specific compounds mineralize slowly: Plasticizers (Madsen et al, 1999; Lindequist et al., 1999) and Detergents (LaGuardia et al., 2001); while others found rapid rates: Steroids (Mansell and Drewes, 2004; Snyder et al., 2004; Topp and Colucci, 2004).

These studies suggest that overall, organic matter in biosolids is relatively long-lasting. In addition, organic compounds may bind with metals and keep them immobile. However, some fraction of the organic matter in biosolids, along with some metals can be transported in ground- and surface waters (Gooddy et al., 2002; Pyke et al., 2003; Peckenham et al., 2004). Existing data are insufficient to support strong conclusions about risks to groundwater. Some connections between land uses and water quality are likely to exist because of the effects of long-term agricultural practices (chemicals, manures, and biosolids). Richards et al. (2004) detected associations between organic matter and metals such as sodium, copper, lead, and molybdenum in both soil percolates and the baseflow of nearby streams.

3.4 Summary

Biosolids contain water soluble compounds that could affect water quality. Nutrients, organic carbon, and some metals can leach from biosolids. It is important to stress that biosolids are mainly derived from the least water-soluble components of the waste stream. As biosolids age and decompose, all of the components are either consumed by biota or transferred to the surrounding media (soil or water or air). The use of good agricultural practices, including soil erosion control measures, minimizes the impact of biosolids and other nutrient sources on water quality (e.g. Mostaghimi et al., 2001). The risks posed to surface and ground waters by spreading biosolids are small when appropriate setbacks are utilized (Chaney et al., 1996; USEPA, 2003). Uncovered stockpiles on bare ground will leach small volumes of concentrated liquid that can affect groundwater with leachate containing elevated concentrations of nitrogen and trace metals.

The NRC (2002) study recommended performing multi-pathway risk analyses that would include water. In addition, the study identified the need for better monitoring and assessment of biosolids utilization. The Biosolids Summit (Dixon and Field, 2004) also stressed many of these same recommendations as well as the need for new protocols to characterize the fate and transport of chemicals from soil into water. Following a summary of the potential benefits and deficits on water quality from using biosolids as a fertilizer.

Potential Benefits:

+ Required separation distances from surface water and biosolids protect water quality.
+ The thickness of soils and absorption onto soil particles protects groundwater below fields approved for land application of Class B biosolids.
+ Plant nutrients in biosolids are released slowly and are readily consumed by plants.
+ Metals contained in biosolids are retained by organic matter and minerals in near-neutral soils.

Potential Risks:

– Nutrients from biosolids stockpiles can be leached to groundwater or be too concentration for plant uptake.
– Soluble metals from biosolids may be transported to groundwater.
– Plants can incorporate potentially toxic metals from soil solutions.
– Long-term management of soil pH is needed to minimize metal loss.

Following is a relative assessment of how Maine’s rules protect soil quality.

Chapter 419 Management Goal	**Rules Commentary**	**Possible Deficiencies**
Surface Water Quality	Appropriate and adequate within agronomic plan with proper use of setbacks. Restricted uses in threatened watersheds.	Inappropriate applications on erodable land, or excessive application when used with other unregulated nutrient sources.
Groundwater Quality	Loading using appropriate application rates are adequate when combined with good agronomic practices	Transport of nutrients via porous zones may lessen protection to groundwater. Shallow groundwater table conditions (seasonal) may be vulnerable.
Stockpiles	Allow uncovered stockpiles on certain soils.	Concentrated solutions may transport nutrients and some metals rapidly. Separation distance to groundwater beneath unlined stockpiles of Class B biosolids may offer insufficient protection except for short time periods.

Section IV Pathogen and Odor Issues.

4.1 Introduction.

There is some debate about the potential for biosolids to present a risk to public health. The Class A and B standards have only a small fraction of the number of pathogens found in raw sewage or manures. The debate has focused on whether biosolids contain viable pathogens that could be infectious. Dosing could occur if biosolids were ingested via direct contact, inhaled as bioaerosols, or possibly through exposure to soil containing biosolids residues. The magnitude of these risks is a source of contention because risk-assessment and the protection of public health is one of the objectives of the regulations; the completeness of the regulatory assessment has been questioned (Smith and Perdek, 2004).

Biosolids are derived from human wastes and Class B biosolids are allowed to contain markedly reduced populations of viable enteric bacteria and possibly-pathogenic organisms (bacteria, viruses, and parasites) that have survived the treatment process. The biosolids also contain other organisms that helped to convert the raw sewage into a sewage sludge and ultimately become incorporated into a Class A or B biosolids. The survival of pathogens during the production of biosolids and the ability of these organisms to be infectious is a fundamental public-health concern addressed by the US EPA in the federal rules (Smith and Perdek, 2004). Maine, under Chapter 419, also follows the US EPA guidelines.

Biosolids are classified on the basis of pathogen reduction (Chapter 419, Section 4 (I)). The goal for Class A pathogen reduction is to destroy or inactivate pathogens to a concentration equivalent to natural background content in soils. Class A biosolids must have a density of *Salmonella* bacteria that is less than three Most Probable Number (MPN) per four grams of total solids (Standard Methods). This pathogen reduction goal can be assumed to have been met if the density of fecal coliform has been reduced to less than 1000 MPN per gram of total solids. The Class B standard requires that pathogens be reduced by 90 per cent. Animal manures have many times more pathogens than even Class B biosolids (Moss et al., 2002; Pyke et al., 2002).

In addition to the question of pathogen content, sewage sludge, and some biosolids have odors. Human wastes have a distinctive odor that most people find unpleasant (Witherspoon et al., 2004). Sewage sludge (unprocessed) has a distinctive, and possibly offensive, odor. The intensity and composition of the odors in biosolids can vary from strong to nearly none. Biosolids may have odors not unlike sewage sludge, or may even smell earthy when processed into compost. Odors associated with biosolids are typically the primary cause of complaints from those living near land-spreading sites, even though Maine requires a minimum 300-foot setback because of odors. The question arises: do biosolids pose a risk if they produce an odor?

