



## **National Manual of Good Practice for Biosolids**

**Last Updated June 2011**

View the Document Control Log for a Summary of Revisions

# *Table of Contents*

## **Introduction**

### *Acknowledgements*

## **1 Public Acceptance**

- 1.1 *Sharing Public Perception*
  - 1.1.1 Environmental Benefits
  - 1.1.2 Community Benefits
- 1.2 *Analyzing Operations*
- 1.3 *Dealing with Odors*
- 1.4 *Developing Effective Communication*
  - 1.4.1 Communication Approaches: Proactive Reactive
  - 1.4.2 Communication Tools
- 1.5 *Environmental Management System Connections*
- 1.6 *Message Development*
  - 1.6.1 Risk Communications
  - 1.6.2 Information Examples with Land Application
  - 1.6.3 Presenting Messages Effectively
  - 1.6.4 Developing Outreach
- 1.7 *Maintaining Support*

## **2 Federal and State Regulations**

- 2.1 *Federal Regulations*
  - 2.1.1 *History and Background*
  - 2.1.2 *Standards for the use or Disposal of Biosolids*
- 2.2 *General Requirements – 40CFR Part 503.12*
  - 2.2.1 *Land Application*
  - 2.2.2 *Surface Disposal*
  - 2.2.3 *Incineration*
- 2.3 *Risk Assessment*
- 2.4 *Biosolids Quality Information*
- 2.5 *Proposed Dioxin Standards*
- 2.6 *State Regulations: Who's In Charge?*
- 2.7 *Local Government Regulations*

## **3 Wastewater Treatment Overview**

- 3.1 *Pretreatment and Pollution Prevention Programs*
- 3.2 *Liquid Stream Impact on Solids Management*
- 3.3 *Solids Generation*
  - 3.3.1 Primary Solids Generation
  - 3.3.2 Secondary Solids Generation
  - 3.3.3 Tertiary Treatment and Solids Generation
  - 3.3.4 Impact of Sidestreams on Solids Generation
  - 3.3.5 Solids Generation for Lagoon Systems

- 3.4 *Septage Handling at a Wastewater Treatment Facility*
  - 3.4.1 Characteristics of Septage
  - 3.4.2 Incorporation with the Liquid Stream
  - 3.4.3 Septage Treatment and the Solids Process Stream

#### **4 Solids Stabilization Systems**

- 4.1 *Stabilization Considerations*
- 4.2 *Anaerobic Digestion Systems*
  - 4.2.1 Critical Control Points / Operational Controls
- 4.3 *Aerobic Digestion Systems*
  - 4.3.1 Critical Control Points / Operational Controls
  - 4.3.2 Process Variations
- 4.4 *Alkaline Treatment Systems*
  - 4.4.1 Critical Control Points / Operational Controls
- 4.5 *Composting Systems*
  - 4.5.1 Critical Control Points / Operational Controls
- 4.6 *Air Drying Systems*
  - 4.6.1 Two Summer Method
  - 4.6.2 Rapid Drying Method
- 4.7 *Thermal Drying Systems*
  - 4.7.1 Direct Dryer
  - 4.7.2 Dryer Selection
  - 4.7.3 Critical Control Points / Operational Controls

#### **5 Solids Thickening and Dewatering Systems**

- 5.1 *Solids Thickening*
  - 5.1.1 Gravity Thickeners
  - 5.1.2 Gravity Belt Thickeners
  - 5.1.3 Dissolved Air Flotation Thickeners
  - 5.1.4 Rotary Drum Thickeners
  - 5.1.5 Centrifuge Thickeners
- 5.2 *Solids Dewatering*
  - 5.2.1 Belt Filter Press Dewatering
  - 5.2.2 Centrifuge Dewatering
  - 5.2.3 Recessed Chamber Press Dewatering
  - 5.2.4 Vacuum Filtration
  - 5.2.5 Drying Beds

#### **6 Odor Control**

- 6.1 *Odor Controls*
- 6.2 *Ventilation Rates*
- 6.3 *Odor Treatment Technologies Methods*

