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Studying Land-Applied Biosolids: An Integration of Research and Teaching in an Environmental Engineering Curriculum

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Abstract

The selection of appropriate reuse, recycling and disposal options for biosolids requires an understanding of many factors including the physical and chemical properties of the biosolid, risks posed to potential receptors and applicable regulatory requirements. These options continue to evolve due to new technologies and changes in regulatory requirements. Many "new" options for biosolid reuse and recycling have met regulatory acceptance due to pressures from limited landfill space and advances in risk assessment. This paper is a presentation of how current research in biosolid characterization and biosolid management are being integrated into selected courses in Wentworth's undergraduate environmental engineering program.

With participation from the Biosolids industry, lecture material, laboratory studies and a Capstone Design project have been developed. The lecture and laboratory studies have focussed on assessing risks posed by the presence of trace levels of organic chemicals. Trace level organic compounds, including 4-methyl phenol, have presented regulatory issues with municipal and industry generators of biosolids. Students have investigated the natural and anthropogenic sources of these organic compounds in biosolid matrices. The Capstone Design project involves the design of a pulp and paper/municipal biosolid blend for use as topsoil at a local quarry that is being developed into a municipal golf course. Critical issues in this design concern nitrate leaching and slope stabilization.

The paper also provides a review of resources that may be used by environmental engineering educators for the development of teaching modules in other topic areas involving biosolids.

Background

Biosolids (better known in the past as sludge) is a product of municipal wastewater treatment. The study of the production and treatment of biosolids is an essential component in the study of wastewater engineering in the undergraduate environmental engineering curriculum. In addition to organic matter, nutrient and water, biosolid management must consider the presence of pathogens. For this reason, undergraduate environmental engineering programs also study biosolids in microbiology and/or related biological coursework. Often, the study of biosolids in wastewater and microbiology courses focuses on treatment options and less attention is afforded to post-treatment reuse options. Biosolid reuse is an important topic area that integrates fundamental principles of environmental chemistry, chemical fate and transport, risk assessment and contemporary regulatory issues. This paper presents examples of how the land application of biosolids may be studied at the undergraduate level to supplement student learning acquired in wastewater engineering and microbiology coursework.

Reuse versus disposal of biosolids is a contentious issue for municipalities, taxpayers, environmentalists and regulators in the New England states. Reuse through land applications saves landfill space, reduces air pollution, provides nutrients and organic matter to cropland and, in many instances, serves to reclaim barren lands. However, land application of biosolids have been perceived by some as a threat to public health due to potential exposure to pathogens, metals and trace levels of organic compounds. Though the debate over the risks and benefits of biosolids is not unique to New England, the percentage of biosolid reuse in New England falls short of the national average (26% recycled in N.E. versus 60 % in U.S.). Despite limited available landfill space and public wariness of incineration technologies, it is uncertain whether recycling of biosolids will significantly increase in the near future.

Acceptance of biosolids recycling relies on public acceptance through the collection and distribution of sound scientific data characterizing risks and benefits. Regional biosolid associations, EPA and the National Biosolids Partnership have taken responsibility to develop, critiqued and share relevant scientific information. The laboratories, student projects and lecture material described in this paper were developed with the aid of the New England Biosolids and Residuals Association (NEBRA) and information data accessed through their web-site. Data collected by students during these assignments have, in turn, been shared with NEBRA to enhance the body of information to their membership.

Biosolids Teaching Material for an Undergraduate Curriculum

For land application as a recycling option, common issues of concern in New England include nutrient fate and transport (through leaching), human and environmental risk assessment, biomix design and regulatory acceptance. Teaching material was developed for the study of each of these topic areas in upper-class courses. Assigned student work was designed to be performed in groups. Successful completion of the assignments required independent literature research using technical resources accessed through government and biosolid association web-sites. Problem statements were open-ended. Solutions required the use of fundamental environmental engineering principles acquired in previous coursework.