4.2 Pathogen Reduction Methods and Vector Attractiveness Reduction.

Pathogen reduction is an essential part of converting sewage sludge into biosolids. Maine recognizes nine methods to produce Class A biosolids and six methods to produce Class B biosolids (Table V). The standards allow the Maine DEP to evaluate the use of new methods that can meet the pathogen reduction goals. In Maine, composting is the most commonly employed method to produce Class A biosolids, followed by alkaline stabilization. Most of the Class B biosolids meet the pathogen reduction goal by using the lime-stabilization technique. The goal of these processing methods is to destroy or inactivate pathogenic organisms (Capizzi-Banas et al., 2004). The performance standards for Class A Biosolids include monitoring these four groups of pathogenic organisms:

- *Salmonella*
- Fecal coliform
- Enteric viruses
- Helminth ova.

TABLE V. Biosolids Processing Methods (06-096 CMR Chapter 419).

Method	Class	Method Outline
Composting	A	3 days >55º C (15 days for windrows)
Composting	B	5 days >40º C and 4 hours >55º C
Alkaline Stabilization	A	pH >12 for 72 hours and temperature >52º C for 12 hours
Alkaline Stabilization	B	Raise pH >12 after 2 hours of contact
Aerobic Digestion	A	Aerate cell for 10 days at temperature 55 to 60º C
Aerobic Digestion	B	Aerate cell for 40 days at temperature 20º C or 60 days at temperature 15º C
Beta Ray Irradiation	A	Beta radiation > 1.0 megarad at room temperature
Gamma Ray Irradiation	A	Gamma radiation > 1.0 megarad at room temperature
Pasteurization	A	Maintain temperature >70º C for >30 minutes
Heat Drying	A	Dry to <10% moisture and attain temperature of 80º C
Time and Temperature	A	Target temperature must be maintained for a certain period of time, based on formulae and moisture content
Air Drying	B	Minimum 3 months, with 2 of the 3 months at ambient average temperature >0º C
Anaerobic Digestion	B	Air-free cell residence time between 15 days at temperature 35 to 55º C and 60 days at temperature 20º C
Test Out	B	Geometric mean of seven samples <2,000,000 MPN per gram or <2,000,000 *Salmonella sp.* colony forming units per gram

Closely associated with the destruction or inactivation of pathogens is vector reduction. A vector is an organism that is attracted to the biosolids *and* has the potential to transfer pathogens. Example vectors are flies, mosquitoes, and rodents. In Maine, the Chapter 419 (Appendix B) rules address vector reduction. The Maine rules set vector attractiveness reduction goals involving the control of volatile solids. Volatile solids are organic compounds that can be evolved from the biosolids, some of which are odor causing compounds. It is assumed that since volatile solids may include odors that attract vectors, reduction controls odors and thus attractiveness to vectors. The preferred attractiveness reduction standards for Class B biosolids are: (1) direct injection into the soil; (2) incorporation into the soil within six hours of application; or (2) use of alkalai (*e.g.* lime) to raise the pH to 12 for two or more hours and then have it remain at pH 11.5 for 22 more hours.

4.3 Health Risks.

Defining a health risk due to residual pathogens in biosolids is difficult because of uncertainties in determining actual exposure routes and the designation of an exposed population (Harrison and Oakes, 2002). In addition, there have been few rigorous epidemiological studies of biosolids utilization (Lewis and Gattie, 2002). Many of the researchers who have studied the exposure health risks have concentrated on wastewater-treatment-plant workers, or workers at composting facilities, where the potential for exposure to pathogens is greatest. A cohort study of treatment plant workers, using a cumulative 6,886 person-years of exposure, found no elevated cancer risks relative to the general population (Lafleur and Vena, 1991). Risks have been assessed by considering the type of pathogen that can occur in biosolids and how long they can survive under exposed conditions (stockpiles, or after spreading). The presence of pathogens in biosolids does not necessarily imply that a person would become ill after exposure (Epstein, 1998; NIOSH, 2002). Illness occurs when two events happen in sequence: (1) exposure to a sufficient quantity of pathogens from inhalation or ingestion; and (2) the dose of pathogens must be in a sufficient quantity to overwhelm the immune system's ability to contain the pathogen. NIOSH (2002) does not view biosolids as presenting an extraordinary health risk and recommends that workers exposed to Class-B biosolids employ good environmental practices and use care in maintaining good personal hygiene.

According to the commonly accepted definition, a pathogen is any organism or genetic substance that causes disease; bacteria, viruses, parasites, cell substances, and fungi are all potential pathogens (Epstein, 1998). Some pathogens are sufficiently aggressive that they can invade and infect any healthy individual. For example, a cold virus can quickly spread through a commingled population. Many other pathogens can only affect people predisposed with weakened or suppressed immune systems.

Some pathogens do occur in biosolids and survive well past the time of land application (Epstein, 1997, 1998; Millner et al., 1994). The distinction needs to be emphasized that Class B biosolids have reduced content of pathogens while Class A biosolids have pathogen content nearly equal to natural soils. Additional pathogen reduction likely occurs in, or on the surface of, soil. Soils are full of predatory microorganisms, while the ground surface is subjected to the sterilizing effects of ultraviolet radiation (UV). These two factors work against the survival of pathogens from biosolids (Epstein, 1998). Lan et al. (2004) reported that *e. coli* decayed to background concentrations in biosolids in less than 96 days. Pathogens associated with biosolids and their persistence in soils are summarized in Table VI; note that local climate will affect these values significantly. The persistence of pathogens is the basis for the 30-day and one-year rules restricting access and use of fields receiving Class B biosolids. Epidemiological data contain evidence that these rules for biosolids work, along with other measures to protect food quality. Health survey data collected by the Center for Disease Control (CDC) for food transmitted pathogens show a significant decline in occurrence rates between 1996 and 2002 (http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5316a2.htm).

TABLE VI. Pathogens in Biosolids and Their Persistence in Soil (modified from Epstein, 1998).

Organism	Persistence in Soil (days)
Coliform	<38
Streptococci spp.	35 to 63
Samonella spp.	15 to 280
Shigella spp.	<42
Microbacterium spp.	>180
Leptospira spp.	15 to 43
Entamoeba histolytica	6 to 8
Enterovirus	<8
Ascaris spp. eggs	< 7 years
Hookworm larva	42 to 180
Tania saginata eggs	90 to 365
Poliovirus	<100

Work continues to define the risks to human health with greater certainty. Two variables are needed to quantify the risk from pathogens: (1) a human health effect that is a function of a given pathogen; and (2) an exposure risk that is a function of a given biosolids product *and* the route of exposure. Combining these two variables defines the actual health risk posed by biosolids to people. Colford et al. (2003) have developed a theoretical dynamic model using these two variables. The output of the model is a matrix that differentiates exposure and risk for different scenarios. The utility of this model is limited because some of the key variables have been estimated, not measured. The model will not be capable of determining human health risks until the biosolids exposures are quantified with more precision.