#### **7 Transportation**

- 7.1 *Critical Control Points / Operational Controls*
- 7.2 *Transport Method*

7.3 *Other Transport Methods*

7.4 *Spill Prevention*

## **8 Agricultural Land Application**

8.1 *Biosolids Characteristics*

8.2 *Land Area Requirements*

8.3 *Site Selection*

8.3.1 Preliminary Evaluation

8.3.2 Soil Properties

8.3.3 Buffer Zones

8.3.4 Conservation Planning

8.3.5 Nutrient Assessment

8.3.6 Access to the Farm

8.3.7 Distance to neighbors

8.4 *Permitting Sites*

8.5 *Field Operations*

8.5.1 Scheduling

8.5.2 Determining Application Rates

8.5.3 Field Operation Checklist

8.6 *Managing Operations*

8.6.1 Biosolids Management Plan

8.6.2 Plan to be a Good Neighbor

8.6.3 Coordinate Operations with the Farmer

8.6.4 Identify Buffer Zones and Restricted Areas

8.6.5 Managing Areas for Staging, Storage or Stockpiling

8.6.6 Site Application Equipment

8.6.7 Equipment Calibration

8.6.8 Recording Field Applications

8.6.9 Scheduling Applications

8.6.10 Housekeeping - Good Neighbor Policies

8.6.11 Site Restrictions and Public Access

8.7 *Monitoring*

8.7.1 Monitoring Frequency

8.7.2 Measuring Biosolids Characteristics

8.7.3 Sample Collection

8.8 *Record Keeping and Reporting*

## **9 Non-Agricultural Uses**

9.1 *Critical Control Points / Operational Controls*

9.1.1 Effects of Organic Matter from Biosolids on Soil Properties

9.2 *Reclamation Sites*

9.2.1 Regulatory Considerations

9.2.2 Environmental Considerations

9.2.3 Design and Operational Considerations

9.2.4 Factors Affecting Success

9.3 *Silviculture (Forestry) Application*

- 9.3.1 Application to Forested Sites
- 9.3.2 Physical Features to be Evaluated
- 9.3.3 Application to Cleared Sites
- 9.3.4 Application to Young Forests
- 9.4 *Other Non-Agricultural Uses of Biosolids*

## **10 Non-Restricted Distribution**

- 10.1 *Critical Control Points / Operational Controls*
- 10.2 *Regulatory Requirements*
- 10.3 *Product Quality*
  - 10.3.1 General Product Quality Issues
  - 10.3.2 Compost Product Quality
  - 10.3.3 Heat Drying/Pelletization Product Quality
  - 10.3.4 Alkaline Stabilization Product Quality
- 10.4 *Wastewater/solids Treatment*
- 10.5 *Meeting Consumer Needs*
- 10.6 *Maintaining Product Outlets*
- 10.7 *Market Development*
  - 10.7.1 Demonstrating Product Potential
  - 10.7.2 Expanding and Maintaining Markets
  - 10.7.3 Exploring Market Options

## **11 Odor Control and Aesthetics in Land Application Programs**

- 11.1 *Liquid Stream Treatment*
  - 11.1.1 Influent Screening
  - 11.1.2 Grinding
  - 11.1.3 Grit Removal
- 11.2 *Biosolid Treatment*
  - 11.2.1 Biological Treatment
  - 11.2.2 Chemical Treatment
- 11.3 *Transportation*
- 11.4 *Storage*
- 11.5 *Buffers*
- 11.6 *Operating Practices*
- 11.7 *Community Relations*

## **12 Storage**

- 12.1 *Critical Control Points / Operational Controls*
- 12.2 *Odor Potential During and as a Result of Storage*
- 12.3 *Volume of Biosolids to Store*
- 12.4 *Solids Content of Biosolids to be Stored*
- 12.5 *Biosolids Stability*
- 12.6 *Recommended Management Practices*

## **13 Biosolids Nutrient Management/Calculating Agronomic Rate of Application**

- 13.1 *Critical Control Points / Operational Controls*

- 13.2 *What is Nutrient Management?*
- 13.3 *Nutrient Management Planning and Biosolids*
- 13.4 *Biosolids and Phosphorus*
- 13.5 *Components of a Biosolids Nutrient Management Plan*
- 13.6 *Fundamental Terms and Concepts*
- 13.7 *Determining Crop Nitrogen Removal*
- 13.8 *Biosolids Plant Available Nitrogen*
- 13.9 *Crop N Contributions from Conventional Fertilizers*
- 13.10 *Crop N Contributions from Previous Legume Crops*
- 13.11 *Crop N Contributions from Manures and Other Amendments*
- 13.12 *Determining the Biosolids Agronomic Rate*
- 13.13 *Step-by-Step Agronomic Rate Calculation*