A summary of topic areas addressed in teaching material described in this paper is given in Table 1. The second column lists suitable courses for the topic areas listed. The bold-face course is the course where the lab, lecture or project was used in the environmental engineering curriculum at Wentworth Institute of Technology. Copies of assignment summaries for the first three topic areas are attached to this paper.

Fate and Transport. Trace levels of organic chemicals are often found in biosolids. In many cases, the source of these chemicals (natural and/or anthropogenic) is unclear. For example, while acetone is commonly found in wastewater influent streams from industrial and municipal discharges, it is also produced by aerobic bacteria. The presence of acetone raises concerns of potential exposures to human and environmental receptors potentially impacted by land applied biosolids. Students investigated source mechanisms for common organic chemicals found in biosolids and assessed the fate and mobility potentials in land applied settings.

Risk Assessment. Residual levels of trace elements and chemicals in biosolids pose a concern to environmental and human potential receptors. Students developed toxicity profiles for assigned trace constituents often found in biosolids and assessed the risks posed based on toxicity databases including IRIS and HEAST.

Design. For their major design experience, a group of students is working with New England Organics to design a topsoil mixture for the Quarry Hills Golf Course in Milton, MA. This land reclamation project has been given strict regulatory limits for nitrate loading to local receiving water bodies. The group is designing a topsoil mix using biosolid material from the Massachusetts Water Resources Authortity and recycled Short Paper Fiber (SPF) from a local paper mill.

Environmental Laws, Regulations and Policies. Regulatory perspectives have been introduced to students through student attendance at regional professional meetings. Regulatory and industry experts introduce students to the general issues, practices and future trends of biosolids management. This has been coordinated with regional professional organizations (New England Water Environment Association (NEWEA) and New England Biosolids Reuse Association (NEBRA)).

Table 1
Integration of Biosolids in an Environmental Engineering Curriculum

Topic Area	Applicable Course	Learning Tasks
Contaminant Fate and Transport	**Environmental Impact and Protection** Environmental Chemistry	Students perform a literature-based research laboratory to determine natural and/or anthropogenic source(s) of organic compounds (such as 4 -methyl phenol, acetone and methyl ethyl ketone) found in trace levels in New England biosolids (attachment 1).
Risk Assessment	**Environmental Risk Assessment** Environmental Toxicology	Students use IRIS, HEAST and other available toxicological databases and resources to develop a toxicity profile for chemical constituents found in biosolids (attachment 2). Students use biosolids composition profiles to develop sampling plan and comprehensive site assessment for a proposed property redevelopment (attachment 3).
Design	**Capstone Design**	For their major design experience, a student group has developed a biosolids/Pulp and Paper Mill residuals mix for a golf course land application in Quincy, MA. The biomix must meet both physical and nutrient and leaching criteria for land application. The design considers mix alternatives, economics, construction specifications and exposure potentials (attachment 4 – selected Student Work).
Laws, Regulations and Policies	**Professional Practice** Environmental Law	Regulatory and Industry experts introduce students to the general issues, practices and future trends of biosolids management. This has been coordinated with regional professional organizations (New England Water Environment Association (NEWEA) and New England Biosolids Reuse Association (NEBRA)).

Industrial and Regulatory Resources

Biosolid topic material for undergraduate environmental engineering curriculum described in this paper was developed with the assistance of NEBRA and NEWEA. These professional organizations have gladly offered their time and expertise to provide their perspectives to biosolids issues. The NEBRA web-site has served as a valuable link to accessing the theory and practice of biosolids and residuals management. Also, this website posts up-to-date information on regional issues and the perspectives of regulators, operators, researchers and public interest groups.

The following Table provides a list of regional biosolids associations as well as national biosolid –related web-sites including the National Biosolids Partnership, the Water Environment Federation and the Environmental Protection Agency. These links provide interpretation of current regional and national biosolid issues as well as access to relevant documents developed by, EPA, EPA's Pathogen Equivalency Committee and the National Research Council. Links to state, county and local biosolids programs may often be made through the regional associations sites.