4.4 Evidence of Pathogenicity.

The presence of pathogens in sewage sludge is unarguable; as is the reduction in numbers of pathogens when the sewage sludge is processed into biosolids. The ability of the remaining pathogens in biosolids (applicable to Class B) to be infectious is less certain (Lewis et al., 2002). Is there evidence that exposure to biosolids can cause illness? The summary that follows focuses on two specific routes of exposure: inhalation and ingestion in water. This is based on the current practices that limit the potential for direct human contact by keeping the general public away from land application sites. Thus, the risks posed by direct ingestion are minimized by site access control. These pathways both require the transport of pathogens through another media (air or water) before they can have human contact. Very small and biologically active particles that are transported by air currents are called bioaerosols. These particles can range in size from 0.02 to 20 micrometers in diameter (Pillei and Ricke, 2002).

Bioaerosols in Confined Composting Facility. Epstein et al. (2001) reported on two documented cases of worker reaction to bioaerosols (dust) at an enclosed composting facility:
Case No. 1: A worker reported respiratory discomfort that disappeared on weekends and,
Case No. 2: A worker developed a rash.
A survey of the facility found respirable quantities of dust, endotoxins and non-viable *Aspergillus*. Although there are no air quality standards for these aerosols, they appeared to have

caused allergic reactions in the sensitized individuals. This problem was managed using water to minimize dust and improving ventilation; no lasting symptoms were reported.

Evidence of Infection- Farm Application. A rigorous study of biosolids and ill health was performed in Ohio between 1977 and 1983 (Ohio Farm Bureau, 1985). The Ohio study concluded that the health of residents on 47 farms receiving sewage sludge were no different from the residents of 45 control farms. The occurrence of illness was the same for both groups. A complaint response in an agricultural area studied by NIOSH (Burton and Trout, 2000) identified enteric bacteria as the source of illness. The NIOSH study did not link the illness occurrence with land spreading of biosolids. All of the pathogenic organisms identified as potential infectious agents in the NIOSH study occurred in the natural background. Gattie and Lewis (2002) conducted a retrospective analysis of health effects reported as associated with biosolids utilization and reported ill-health concerns in the general public in association with land application of biosolids (Class B).

Some authors have cited that the limited number of comprehensive health-related studies and the lack of timely investigations of complaints have prevented the development of any generalized conclusions (Harrison and Oakes, 2002; Brobst et al., 2004; Lewis and Gattie, 2004). As an example of how *ad hoc* studies can add to the confusion, a study of treatment plant workers found overall very good health and the authors proposed that this was due to a robust-worker effect (Bunger et al., 2000). Exposures are greater at sewerage treatment plants than at biosolids utilization sites. This can be interpreted to mean that reasonably healthy individuals in the general public have a minimal pathogen-exposure risk associated with well-managed biosolids utilization.

The research reviewed presented information about the complex interactions that define a minimum infective dose; a valuable measure of risk but nearly impossible to establish. Stated simply, this concept attempts to define how many pathogenic organisms are needed to make someone sick. Lewis and Gattie (2004) expressed a concern that the other chemicals present in biosolids could act as irritants that then allow fewer opportunistic pathogens to infect. A synergistic effect between pathogens and irritating chemicals opens a new area of risk assessment. The irritant-infection hypothesis is tempered by the very small number of documented health problems related to exposure to biosolids (Epstein, 1998).

Retrospective analyses of wastewater treatment plant workers have identified some immune system response to endotoxins and enteric pathogens (*i.e.* evidence of pathogens being controlled by the immune system). The endotoxins come from the breakdown of gram-negative bacteria that are produced in quantities during the sewage treatment process (Gattie and Lewis, 2002). Exposure to endotoxins in dust at a composting facility in Colorado has been cited as a potential health risk (Darragh et al., 1997). Immune system responses are how a body fights off illness or infection; this is a normal and healthy reaction. A survey of 58 workers at compost facilities found a small increase in symptoms of air passageway irritations and gastrointestinal symptoms, but the workers were found to be overall healthier than the general population (Bunger et al., 2000). The exposure of workers at a treatment plant or compost facility is very different from that of the general public. Exposures at a minimum 300-foot setback from spread fields are significantly less than the exposures to workers at treatment plants; especially since biosolids are processed to reduce their content of pathogens.

4.5 Risks Posed by Bioaerosols.

Bioaerosols are very small, biologically active particles containing viruses or bacteria that may become airborne by themselves or in attachment to other fine particles. Bioaerosols are biological particles in the size range of 0.02 to 100 micrometers. These particles are subject to many forces that cause them to be mobile and to form concentration gradients away from a source (Suresh and Pillai, 2002). Very-fine particles such as bioaerosols could move as much as a kilometer from a source, likely much less depending upon a variety of environmental conditions such as terrain roughness, wind speed and relative humidity (Dowd et al., 2000; Brooks et al., 2004). There is disagreement about the risks posed by bioaerosols, with one camp (e.g. Lewis et al., 2002) associating infections with exposure and the other camp stating that bioaerosols present negligible risks (e.g. Millner et al., 2004). The ability of pathogens to infect individuals is strongly dependent upon the specific organism, the transfer pathway, and the health of the exposed population (Eisenberg and Cicmanec, 2004).

Epstein (1998) noted that the lack of significant pathogenicity from bioaerosols is supported by the absence of independently documented dose-response illness associated with biosolids utilization. Millner et al. (2004) found that properly processed biosolids, Class A or B, maintained at a high pH will have no pathogenic bioaerosols. A survey of 15 different sites in the United States found that *staphylococcus aureus* was absent in biosolids and aerosols (Rusin et al., 2003). The existing rules for setbacks and access controls can be inferred to protect the general public (Gerba and Smith, 2004 and 2005; James and Perdek, 2004).