#### **14 Environmental Considerations**

- 14.1 *Critical Control Points / Critical Control Points*
- 14.2 *Possible Fates of Land-Applied Biosolids Constituents*
- 14.3 *Nutrients in Biosolids-Amended Soils*
  - 14.3.1 *Soil Fertility*
  - 14.3.2 *Nitrogen, Phosphorus, Potassium*
- 14.4 *Trace Elements in Biosolids-Amended Soils*
  - 14.4.1 *Trace Element Transformation Processes*
  - 14.4.2 *Soil-Plant Relationships*

#### **15 Biosolids Incineration Systems**

- 15.1 *Multiple Hearth Furnace*
- 15.2 *Fluidized Bed Incinerator*
- 15.3 *Critical Control Points / Operational Controls*

#### **16 Incineration System Optimization**

- 16.1 *Critical Control Points / Operational Controls*
- 16.2 *General Controls*
  - 16.2.1 *Operator Training*
  - 16.2.2 *Record Keeping and Reporting*
  - 16.2.3 *Feed Characteristics*
  - 16.2.4 *Feed Rate*
- 16.3 *MHF Controls*
  - 16.3.1 *Air Entry Rate*
  - 16.3.2 *Hearth and Breech Temperature*
  - 16.3.3 *Shaft Rotational Speed*
  - 16.3.4 *Control Logic*
- 16.4 *FBI Controls*
  - 16.4.1 *Air Flow*
  - 16.4.2 *Bed Material and Bed Depth*
  - 16.4.3 *Bed and Freeboard Temperature*
  - 16.4.4 *Emergency Controls*
  - 16.4.5 *Troubleshooting*

## **17 Incineration Emissions**

- 17.1 *Regulatory Summary*
  - 17.1.1 Risk-Specific Concentrations for Arsenic, Cadmium, Chromium and Nickel
  - 17.1.2 NAAQS for Lead
  - 17.1.3 Beryllium and Mercury
  - 17.1.4 Total Hydrocarbons and Carbon Monoxide
  - 17.1.5 Proposed Regulatory Changes
- 17.2 *Critical Control Points / Operational Controls*
- 17.3 *Incinerator System Selection and Design*
- 17.4 *Air Pollution Control Device System Optimization*
- 17.5 *Instrumentation Operation and Maintenance*
- 17.6 *Particulate Emission Controls*
  - 17.6.1 Cyclone Separator
  - 17.6.2 Spray Chamber
  - 17.6.3 Venturi/Impingement Tray Scrubber
  - 17.6.4 Venturi Scrubber
  - 17.6.5 Wet Electrostatic Precipitator
- 17.7 *Organics Emission Controls*
  - 17.7.1 Internal Afterburner
  - 17.7.2 Conventional – External Afterburner
  - 17.7.3 Side Flue Afterburner
  - 17.7.4 Side Exit Afterburner
  - 17.7.5 Post Scrubber Afterburner
  - 17.7.6 Regenerative Thermal Oxidizers
  - 17.7.7 Flue Gas Recirculation
- 17.8 *Dispersion Characteristics*
- 17.9 *Stack Exhaust Plumes*
- 17.10 *Record Keeping and Reporting*

## **18 Ash Management**

- 18.1 *Critical Control Points / Operational Controls*
- 18.2 *Quantity of Ash*
- 18.3 *Ash Collection*
  - 18.3.1 Ash Generation and Collection in a MHF
  - 18.3.2 Ash Generation and Collection in a FBI
- 18.4 *Chemical Characteristics of Ash*
- 18.5 *Ash Disposal*
- 18.6 *Beneficial Use of Ash*
  - 18.6.1 Land Application
  - 18.6.2 Structural Additive to Building Materials

## **19 Biosolids Management at Disposal Facilities**

- 19.1 *Critical Control Points / Operational Controls*
- 19.2 *Biosolids Management at Municipal Solid Waste Landfill*

- 19.3 *Biosolids Use in the Production of Cover Material*
- 19.4 *Biosolids Disposal at Dedicated Facilities*
- 19.5 *Biosolids Management Regulations Impacting Surface Disposal and Landfilling*
- 19.6 *Biosolids Solids Concentration*
- 19.7 *Transportation*
- 19.8 *Material Handling*
- 19.9 *On-Site Storage*
- 19.10 *Odor Control*