Table 2
Links to Biosolid Resources

Organization	Website
New England Biosolids and Residuals Association (NEBRA)	www.nebiosolids.org
Mid-Atlantic Biosolids Association (MABA)	Www.mabiosolids.org
Great Lakes By-products Management Association (GLBMA)	www.glbma.org
Northwest Biosolids Management Association (NBMA)	Www.nwbiosolids.org
The National Biosolids Partnership	Www.biosolids.org
New England Water Environment Association (NEWEA)	Www.newea.org
U.S. Environmental Protection Agency	Www.epa.gov/owm
Water Environment Federation	Www.wef.org/biosolids.html
United States Composting Council	Www.compostingcouncil.org
EPA's Biosolids Data Management	Www.biosolidsinfo.com

Acknowledgements

The author wishes to thank Mr. Ned Beecher, NEBRA Director and Dr. Alex Duran, P.E., Regulatory and Technical Affairs Specialist, New England Organics for their assistance in developing biosolids-related student projects and for their time, energy and contributions to Wentworth's Environmental Engineering Program.

BIOGRAPHICAL INFORMATION

JOHN W. DUGGAN, Ph.D., P.E.

Jack Duggan is the Francis A. Sagan Professor of Environmental Engineering at Wentworth Institute of Technology in Boston, MA. He was an environmental engineer for the Massachusetts DEP, Bureau of Waste Site Cleanup. Jack received a B.S. in Chemical Eng. from Clarkson University in 1982, a M.S. in Civil Eng. in 1989 and a Ph.D. in Chemistry from UMASS Lowell in 1994.

Attachment 1

Environmental Impact and Protection
Spring, 2001

Lab #1
Assessing Risks in Land-Applied Biosolids II:
Background vs. Biosolids Levels of Oxygenated Organic Compounds

Summary

This is the second half of a 2-part laboratory on land-applied biosolids. In the first lab, you researched an organic compound and characterized it in terms of its physical and chemical properties in the environment. the occurrence and effect of low levels of certain chemical compounds in New England Biosolids. Working in groups, you researched existing toxicologic information using available on-line databases. Also, you identified relevant regulatory standards that exist for your chemical of concern. Based on your research, you identified the exposure pathways that may exist when biosolids containing your chemical of concern are applied to land.

For Part II, you will compare levels of your contaminant of concern in biosolids to levels found in other environmental media, i.e., soil water, air, food and human and other environmental receptors. The objective here is to evaluate the relative contribution that land-applied biosolids represent environmental systems. This is of critical importance in evaluating the impact(s) of applying biosolids to environmental systems.

Background

As the name implies, biosolids are organic materials that contain biologically active components. Biosolids is a term used to describe these materials which actually are produced from a diverse range of processes, including wastewater treatment, food processing, and farming. The term can be misleading in that a typical biosolid material contains a significant amount of water in its composition.

As you have learned, the contaminants of concern previously studied: acetone, methyl ethyl ketone and 4-methyl phenol are oxygenated organic compounds. Though these chemicals can be traced to anthropogenic sources, your research also indicated that these chemicals are "naturally" produced as intermediate compounds as more complex organic compounds get degraded in the environment. Biosolids act as very good "reactors" to support the microorganism-mediated oxidation-reduction reactions that produce these intermediates.

As you also can appreciate, microorganisms for the most part do not discriminate between biosolids and organic rich media found "naturally" in an environmental system. For this reason, it is expected that the oxygenated contaminants of concern are also produced "naturally". The purpose of this lab is to investigate and evaluate data that may indicate "background" levels of these contaminants of concern.

Procedure

1) With your lab team from Part I,

Locate all exposure points and determine their exposure point concatenations.