A lack of dose-response does not correspond inconclusively with the absence of pathogenicity in bioaerosols as based on a limited number of epidemiological studies (Lewis and Gattie, 2002; Brobst et al., 2004). Evidence of pathogenicity has been documented for exposures of workers at biosolids processing facilities (Epstein, 1998; Bunter, 2000). Exposure of the general population near biosolids utilization sites is based on few controlled studies. Vulnerable populations may be sensitive to certain pathogens, or they may be more likely to become ill from many causes. Associations between biosolids applications and ill health have been cited by Lewis et al. (2002) and Gattie and Lewis (2004). The Cornell Waste Management Institute (2004) maintains an incident list to track health related complaints. All of these associations of biosolids and ill-health come from anecdotal sources. Self-reporting systems are used to assess the public health issues when regulatory agencies do not track complaints. Such surveys need to be interpreted with care since they lack the needed experimental control for epidemiological analysis and self-reported data could be fabricated by unscrupulous individuals.

In an opinion paper by Lewis et al. (2002) they surveyed a total of 54 people who lived within one kilometer from one of 10 different biosolids utilization sites. The survey of health issues was self-reported and it was not clear how the communities surveyed valued the use of biosolids (i.e. were the participants randomly selected?). Although the size of the population exposed was not stated, approximately 25 per cent of those surveyed (13 people) reported symptoms ranging from skin or upper respiratory tract irritations, to staph infections, to flu-like symptoms. Gattie and Lewis (2004) characterized the health complaints as mostly irritations to the skin, mucous membranes, and respiratory tract; the type of symptoms expected from exposures to volatile compounds and dust in any setting. Symptoms of gastro-intestinal disorders were much less frequent. They interviewed affected individuals and disclosed that the reported exposed population was deeply distrustful of the existing scientific research on biosolids. Also, the same people said that their greatest concerns were about the noticeable odors, vectors (especially flies), and the potential for adverse health effects. This study highlights an important psychological response to biosolids that associates the detection of malodors with pathogens so that any sign of illness is assumed to be caused by the odor. Odors associated with other agricultural practices such as manure spreading were not described in this study. Relative to the volume of biosolids that are land-applied each year in Maine, the number of reported health problems directly related to biosolids is very small.

4.6 Odors and Atmospheric Transport.

The utilization of biosolids, and Class B biosolids in particular, brings attention to itself because of its unique odor. This is an attribute shared with other agricultural materials such as manure. Negative comments about Class B biosolids almost always include mention of their odor. Class A biosolids typically have less intense odors. The association of odors with potential pathogens is a commonly cited trigger for community response to biosolids utilization (Tyson, 2002; Witherspoon et al., 2004). Odor management is an important concern for more than just the a nuisance value. At another extreme of the waste-management field, research has cited confined animal feeding operations as generating odors that pose a health risk (Schiffman and Williams, 2004 and 2005).

What constitutes odor in biosolids? Odors are caused by various organic compounds whose occurrences change with the source of the sewage sludge and the techniques used to transform it into biosolids. The odor compounds are formed as the natural product of biological processes and the decay of organic matter, be it vegetation, manure, or municipal wastes. Common odor-forming compounds are volatile fatty acids that smell like rancid butter or vinegar; ketones that have a slightly sweet smell; aldehydes that may have a pungent odor; amines that have a fishy smell; indole and skatole that have a fecal odor; and phenol that smells like antiseptic (Rosenfeld et al., 2001). The nitrogen in biosolids may be in the form of ammonia which has a characteristic sharp odor, or the fishy odor of an amine. Odor causing compounds containing sulfur are hydrogen sulfide (rotten eggs), dimethyl sulfide (skunk), and methyl mercaptan (rotten cabbage); all of these odors may be persistent. Humans are able to detect some of these odor compounds at very small concentrations- 0.000026 to 20 parts-per-million (Amoore and Hautala, 1983; Rosenfeld and Suffet, 2004).

It is important to distinguish between *odor concentration*, the amount of an odor in a given volume of air, and *odor intensity*, the strength of the human reaction to an odor compound. Concentration can be measured using standardized laboratory methods to generate an absolute value. There is no absolute measure of intensity because of the differences in our perceptions of odor and our individual abilities to smell odors that complicate potential instrumental analysis (Gostelow et al., 2001). There has been a method for measuring the intensity of odors in air, ASTM Method D1391-57 “Measurement of Odor in Atmospheres”. This method uses the dilution-to-threshold (DT) principle to measure the intensity of an odor in air. Another method, ASTM Method E679 uses a triangular forced choice to determine specific odor thresholds in people; this is a perception rather than absolute test.

There has been some research conducted to determine the amount of dilution needed to minimize biosolids odor. Caballero et al. (1997) reported that a compost facility in California needed up to 1,400 volumetric dilutions to threshold. This means that one cubic foot of air with an odor needed to be added to 1,400 cubic feet of clean air. Rosenfeld and Suffet (2004) also reported that some fresh biosolids may have a DT greater than 7,000 when fresh, that falls to ~3,000 within one week. Although these dilution values appear to be large, since volume increases by the cube of distance, a 3,000-fold dilution could occur within 12.5 feet.

Schiffman et al. (2000) argued that odor causing compounds, primarily from confined animal feeding operations, are also capable of causing illness, even without pathogens. Runny noses, itchy eyes, sore throats, coughing, etc., are all symptoms of allergic reactions to odors. That is, some people may have a temporary allergic reaction which is different from a response to simple irritation. Typically, exposed individuals recover quickly after removal from the odors (irritation response). Sensitive individuals, such as asthmatics, may experience much more severe reactions (allergic response). It is very difficult to distinguish the potential responses of sensitive individuals exposed to biosolids odors from those of other natural antagonists.

There are exposure standards for many volatile compounds, including those detected in biosolids. Safe exposure limits expressed over an average work-day (time-weighted average) are available from the American Conference of Governmental Industrial Hygienists (ACGIH; http://www.acgih.org/home.htm). As an example, the data from a confined composting operation are compared to the ACGIH standards. Measured ammonia concentrations in the venting system of a biosolids composting building (Caballero, 1997) were 57 parts-per-million by volume (ppmv), or approximately 43 mg/m^3. This concentration was above the 8-hour time weighted average (TWA) exposure limit of 19 mg/m^3. At the same time measured concentrations of carbon disulfide were approximately 7 mg/m^{3}and the TWA is 34 mg/m^3. Dilution outside of the vent reduced concentrations to below detection. The dilution volume of clean air presented by Maine's setback distances is a factor of 786,000. This amount of vapor dilution provides sufficient protection with respect to ACGIH exposure limits for all commonly encountered volatile compounds.