## **20 Economic Considerations**

- 20.1 *Introduction*
- 20.2 *Components of an Effective Biosolids Program*
- 20.3 *Setting Program Goals*
- 20.4 *Economic Considerations*
- 20.5 *Estimating Solids Production*
- 20.6 *Factors Impacting O&M Costs*
- 20.7 *Establishing Capital Costs*
- 20.8 *Determining Unit Costs (cost per dry ton)*
- 20.9 *Consider All Factors Associated with Alternative Management Methods*
- 20.10 *Program Costs*
- 20.11 *Economic Benefits of Biosolids Recycling*
- 20.12 *Common Sense Suggestions for Cost Effective Biosolids Programs*

## **References**

### Appendices

- Appendix A – Risk Assessment
- Appendix B – State and Regional Contacts
- Appendix C – Soil Characteristics
- Appendix D – Nitrogen Balance Check
- Appendix E – Biosolids Recycling and Soil Conservation
- Appendix F – Critical Control Points



## Document Control Log

<b>Name / Title</b>	<b>Approved By</b>	<b>Approval Date</b>
National Manual of Good Practice for Biosolids	NBP Management Committee	2000

### Revision Log

<b>Revision Number</b>	<b>Description of Revision</b>	<b>Date</b>
00	Original Issue	2000
01	Updated the Introduction and added Appendix F, which lists critical control points throughout the biosolids value chain.	June 2003
02	Updated the Introduction and Appendix F to replace “critical control point categories” with steps in the “biosolids value chain”.	January 2005
03	Updated Introduction and Appendix F to replace EMS with Biosolids Management Program.	June 2011

## Introduction

---

Successful biosolids management programs require careful planning, implementation and operation. These programs encompass the entire wastewater treatment system beginning with collection and pretreatment, through the liquid stream treatment processes, to the use or disposal program. To support these efforts, the National Biosolids Partnership has launched an Environmental Management System (EMS) initiative.

The initiative includes four components:

- A *Code of Good Practice* that defines the goals of the program.
- A series of *Common Elements (EMS Elements)* that agencies will use if they choose to develop an Environmental Management System. The EMS Elements are complemented by a guidance document to assist in the preparation of an EMS.
- A *National Manual of Good Practice for Biosolids* that agencies can use in developing and optimizing biosolids management programs.
- A program of independent third party verification to help agencies maintain and improve their environmental management systems.

This *National Manual of Good Practice for Biosolids* is designed to support agencies in the development of biosolids management programs and environmental management systems. It is not intended to be a stand alone reference document, but rather a guide that:

- Provides a link between all the processes that impact a program;
- Provides recommendations to allow an agency to raise the bar on their biosolids management program;
- Highlights the items that should be addressed during the development of an environmental management system; and
- Provides recommendations to support agencies in obtaining additional information.

The manual is designed to complement the *EMS Elements* developed as part of the EMS initiative. The elements include 17 individual management topics that must be considered in the development of an EMS for biosolids.

These 17 elements are contained in five categories and include:

### **Policy**

1. Documentation of EMS for Biosolids
2. Policy

### **Planning**

3. Critical Control Points
4. Legal and Other Requirements
5. Goals and Objectives
6. Public Participation in Planning

### **Implementation**

7. Roles and Responsibilities
8. Training
9. Communication and Public Outreach
10. Operational Control of Critical Control Points
11. Emergency Preparedness and Response
12. EMS Documentation and Document Control

### **Measurement – Corrective Action**

13. Monitoring and Measurement
14. Nonconformances; Preventive and Corrective Action
15. Periodic Biosolids Program Performance Report
16. Internal EMS Audit

### **Management Review**

17. Periodic Management Review of Performance

The third common element (under Planning) is critical control points. These are at the heart of the *National Manual of Good Practice for Biosolids*.

Critical control points are located throughout the “Biosolids Value Chain”. The biosolids value chain is the sequence of processes from wastewater pretreatment through the biosolids end use or disposal program. Critical control points are those locations, unit processes, events, and activities throughout the biosolids value chain, which must be managed effectively to assure that biosolids management activities meet legal, quality, and public acceptance requirements and do not have undesirable environmental impacts. Examples of critical control points throughout the biosolids value chain are presented as Appendix F of this manual.