2) Conduct a Literature Study

Determine if any literature reviews or summaries regarding the chemical of concern already exist, (i.e., is there already one document that provides all the information you need). If so, reference these documents and summarize their content. The information you need is listed as follows:

a) Levels of your contaminant in environmental media including: soil; water; groundwater, air, food, plants, animals and humans.

b) Any information to explain these levels in these media. Make sure to review the environmental fate and transport resources you used in Part I.

c) Review previously compiled toxicity information: basic toxicity data for human populations and animal/plant species

d) FDA and other regulatory standards and exposure limits for various relevant exposure routes

e) MWRA data on levels in its biosolid products (this information is being delivered to us)

3) Compare and contrast likely exposure pathways between biosolids and natural media for these chemicals of concern.

4) Determine ADDs for each media with documented background levels of your chemical of concern.

5) What is the relative contribution of a biosolid applied in a residential setting that has background levels of your contaminant of concern?

6) Develop a report of your findings (due January 31st or 1 week after receipt of the MWRA data (whichever comes later).

Attachment 2

Risk Assessment
Fall, 2000

Lab #8
Assessing Risks in Land-Applied Biosolids

Summary

For this lab you are asked to research the occurrence and effect of low levels of certain chemical compounds in New England Biosolids. These chemicals, listed below, are of environmental importance for several reasons. Perhaps most importantly, since biosolids are reused in land-applied applications, the presence and effect of these chemicals on human and environmental receptors presents considerable concern. Working in groups, you will perform a literature review of one of these chemicals to identify its relevant physical and chemical properties. You will research existing toxicologic information using available on-line databases. Also, you will identify relevant regulatory standards that exist for your chemical of concern. Based on your research, you will identify the exposure pathways that may exist when biosolids containing your chemical of concern are applied to land.

Background

As the name implies, biosolids are organic materials that contain biologically active components. Biosolids is a term used to describe these materials which actually are produced from a diverse range of processes, including wastewater treatment, food processing, and farming. The term can be misleading in that a typical biosolid material contains a significant amount of water in its composition. Refer to your water/wastewater engineering text to get a better idea of the composition of biosolids generated by a POTW.

For a number of reasons, including the shortage of landfill capacity, the desire to recycle, government regulations, and pure economics, there has been an increasing desire to recycle biosolids via land-applications. This practice isn't new. In fact, farmers have been fertilizing their fields with cow (or other animal) manure for as long as there have been farms. However the practice of land-application (even on farms) is becoming increasingly regulated due to concerns of contamination to not only food products, but also air, soil and water resources. As you will learn during your research, the Clean Water Amendments very much reflect changes in how we manage biosolids due to concerns with non-point source releases of undesirable chemicals into surface water supplies.

Some of the most sensitive issues with land application of biosolids are the presence of pathogens, heavy metals and trace levels of organic chemicals, some of which are considered toxic. For our investigation, you will use your risk assessment research skills to better characterize the issues of risk characterization for trace levels of the organic chemicals of concern identified by the biosolids industry and regulatory bodies.

The chemicals of concern are:

- **4-methyl phenol**
- **acetone**
- **4-chloroaniline**

- **methyl ethyl ketone**
- **bis 2-ethyl hexyl phthalate**

Procedure

1) Choose a partner and choose a chemical to research.

Locate all exposure points and determine their exposure point concatenations.

2) Conduct a Literature Study

Determine if any literature reviews or summaries regarding the chemical of concern already exist, (i.e., is there already one document that provides all the information you need). If so, reference these documents and summarize their content. The information you need is listed as follows:

a) Basic physical/chemical information: synonyms, chemical properties (melting point, boiling point, vapor pressure, water solubility, Kow, etc.

b) Environmental Fate and transport: degradation potential, half-lives in environmental media, transport behavior, toxicity to organisms, bioaccumulation potential, etc.

c) Toxicity information: basic toxicity data for human populations and animal/plant species

d) OSHA and other regulatory standards and exposure limits for various relevant exposure routes

e) Presence in biosolids: Why is the chemical present in the biosolid in the first place, i.e., is it produced by microorganisms present in the biosolid, is at a laboratory artifact, is it from some other process?