Under field conditions, winds can carry odors to greater distances than are possible by molecular diffusion. The calculated risks posed by atmospheric transport from properly managed biosolids utilization are very small (Pillai et al., 1996; Dowd et al., 1997). Odor molecules can be transported greater distances than bioaerosols. A key question is: Is the presence of detectable odors indicative of the presence of pathogenic organisms?

Dowd et al. (2000) modeled the transport of bioaerosols from an actual utilization site using an advection-dispersion model that includes a time-based microbial inactivation factor. The output of the transport model was then entered into a dose-response model to derive a risk value for a given distance at a fixed wind speed. The risk to workers at a biosolids application site to viral or bacterial infections was an increase risk of 3 and 2 per cent, respectively (assumed wind speed of 2 m/s and one hour exposure). At 1,000 meters an exposed population had a bacterial infection risk of 0.46 per cent and a virus infection risk of 0.00000034 per cent (assumed wind speed of 2 m/s and 24 hour exposure). This risk may be over-stated by 1,000 to 10,000 times and risk of infection is less than 1 in a million. Brooks et al. (2004a, 2004b, 2004c) re-evaluated the initial model using newer analyses of Class B biosolids and found: (1) few bioaerosols at a biosolids application site in Arizona, and (2) an error in the Dowd (2000) model that used an erroneous and higher virus infectivity constant. The authors further stated that the risks of viral infections were orders of magnitude smaller for those working with biosolids than for wastewater treatment plant workers. According to these studies, the presence of odors is not equivalent to increased pathogen exposure.

4.7 Transport into Groundwater.

Another possible exposure route to humans is through drinking groundwater. The risk posed by biosolids is much less than raw sludge, septage, or any type of fresh manure. The Maine rules require 300-foot setbacks from wells to minimize risks to drinking water supplies. The occurrence of pathogenic organisms in drinking water is a problem of global proportions, not from using biosolids, but mainly due to the lack of wholly inadequate sewage treatment (Gerba and Rose, 1990). This problem occurs in rural areas mainly because poorly functioning septic systems have been shown to add pathogens to groundwater; yet overall the frequency of contamination is believed to be low (Yates, 1985). In some cases, pathogens may occur but not in ample strength to be infectious. The limited data available suggest that pathogens are sorbed onto soil particles and do no persist in large quantities (Epstein, 1998; Vance, 2002). Field studies using septic systems found that bacterial and viral deactivation were dependent upon soil pH and water saturation (Scandura and Sobsey, 1997). This deactivation is considered to be very important and it provides much protection to water supplies (Macler, 1996).

If we examine viruses, their sorption is controlled by the type of virus, soil composition, water, soil moisture, pH, temperature, and soil-solution chemistry (Gerba, 1984; Jin and Yates, 2002). The degree of moisture saturation and ionic strength of the soil solution are especially important and there is less transport of viruses in more concentrated solutions (Jin and Yates, 2002).

Experiments have been conducted with viruses because they are believed to be more mobile in soils and groundwater than other pathogens, partly because of their small size. For example, Bitton et al. (1984) determined that viruses appeared to bind with sludge solids and that no viruses were transported through 33 centimeter of soil cores. Powelson and Gerba (1994) assessed virus removal in 100-centimeter soil columns and found that virus deactivation followed a first-order rate law. Also, unsaturated flow (wetting-drying) had more deactivation than water-saturated flow; conditions that are common in soils. These near-surface processes help to deactivate viruses and likely lower any viral risks associated with land-applied biosolids. Jin and Yates (2002) confirm the deactivation of certain viruses, but point out that column studies can produce very different results depending upon experimental conditions.

Virus deactivation and transport in groundwater is undergoing additional study because of the increasing interest in wastewater reuse (additional information can be found through the Water Environment Research Foundation and American Water Works Association). According to Straub et al. (1993) more specific microbiological testing is needed because some pathogens are infective in small doses and the current indicator species methods are not adequate to evaluate the risks. Improved predictive models of virus transport into groundwater are currently being developed by the US EPA (Faulkner et al., 2002).

Generalizations about bacteria are more difficult to make because they are ubiquitous in soils and they tend to be retained in the soil (Schafer et al., 1998). Populations of pathogenic bacteria may change in response to environmental conditions so that certain species may seem to disappear and reappear (Gibbs et al., 1997).

Research on the occurrence and movement of bacteria in the subsurface has increased since the late 1980’s (Chapelle, 1992). Considerable effort has been focused on the mechanisms that control bacteria in partially-saturated conditions (see summary in Shafer et al., 1998), such as would occur at a biosolids spreading site. Apparently bacteria become trapped along the air-water interface, thereby arresting or retarding transport (Wan et al., 1994; Shafer et al., 1998). In column studies, less than 15 per cent of test bacteria were carried through a 20-centimeter column (Shafer et al., 1998). These studies suggest the probability that bacteria occurring in biosolids could persist into groundwater is exceedingly small. In contrast, field studies conducted in Canada using manure showed that bacteria can be transported into groundwater via macropores (Unc and Goss, 2003). In this study the authors reported that clayey soils allow deeper transport with peak concentrations at 2 to 4 meters and potential transport exceeds 10 meters. The authors speculate that this deeper transport may be due to macropores that form from cracks or other types of soil disruptions.

There are other pathogens besides bacteria and viruses. A specific and more recent concern to drinking water quality is *Cryptosporidium parvum*. Oocytes (dormant stage) of this organism can survive in harsh environments and are able to be transported in groundwater. Although significant numbers of the oocytes can be removed by soil particles, the oocytes are not strongly held and a fraction can become remobilized (Harter et al., 2000). This means that the oocytes can remain dormant in the soil and remobilize when soil is disturbed at some later date. In fine-grained soils the oocytes are attenuated by three-orders of magnitude (1,000 times) over a distance of 10 centimeters (Harter et al., 2000); so loadings would need to be very high to generate a large risk. The oocytes can also be transported in surface flow along with soil particles. According to Atwill et al. (2002) on slopes less than 20 per cent, buffer strips wider than 3 meters (10 feet) are sufficient to remove 99.9 per cent of the oocytes present. Monitoring of raw surface water indicates that *cryptosporidium* is rare in Maine’s public water supplies (Maine Drinking Water Program, pers. com., 2004). The available research indicates that the likelihood of oocytes, which are very robust, surviving in biosolids from the wastewater treatment process, followed by exposure to air and UV radiation, and then transported down into groundwater as viable organisms is very slight.