The National Manual of Good Practice for Biosolids has been developed to provide guidance for these critical control points. The manual contains recommendations regarding operational controls for the various critical control points that should be considered when establishing or optimizing a unit process or program.

Chapters within the manual include:

- Wastewater Pretreatment and Collection
- Wastewater Treatment and Biosolids Generation
- Stabilization
- Conditioning and Handling
- Transportation
- Storage
- Land Application
- Incineration
- Disposal

Within each chapter are a series of processes. For example, the processes, within the stabilization chapter, include:

- Anaerobic Digestion
- Aerobic Digestion
- Chemical Stabilization
- Composting
- Air Drying
- Thermal Drying

Within each process are a series of critical control points and operational controls. These are the procedures, parameters and activities that an agency should consider in the implementation or optimization of a system. For example, in the anaerobic digestion section, the critical control points and operational controls include:

- Volumetric loading
- Total Solids loading
- Volatile Solids loading
- Digester mixing time
- Digester temperature
- Detention time
- pH, Nutrients
- Volatile Acids/Alkalinity
- Methane gas production

The manual provides guidance for each process throughout the biosolids value chain. The guidance and recommendations contained within the manual are based on available literature and experience. It is not necessary to incorporate every critical control points and operational control in an EMS – only those that apply to local operations and conditions. It is recommended that each be reviewed and considered when developing the standard operating procedures (SOP) associated with an EMS.

Again using the example of anaerobic digestion, it is not necessary to include each of the nine controls in an agency's SOP for stabilization. It is recommended that a number of the controls be used to verify the adequacy of the system for its intended purpose and that appropriate controls be incorporated into an EMS and be monitored, and documented.

The manual can also be used to optimize existing practices. If an agency composts biosolids prior to distribution, it may consider reviewing the chapters relating to regulations, non-restricted distribution, and stabilization. While reviewing the Composting Systems Section within the stabilization chapter, the agency may determine that the total solids content of its dewatered cake should be investigated. This would lead them to the chapter on thickening and dewatering. If odors at either the dewatering or composting facility are an issue, the agency may also decide to review the chapter on odor control.

The manual also contains six chapters that address considerations. These chapters, while not specific to critical control points, provide information that pertain to most, if not all, biosolids management programs. The six chapters are:

- Odor Control

- Public Acceptance
- Federal and State Regulations
- Nutrient Management
- Environmental Considerations
- Economic Considerations

These chapters provide additional guidance for agencies to consider when evaluating alternatives, developing programs and establishing environmental management systems.

As discussed, the EMS initiative includes a program of independent third party verification. Verification is intended to help agencies maintain and improve their environmental management systems. The guidance contained in this manual is not intended to be interpreted as requirements that third party auditors will use. Auditors may ask if the manual was consulted during the planning and the implementation of the agency's EMS.

Auditors also may compare established operating procedures in an EMS with those contained in this manual. Each facility and biosolids management program is unique. Consequently operating procedures also will be unique. Auditors will recognize these differences and take them into account when reviewing systems.

The development of this manual included the review of the other manuals, texts, and research available regarding biosolids management. This manual summarizes the best practices contained in those references and presents them in a single document. References are cited for each chapter. In addition, a complete list of publications reviewed is contained in the reference section, which follows Chapter 20.

## Acknowledgements

---

---

### Project Subcommittee

---

**Research Council Liaison:** David S. Taylor  
Madison Metropolitan Sewerage District

Rufus Chaney, Ph.D.  
U.S. Dept. of Agriculture

Albert L. Page, Ph.D.  
Professor of Soil Science  
University of California

Robert Dominak, P.E.  
Northeast Ohio Regional Sewer District

Robert Brobst, P.E.  
United States Environmental Protection Agency,  
Region VIII

Cecil Lue-Hing, D.Sc., P.E.  
Cecil Lue-Hing & Associates, Inc.