3) Identify likely exposure pathways if a biosolid containing your chemical of concern is applied in the following setting:

The chemical is present at a level of 10 ppb (ug/kg). The biosolid is a product of a wastewater treatment operation. It is applied on a fruit orchard as a fertilizer and for soil amendment. The soil at the orchard is slightly acidic under natural conditions. The bedrock at the orchard is limestone. The orchard is located along an inland waterway. The area around the orchard is agricultural.

You should provide a schematic describing the exposure pathways and briefly explain why each pathway is (or isn't) significant). Also, describe who (or what) are the receptors for each pathway.

4) Submit a Report.

The report of your findings is due on the last day of class (Tuesday, December 5th.)

Attachment 3

ENVM 805
Risk Assessment
Fall 2001

Lab #7
Comprehensive Site Assessment

Summary:

Current property owners want to develop a former industrial facility but prospective buyers are concerned about possible contamination that may be present. For this laboratory, a group of engineering professional, ENVM'01, has been hired to determine within a limited budget, if any harmful contaminants exist at an urban park. Also, if any contaminants present pose a significant risk, you will provide some conceptual designs of remediation measures and propose alternative limitation of use strategies that adequately reduce risks to acceptable levels.

The site setting is the Evan's Way Park. The park is being developed into a mixed income housing development (let's assume it's part of a land-swap deal between the city and the developer). Assume that a former dry cleaning operation was apparently located at the Muddy River end of the property (no one really has any plans or records to show this though). Also it should be noted that the parks department routinely used municipal biosolids to fertilize planting beds used throughout the park. You will have to apply the knowledge and skill you have acquired in previous course-work over the past 4+ years at Wentworth (and Coop) to perform the risk assessment. The laboratory will be performed over the two weeks of class with one interim "deliverable". This deliverable is due December 10th. The laboratory will be performed with the class operating as one team, each student assuming specific tasks in the team.

Prospective buyers have identified the following concerns:

1) Is the property developable? How much, if any contamination is on the property?

2) Does contamination, if present, pose a threat to the nearby residents?

3) Is there any contamination in the sewer and/or storm water system from previous operations?

4) Is there anything else out there that the sellers haven't told us about?

Schedule and Deliverables:

Tuesday, November 20, 2001.

Perform a limited site walkover of the facility. Observe and note site features and use this information to develop a site characterization strategy. Based on the limited site information, research dry cleaning operations municipal biosolids and the types of wastes that may be of concern at this facility.

Tuesday, November 27, 2001

Develop a Health and Safety Plan for the site sampling and other tasks ENVM'01 staff will undertake for this assessment. Develop a budget and schedule for these tasks. The budget should include time and billing rates for staff members performing specific tasks. The budget should account for overhead and 10% profit to ENVM'01. (Note: we do not have a Means Cost catalog for equipment, labor and analysis costs. You will have to interact with the Instructor to come up with the budget. Present the schedule and budget in a group meeting.

Thursday, November 29, 2001

Submit the Sampling Plan. "Perform" this sampling. Receive and process sampling results (from Instructor). Start your comprehensive Risk Assessment

Thursday, December 6, 2001

Oral Quiz. Team members will be selected randomly and asked to describe (independently) any aspect of the project. The team gets graded (25% of lab grade) based on individual answers.

Monday, December 10, 2001

Complete and submit your Risk Assessment and Final Report based on sampling results, identified exposure pathways, potential receptors and anticipated future use of the property.

Attachment 4

Student Work:

Draft Leaching Model

Draft Design Specifications

RCMW Engineering
550 Huntington Avenue ♦ Boston, MA 02115

Specifications for Environmental Capstone Design Project

Prepared For:
Professor Jack Duggan
Wentworth Institute of Technology

Prepared by:
Tara A. Cargill
Sara J. Madore
Timothy M. Reilly
Jason T. Wiggin
Fifth Year Environmental Engineering

November 19, 2001

1.0 SPECIFICATIONS

These SPECIFICATIONS provide the guidelines and requirements to be followed for all activities necessary for Biomix APPLICATION. These SPECIFICATIONS are based on, but not limited to the guidelines, requirements and/or standards prescribed in the following:

- Massachusetts Department of Environmental Protection's Beneficial Use Determination guidelines for the Biomix;
- Transportation and handling of Biomix components;
- On-site storage and preparation of Biomix;
- Physical and chemical composition requirements of the Biomix;
- Health and safety guidelines;
- Monitoring and reporting.