4.8 Summary

Class B biosolids are processed to reduce significantly, but not eliminate, pathogen content. Biosolids (Class B) thus present some risk to humans due to exposure from accidental ingestion, or via inhalation of bioaerosols. These two routes of exposure require very close physical contact to cause exposure that may lead to illness. The small size of the illness risk is substantiated by epidemiological studies of treatment plant and compost facility workers, and of healthy people having direct or indirect exposure to biosolids at land-application sites. Pathogen viability is affected by many environmental conditions; conditions that allow few organisms to persist for long. The current standards reduce risks to very small levels, but do not eliminate them. A study of microbiological risks from sewage sludges applied to food crops in the United Kingdom substantiates the protection offered by both sludge processing methods (equivalent to biosolids) and the use of suitable harvest intervals (Gale, 2003).

The NRC (2002) study recommended that future research goals include a better characterization of pathogens and associated health risks. This includes adding *clostridium* to the list of pathogens and improving overall testing methods. Anecdotal reports of exposure-related illness underscore the need for more rigorous complaint tracking so that we have a better database for epidemiological studies and risk assessments. Multi-pathway, multi-stressor analyses of risk are needed to reflect realistic conditions. The NRC study recommended improved quality assurance standards using performance-based monitoring, especially of bioaerosols. The Biosolids Summit (Dixon and Field, 2004) was essentially in agreement with the NRC recommendations. The key findings of the Summit also emphasized bioaerosols and odors as areas needing more research. Current regulations do not try to anticipate new or emerging pathogens. Odors need to be managed for the general perception of increased risk, and the reality of well-being

Following is a summary of the relationship between public health and the use of biosolids as a soil amendment.

Potential Benefits:

+ Class B biosolids protocols significantly reduce pathogen content to concentrations lower than detected in untreated animal manures.
+ Class A biosolids have a pathogen content equal to background soil concentrations.
+ Epidemiological studies show that risks of infection to a healthy population adjacent to properly managed biosolids facilities or Class B application sites are low.
+ Transport of viable pathogens to groundwater is strongly attenuated by soil processes.
+ Regulatory controls minimize public exposure (risks) to biosolids.
+ Class A biosolids have odors similar to organic soils.

Potential Risks:

– Class B biosolids contain some residual concentrations of viable pathogens.
– Pathogens may be infectious and mobile as bioaerosols close to Class B biosolids, but not Class A.
– Pathogenic organisms in Class B biosolids may remain dormant but potentially infectious in the soil (this is addressed by site access restrictions).
– Odors may act as irritants or trigger immune responses.
– Rapid identification of pathogenic organisms is not a mature technique and it is difficult to accurately document presence or absence.

Following is a relative assessment of how Maine’s rules protect people from pathogens in biosolids.

Chapter 419 Management Goal	Rules Commentary	Possible Deficiencies
Pathogen Reduction	Class A and Class B pathogen reduction standards provide substantial protection of public health. Class A is equivalent to background and is suitable for many more uses than Class B.	Specific viability of organisms, i.e. better testing methods are needed for certain organisms such as viruses.
Pathogen Transfer	Vector attraction reduction standards are, in general, effective. Potential human contact is controlled when appropriate guidance is followed. Relevant only for Class B biosolids.	Site utilization management controls to limit accidental contact, *i.e.* it is difficult to prevent trespass on large agricultural parcels.
Odor Control	Boundary and occupied building setbacks provide sufficient buffer for most common situations. Most relevant for Class B biosolids.	Odors are the primary cause of complaints at utilization sites for Class B and processing facilities for Class A and B. Site specific bioaerosol transport measurement or modeling may be more useful than numerical standards.

Section V. An Assessment of Maine's Regulation of Biosolids.

5.1 Introduction

In this assessment of how well Maine's regulations work to protect the public health and environment, five topics have been addressed:

1. Soil fertility amendment;
2. Soil quality and human risks via soil;
3. Water quality and associated risks;
4. Air quality changes due to odors and bioaerosols; and,
5. Sustainability (long-term effects).

First and foremost, biosolids are regulated and managed for their agronomic value. Using these residuals for fertilizer dates back to the earliest municipal sewerage systems, prior to waste water treatment and well before the current biosolids standards. The regulations are designed to protect soil quality, and ultimately human exposure pathways, by limiting the addition of certain metals or organic compounds to soil. Interactions of biosolids with water are the third topic and this covers impact to water quality, as well as the ability of water to transport components away from the site of utilization. Air is the focus of the fourth topic with particular emphasis on odor and bioaerosols. Finally, the topics of sustainability and the management of biosolids are addressed. The regulations address some of the issues associated with the short and long-term objectives for biosolids utilization.

A basic question asked is, 'Do the regulations work?' The simple answer is yes. The validity of a *yes* answer is substantiated by the numerous land application sites and programs approved for biosolids that meet Maine's standards. Underlying these approvals are full characterizations of the biosolids, site monitoring, an open review of permits, and compliance with the applicable utilization standards. Site managers and regulators can attest to the hundreds of hours of meetings with town officials and concerned citizens needed to maintain a land-spreading program. Regulatory compliance has been carefully monitored and managed with due diligence, albeit with a currently small staff.

Another basic question is, 'Do the regulations go far enough to protect the public?' Again, in many areas the basic answer is yes. The regulatory agency can change regulations in response to advances in knowledge; rarely does this occur quickly. There is a continued need to improve the public dialogue about biosolids and to build a true consensus (Beecher et al., 2005). In part this is because some regulations are set-pieces that are established by legislation, while other aspects may be classified as best-management practices that are evolutionary concepts. Another criticism, one that illustrates differences in the philosophy of reusing waste products, is that the rules do not necessarily support sustainable practices. For example, metal loadings are based on either a maximum concentrations for a single application, or cumulative loading at the ceiling concentration over a period of 20 years. A longer time period, of decades to centuries, is needed for sustainability. Although the rules protect the environment with a reasonable safety factor, the need to utilize biosolids will exceed a 20 year window. This is a logical consequence of our civilization continuing to make wastewater and biosolids for much longer than 20 years.

5.2 Agronomic Value

As mentioned in the introductory chapter, biosolids must be used for a defined agronomic benefit (Chapter 419, Section 4(B)). This benefit comes from the addition of plant nutrients, such as nitrogen or phosphorous, and depending on the type of processing, a liming benefit. The amount of biosolids utilized at a land-spreading site must be calculated based upon soil testing, biosolids composition, and crop requirements. This is a very important concept, because biosolids contain several major plant nutrients and utilization must not exceed any crop need so that the soil chemistry remains balanced. Since Class B biosolids are land-applied, attention is paid to the nitrogen loading and cumulative phosphorous additions.