Peter S. Machno, Ph.D.  
EMS Project Manager  
National Biosolids Partnership

Robert O'Dette, P.E., DEE  
Vice President  
Synagro Technologies

---

### Project Advisory Team

---

Herschel Elliott, Ph. D., P.E.  
Penn State University

Lee Jacobs, Ph.D.  
Michigan State University

George O'Connor, Ph.D.  
University of Florida

Layne Baroldi  
Orange County Sanitation District

Michael Scharp  
Parker Agricultural Services

Steve Stark, P.E.  
Metropolitan Council Environmental Services

Sally Brown, Ph.D.  
University of Washington

R. Tim Haug, Ph.D., P.E.  
City of Los Angeles

Steve Welch  
University Area Joint Authority

Allen Baturay, P.E.  
Carlson Associates

James Summer  
State of West Virginia DEP

Jon Ware  
State of Indiana DEP

Kyle Dorsey  
State of Washington

Michael W. Heitz, P.E.  
Metropolitan Sewer District of Greater Cincinnati

Shelagh Connelly  
White Mountain Resource Management, Inc

---

**Manual Preparation**

---

**Principal Investigator:** Mark Lang, P.E.  
Sear-Brown

**Project Team:** Jane Forste, CPAg  
Jane Forste Associates

Nora Goldstein  
JG Press, Inc.

Trudy Johnston  
Material Matters

Robin Brandt, P.E.  
Material Matters

---

**Water Environment Research Foundation**

---

**Foundation Director:** Glenn Reinhardt

**Research Program Director:** Amit Pramanik



## Chapter 1 – Public Acceptance

---

Various barometers may be used to measure whether or not a biosolids program is following good management practices. One is technical, focusing on equipment performance (i.e. the mechanical infrastructure) needed to run a good program. Others revolve around personnel, regulatory compliance, and overall program logistics (i.e. coordinating all program elements). But one of the most critical, and most often overlooked, barometers is public acceptance of the biosolids management program. Building in the infrastructure to gain and maintain public acceptance is just as crucial as having all the screens, dewatering presses, field equipment and other mechanical components necessary to treat wastewater and manage the solids. Too often, however, public acceptance doesn't enter the picture until there is a problem with the biosolids management program.

The goal of this chapter is to foster the “mindset” that public acceptance is an integral component of good biosolids management practices. It is perhaps one of the most important considerations of any biosolids management program, especially if land application is selected as a management method.

At the core of this mindset is putting public acceptance issues and strategies at the same level of importance as other elements of a biosolids management program. This means that throughout the decision-making and design processes, impacts on public acceptance must be addressed.

Typically, the need for public acceptance is most directly associated with beneficial use (land application) programs. Beneficial use programs often put biosolids into the public arena more broadly than incineration or disposal, since the biosolids are used in more diverse geographic areas. However, any biosolids management method must consider issues such as truck traffic and air quality/odors, both of which affect public acceptance. More importantly, addressing public acceptance from day one goes a long way toward building flexibility into a biosolids program because managers have laid the groundwork -- the infrastructure -- for gaining public support.

This chapter is structured around the issues that need to be considered in developing an effective public acceptance strategy. These issues are:

- Shaping public perception
- Analyzing operations
- Dealing with odors
- Developing effective communication
- Environmental management system connection
- Message development
- Maintaining support

### 1.1 Shaping Public Perception

The public's perception of biosolids can make or break any management program, no matter how well it is run. Biosolids managers should take advantage of every avenue and opportunity to have a positive impact on that perception.

The foundation for that effort is a well-run operation, one that has a basic commitment to avoid negative impacts on the community and the environment. A well-run program provides the foundation upon which public support can be built. It gives you the confidence to go out to your community and emphasize the benefits of your program to win public support.

To succeed in community outreach, everyone involved in the biosolids program must understand and believe steadfastly in its benefits, and convey them to the public. Two important categories are environmental and community benefits.

### **1.1.1 Environmental Benefits**

Connecting wastewater treatment (and therefore biosolids) to the goal of clean water is a fundamental message to take to communities (Powell Tate Communications 1993; USEPA 1994). Wastewater treatment is specifically designed to prevent negative environmental and public health impacts, and managing biosolids from that treatment should be understood in the same context. The link with clean water is a significant community benefit that people can relate to. Issues surrounding biosolids management (including potential odor and nuisances) are more readily resolved if communities appreciate why we produce biosolids in the first place.