Massachusetts Beneficial Use Determination

Biomix applied in the Commonwealth of Massachusetts shall conform to the guidelines and conditions set forth in the Massachusetts Department of Environmental Protection's (MADEP) Beneficial Use Determination (BUD), titled BWP SW 13 – Beneficial Use Determination – Major, "Request for Use of Short Paper Fiber for Use as the Vegetative Support Layer in Landfill Capping Systems." (DeGabriele, Steven A., MADEP, Bureau of Waste Prevention).

Transportation and Handling

Biomix components, including but not limited to short paper fiber (SPF), Bay State Fertilizer Pellets, sand or equivalent mineral component and additional organic components such as compost, shall be handled in accordance with all local, state and federal regulations including all Massachusetts Department of Transportation (MA DOT) provisions. All components shall be handled as to prevent spillage on roadways and during loading and unloading in areas not able to handle such spillage. Components shall not be handled in close proximity to wetlands, surface water bodies or other sensitive environmental receptors without the permission of the MADEP or local conservation commission. All trucks and equipment exposed to Biomix, shall be decontaminated prior to leaving the Site.

On-site Storage and Mixing

Unmixed Biomix components and processed Biomix shall be stored in accordance with all local, state and federal regulations. Best management practices (BMP) shall be employed to prevent adverse impacts to sensitive environmental receptors. Stockpiles of the aforementioned materials shall be covered when not in use. Contingencies shall be planned for preparing Biomix during heavy rain events. It may be appropriate to construct temporary, sheltered mixing stations to prevent saturation of Biomix, which can cause poor handling and application characteristics causing increased runoff. Silt fences and/or hay bales shall be used to prevent sediment loading to adjacent wetlands and surface water bodies. Biomix and/or Biomix components shall not be supplied to the Site in quantities greater than can be handled by specific site conditions and work and storage areas.

In the event that odor associated with Biomix mixing becomes a nuisance, a 'Good neighbor' policy will be practiced, and measures shall be employed to prevent nuisance odors from migrating beyond site boundaries.

Biomix Composition

Prepared Biomix shall provide adequate structural stability to be applied on the side slopes at the Site and shall promote sufficient vegetation growth applicable for golf course appearance and usability. Based on the specific Biomix used on the site, adequate and sufficient mixing shall be conducted to assure that the Biomix will meet its structural and vegetation support requirements. Biomix shall meet all the requirements for vegetative support material contained in 310 CMR 19.112(9) and shall be in accordance with sound agricultural practices and 310 CMR 32.23. (DeGabriele).

Health and Safety

All applicable health and safety guidelines shall be followed during Biomix APPLICATION activities, including but not limited to 29 CFR 1910 – Occupational Safety and Health Standards and part 5. *Personnel Training*, Section IV. General Permit Conditions listed in the BUD, which specifies that any personnel involved in any activity authorized by the permit shall receive on-the-job training, teaching the personnel how to comply with the conditions of the permit and carry out the authorized activity in a manner that is not hazardous to public health, safety, welfare or the environment. (DeGabriele)

Monitoring, Testing and Reporting

Monitoring of the Biomix as a vegetative support layer shall be conducted in conjunction with and in accordance with requirements of any landfill closure permits. Testing and reporting requirements shall be followed pursuant to Section VI. – Material Specific Conditions of the BUD. In accordance with the BUD, the Biomix shall be tested for the following parameters:

-Pathogens	-Dioxins/Furans	-Metals
-PCBs	-pH	-Percent Solids
-Percent Nitrogen	-Percent Ammonia Nitrogen	-Percent Nitrogen Nitrate
-Percent Phosphorous	-Percent Potassium	

Analysis of the Biomix shall be submitted to the Solid Waste Management Section within the MADEPs Northeast Regional Office (NERO) in accordance with the modified closure plan approval. (DeGabriele).