Nutrient loading calculations include the carry-over of nitrogen from year to year as organic nitrogen is mineralized into a plant available form (Chapter 419, Appendix A). A sample calculation for a typical Maine biosolids (Class B) is shown in Table VII. In this table, nitrogen loading is calculated for three consecutive years. Notice that there is some small variability in the solids content and total kjeldahl nitrogen content of the biosolids. The crop nutrient requirement is constant (*e.g.* single crop of hay). The biosolids loading rate is in metric tons per hectare and has been calculated using a conservative loading assumed to be 75 per cent of the target value to avoid excess nitrogen addition. The loading of organic nitrogen is greater than the crop requirement because all of the nitrogen is not plant-available. The organic nitrogen is mineralized over several years and causes a nutrient carry-over that must be tracked; this is the added N-mineralization factor. The net added plant-available nitrogen is slightly less than the crop need and nitrogen loss should be minimized.

TABLE VII. Nitrogen Loading of Biosolids, Sample Calculations.

	Year 1	Year 2	Year 3
% Total Solids	27	34	28
% TKN	3.41	2.90	3.30
% Organic N	3.30	2.85	3.15
% Ammonia-N	0.11	0.09	0.15
% Nitrate + Nitrite	0.001	0.003	0.008
Crop N Requirement (kg/ha)	112	112	112
Loading Rate Sludge (mt/ha)	22.4	17.9	20.2
Loading Rate Org.-N (kg/ha)	199	174	181
Added N-Mineralization (kg/ha)	0	24	30.5
Plant Available N (kg/ha)	83.5	96	95

Biosolids also contain the essential plant nutrient phosphorous. Certain additional restrictions apply to the land applications within the direct watersheds of sensitive water bodies. If the biosolids contain more than plant requirements, additional controls on timing, suitable slopes, and setbacks are employed. Using the same example Class B biosolids, phosphorous provides 72 kilograms total-P in year one, 73 kilograms total-P in year two, and 68 kilograms total-P in year three. The annual plant requirement for phosphorous is 22 kilograms per hectare and loading will exceed plant requirements. Presumably the excess phosphorous will remain with the soil. Loading may continue until plant-available phosphorous concentrations exceed 100 pounds per acre (112 kg/ha). Based on our example, site utilization would have to cease after a few years until the stored phosphorous is used up by the crops.

Based upon the example worked here, the Maine rules for the land application of biosolids provide sufficient guidance for agronomic uses. Specific application rates will be determined by the type of crop grown and farmers need to have a nutrient management plan.

5.3 Soil Quality

The greatest benefits derived from applying biosolids to land are an increase in soil fertility (Section 5.2) and an improvement in soil properties caused by the addition of organic matter that lowers soil density and increases moisture retention capacity. These benefits accrue outside of any regulatory constraint. Biosolids also contain trace metals that may also be plant nutrients, possibly some pathogens in Class B, and possibly some trace organic compounds of concern. The environmental fates of these components of biosolids vary by source and local conditions. Some may move into soil and water, but most tend to reside in the soil. In addition, even though some of these compounds may be present, they are not in an available form because the stability of biosolids retards the release of bound metals or organic compounds (Switzenbaum et al., 1997). The regulations do address biosolids stability during processing, but in a different rule chapters (06-096 CMR Chapters 405 and 409). The regulatory approach has been to set standards that protect the public from likely worst-case situations based upon the state and federal risk assessments.

Metal accumulation in soil is controlled by restricting metal content in biosolids that are land-applied along with a cumulative upper loading limit. Exceptions may occur for metal concentrations exceeding the limit for single application, but not for the cumulative loading. The loadings are consistent with available research on the transfer of metals from soils to plants. A second layer of protection is offered by grazing restrictions. These restrictions control the transfer of metals from the soil to animals via direct ingestion. In terms of the cumulative metal loading limits, the Maine rules are conservative. Cumulative metal loading limits were estimated using the same example biosolids, with continuous land applications at the same rate as needed for crop nitrogen demands. The times needed to reach the cumulative limits are summarized in Table VIII and range from 552 years for copper to 8,055 years for cadmium. This is assuming that all metal loss is through cropped plants and does not account from increased soil mass (a relevant change for that number of years).

The cumulative trace metals added over a 20 year period are most likely to accumulate in the plow layer and slightly deeper. There is some variability in where metals end up that was described in Section 2. The total cumulative metal concentrations are compared to Maine soils and shown in Table VIII. Using this example calculation, the total mean masses of cadmium, copper, and zinc in soil would increase in the plow layer by 144 to 240 per cent. The metal additions still fall within the natural ranges for these metals found in typical Maine soils

(Houtman et al., 1995). Significantly smaller increases will occur for molybdenum and lead because their concentrations are so low in biosolids.

TABLE VIII. Nutrient and Metal Loading to Soils Using Cumulative Limits.

Chemical Variable	Concentration	Units	Annual Load (kg/ha)	Removal Rate (kg/ha/yr)	20 year Cumulative Load (kg/ha)	419 Soil Max. (kg/ha)	Change in Plow Layer Mass (ppm)	Maine Soil Mean (ppm)	Percent Change from Mean	Years to Max. Load (No Removal)
TKN	3.12	%	189	112	1537		1694.5			
P	0.6	%	36	8.6	554		611.2			
K	0.1	%	6.1	34	-559		-616.4			
Cd	0.8	mg/kg	0.0048	0.0005	0.087	*39*	0.1	0.06	160.2	***8055***
Cu	449	mg/kg	2.72	0.54	43	*1500*	47.9	20	239.7	***552***
Mo	3.6	mg/kg	0.022	0.011	0.22	*15*	0.2	2	12.0	***688***
Pb	32	mg/kg	0.19	0.010	3.7	*300*	4.1	10	40.6	***1549***
Zn	721	mg/kg	4.4	1.1	65	*2800*	72.2	50	144.4	***642***
$CaCO_3$ eq	4	%	897	?	17,933	134,496				

The presence of potentially hazardous organic compounds in biosolids is explicitly managed under Chapter 419 for dioxin and under Chapter 418 for other listed compounds (579 compounds, many of which are organic compounds). There are few of these listed compounds detected in Maine's sewage sludges that could ultimately be in biosolids. Although there are genuine concerns about emerging contaminants, the present screening requirements appear to be adequate for most situations since the majority of the organic compounds detected in sewage sludge are decomposed in soils. Additional soil testing at land applications sites would help define changes to soil quality.

5.4 Water Quality

The protection of water resources, both surface and ground, is accomplished through the siting criteria for permitting utilization sites and restrictions on stockpiling. There is not any systematic monitoring of water quality adjacent to biosolids land-spreading sites. The indirect evidence for surface water quality is that the Maine Chapter 419 regulations adequately manage nutrient loss in runoff. Overall, Maine's surface waters in rural areas have shown continual improvement in classification, including some streams in agricultural areas (Maine DEP, 2004). Proper site management to control soil erosion and to manage buffer strips around draingeways and water bodies has worked. Protection of groundwater has been harder to assess because much more expense and effort is needed to make a determination. This is further complicated by the use of manure and chemical fertilizers on the same fields as biosolids. In areas of intense agriculture, groundwater may contain elevated concentrations of nitrogen that cannot be attributable to any single source (Pinette, 1993; Pinette et al., 1999).

Field stacking of Class B biosolids can affect groundwater by leaching high concentration liquids. Depending upon weather and soil conditions, leachate can form over several weeks and move below the root zone. Transport of nutrients and other soluble constituents to depths greater than 1 meter can occur below the stockpile. The Maine rules for field stacking are not sufficient to protect groundwater quality directly below unlined stockpiles. Improper storage or failure of a storage containment structure has contributed to groundwater contamination (nitrogen) at four locations (Maine DEP, 2004). This represents a very small fraction (0.7%) of all the 536 licensed biosolids utilization sites or composting facilities in Maine. The potential for stockpiles to affect water quality is probably much greater because the state has monitored very few sites. According to unpublished data collected by the Maine DEP, groundwater impacts were documented at six of eight sites with required monitoring. In general, the occurrence rate and magnitude of groundwater contamination can not be estimated due to insufficient monitoring. The concentrated solutions associated with storage sites present a very different situation from properly spread biosolids where leachable constituents are loaded at rates more conducive to plant uptake. Properly applied biosolids probably have had minimal impact to groundwater quality (McDowell and Chestnut, 2002). More water quality monitoring would define the occurrence and magnitude of impacts to water quality.

Pathogen transport in waters is not addressed explicitly by Chapter 419. The available research indicates that pathogens usually attach to solids and as long as erosion is prevented, pathogenic organisms are immobile. Surface exposure to ultraviolet radiation and drying rapidly destroys organisms that remain after Class B treatment. Pathogen viability in groundwater is attenuated by soil absorption. The available data support the adequacy of the Maine rules.

5.5 Air Quality

Chapter 419 regulations address controlling odors coming from biosolids. The control of odors during composting, storage, and land application is a major source of complaint about the use of biosolids. Minimizing the impact of odors associated with Class B biosolids is an operational issue. Difficulties in controlling odors illustrate the limitations of both control technology and regulatory oversight. Nevertheless, the number of active permits relative to the occurrence of nuisance odor complaints indicates that most biosolids programs have successful air-quality management techniques. The mandated setback distances from occupied dwellings provide thousand-fold dilutions of odor-causing compounds.

A new concern about pathogenic bioaerosols has grown since the Chapter 419 rules were completed. The studies reported in this document concur that pathogen transport, as air-suspended particles, is possible over relatively short distances. Since biosolids have significantly reduced concentrations of pathogens relative to raw sewage sludge, the current setbacks for odor control are also likely protective of public health from bioaerosols. This aspect of biosolids regulation will need to be addressed in future revisions of the regulations after more research is completed.

5.6 Sustainability

The current rules for the agronomic utilization of residuals do not incorporate the full concept of sustainability (O’Connor et al., 2005). Sustainability, in its simplest form, means a process that balances present day needs with that of the physical world and the demands of future generations. It fuses the daily and future sustenance of human society with the dynamics of an agricultural ecosystem, all subject to the forces that energize economies (Dentel, 2004). The Chapter 419 rules define nutrient management goals that fall within a range of years and metal loading rates that could cap in 20 years, far short of multiple generations.

A field lifetime is almost impossible to define because many variables must be managed. Agricultural fields in some parts of Europe have been farmed continuously since the Iron Age. A sustainable process must have a very long life-cycle. Historical evidence shows this to be a logical desire for agriculture. The prospect of feeding people for centuries to millennia underlies the philosophy of sustainability. Sustainable practices lie within a larger context of economics (profitability), social benefit (food availability), and environmental health. These components need to be considered as a whole to be balanced. Biosolids utilization needs to be managed as part of a sustainable agronomic system. The generation of biosolids is the direct consequence of making surface waters cleaner and sustainable. The best use of biosolids is equally important.

5.7 Management.

An examination of how the State of Maine actually manages the biosolids program was not an explicit objective of this review. The staff of the Maine Department of Environmental Protection should be commended for developing the rules that make up Chapter 419-Agronomic Utilization of Residuals. The research reviewed supports most of the assumptions that are the basis for the rules. The body of scientific research continues to grow and the regulatory process can be adaptive to incorporate new knowledge. The Department has the authority under 38 M.R.S.A. § 1304 to revise Solid Waste Management Rules, including those for regulation of biosolids.

Staffing levels within the Department are low relative to the work load. Staff are required to perform numerous tasks: review and process program applications and site licenses; review required monitoring submissions; approve annual utilization reports; audit operations; approve new technologies; and investigate complaints. The workload required to provide regulatory oversight for 536 sites is divided between five staff in three offices. Time consuming tasks, such as site inspections, clearly have to be sacrificed to other duties of regulatory oversight. This high workload appears to be the rule in the region; other New England states also struggle with few staff assigned to biosolids management.

These demands on staff time affect the Department's ability to deal with new issues that require policy decisions. Also, the public perception of an agency that may not be able to respond quickly to complaints works against the long-term viability of land-application programs. The public needs to feel confident that the Department can respond to concerns about biosolids and insure that they are protected from unnecessary risks. In particular, what is the Department's ability to assess quality and perform spot checks? Should there be more field inspections? How can the Department effectively communicate risk management to the public? Clearly, more staff is desirable and there are creative options to cross-train other State agencies to assist in collecting field information.

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