REFERENCES

DeGabriele, Steven A. Massachusetts Department of Environmental Protection (MADEP). Business Compliance Division, Bureau of Waste Prevention. Letter. "BWP SW 13 – Beneficial Use Determination – Major "Request for Use of Short Paper Fiber for Use as the Vegetative Support Layer in Landfill Capping Systems.""

RCMW Engineering
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Nitrate Leaching Model for Environmental Capstone Project

Prepared For:
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Prepared by:
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Timothy M. Reilly
Jason T. Wiggin
Fifth Year Environmental Engineering

November 16, 2001

Calculations

<u>Assumptions:</u>

$k = 1^{st}$ order rate constant

Organic nitrogen goes through a microbial reaction, represented by k which is equal to the first order rate constant, to become nitrate.

$$ORGANIC\ NITROGEN \Rightarrow NO_3^-$$

The concentration of nitrate changes with time.

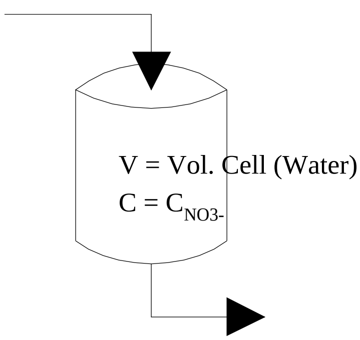
$$1^{st}\ order: \quad \frac{dC_{NO_3^-}}{dt} = kC_{NO_3^-}$$

C = concentration

The k constant changes with temperature. The Arrhenius equation accounts for this change.

$$\frac{\Delta \log k}{\Delta t} = \frac{E_a}{2.303RT^2}$$

E_a = activation energy
R = universal gas constant
T = temperature



The mass balance equation:

$$\frac{dM_{NO_3^-}}{dt} = M_{NO_3^-\ in} - M_{NO_3^-\ out} \pm M_{rxn}$$

$$\frac{[vol.]\left[\frac{mass}{vol.}\right]}{[time]}$$

$$V\frac{dC_{NO_3^-}}{dt} = QC_{NO_3^-\,in} - QC_{NO_3^-\,out} + VkC_{NO_3^-\,out}$$

$$\frac{dC_{NO_3^-}}{dt} = \frac{VkC_{NO_3^-}}{V} - \frac{QC_{NO_3^-}}{V}$$

$$\frac{dC_{NO_3^-}}{dt} = C_{NO_3^-}\left(k - \frac{Q}{V}\right)$$

The following is the derived equation to model the leaching of nitrate from a biomix topsoil.

$$C_{NO_3^-}(t) = e^{\left(k - \frac{Q}{V}\right)t}$$

$$\sum C\,x\,Q = M_{NO_3^-\,TOTAL}$$

$$N_{IN\ SOIL} - M_{NO_3^-} = N_{N\ \mathrm{Re}maining}$$

Biomix Reaction Cells

Cell Number	Volume of Water, L
1	2.53
2	2.14
3	1.91
4	2.53
5	2.74
6	3.55

The K constant to be used for the nitrification process is 2.6 mg N/kg soil per day. (Sumner C-174)
The volumetric flow rate per week is based on 1 in of water per week on the golf course.
Our concern is the length of time it will take for the concentration of nitrate in the cells to equal approximately 0.0 mg N/kg soil.

Cell Number	Time, Days
1	
2	
3	
4	
5	
6	

Total Nitrogen in Cells
Total nitrogen guaranteed in MWRA soil is 4%. This soil makes up 3% of the cell.

$$(0.04)(0.03) = 0.0012$$
$$(0.0012)(10^6) = 1200\,ppm = 1200\,mg/kg$$
$$(1200\,mg/kg)(wt of soil) = total mass N$$