As part of the clean water message, the public needs to understand the role of industrial pretreatment in the wastewater treatment process. The pretreatment program directly determines biosolids quality and is not well understood by the general public – or sometimes by biosolids managers. Public outreach should include specific information about the requirements and implementation/enforcement of the local pretreatment program. The basic principle of pollution prevention is at the heart of industrial pretreatment. Industry has learned, especially over the past 15 to 20 years, that it makes good business sense to minimize the amount of pollutants that go out of their pipe by recapturing and recycling them within the industrial process. Capital investments in industrial recycling processes provide an excellent return on investment to companies, and have gone a long way to improving biosolids quality. Industrial pretreatment practices and household hazardous waste programs should be showcased as part of the biosolids quality assurance program.

Land application programs should highlight the beneficial impacts that result from biosolids use. For example, biosolids provide nutrients and valuable organic matter to improve soils. They can play a critical role in remediating contaminated or disturbed sites that are eyesores in the community.

### **1.1.2. Community Benefits**

Wastewater treatment and thus biosolids management are a critical component of any economic development effort. Wastewater treatment enables residential and industrial growth. It is important that the public understand that connection, especially if industries are providing jobs to a community.

Biosolids managers also need to have the mindset that a well-run biosolids program can benefit the community just as a solid waste recycling program does. The public has been

educated about the importance of recycling, and most citizens willingly take on the responsibility to participate in programs. Unfortunately, wastewater treatment is usually an out-of-sight, out-of-mind infrastructure, an “assumed” service. Often, the public’s only connection to that service is flushing the toilet and sending the dish or bath water down the drain. Building a positive perception for biosolids requires that a connection be made to this assumed service, that biosolids result from this process and must be managed, just as the trash a household generates must be managed.

Communities located at a distance from the treatment plant also need to be part of a facility's outreach program. Agricultural application, in particular, often operates in different communities at varying distances from the treatment facility and in different political jurisdictions. Outreach efforts should be designed to be flexible enough to work in various settings -- from rural agricultural to rapidly developing suburban areas. Biosolids managers will need to become familiar with these diverse communities, and remain flexible enough to establish rapport with all of them to maintain a successful land application program.

### 1.2 Analyzing Operations

With public acceptance as a core component of wastewater treatment and biosolids management, operators should first analyze the impact of their design and operational decisions on the public. Each decision, in other words, should be evaluated for its nuisance potential and the degree of flexibility that decision provides in terms of ultimate management options. Engineering considerations based only on efficiency and conformity to regulations will seldom meet all the needs of neighbors and the public.

*Operators should first analyze the impact of their design and operational decisions on the public*

Some questions that should be answered in selecting biosolids handling alternatives may include:

- Is there a connection between processing and odor generation at the biosolids management facility?
- What impact will dewatering have on management options?
- In transporting and storing biosolids, what are the possible public impacts resulting from vehicle traffic, spills, odors and vectors?

Another important consideration is developing a recordkeeping and biosolids tracking systems -- not just for regulatory compliance, but for achieving public acceptance as well. Accessible and understandable tracking systems give operators the ability to demonstrate that they know exactly what is going on in their programs. The information contained in project records is a valuable source of data to provide to various segments of the public, both on a regular basis and to address specific concerns as they arise. This linkage in turn builds public confidence, as well as the confidence of local officials and regulators.

Each biosolids management alternative -- landfilling, land application, incineration and surface disposal -- has its own set of process-specific issues that affect public acceptance. Biosolids managers should be prepared to make the appropriate connections described in this chapter to

help create the public acceptance mindset.

### 1.3 Dealing with Odors

Probably no issue in biosolids management is more important than addressing odors. Every biosolids processing and management technique has some odor associated with it. Because current treatment and handling methods cannot eliminate odors, managing operations to minimize odors must be a fundamental consideration for all biosolids programs.

Odors are, in short, one of the biggest red flags when it comes to public acceptance. Since no biosolids management practice is immune from public issues relating to odors (unlike, for example, pathogens, which are primarily connected to land application of biosolids), they are a universal management reality.

For a long time, many wastewater treatment plants and biosolids facilities had the “luxury” of being in relative isolation, away from housing developments and industrial parks. That is no longer true in many places, with neighbors often a stone’s throw away from the operation. Even when the operations are in areas with “compatible” neighbors, e.g., farms or industrial facilities, odors may be linked in the public mind with the biosolids, even if operation isn’t the source.

These realities translate into the need for an effective outreach effort that addresses odor issues and includes budgeting resources for both preventive and corrective actions that may be required. Such corrective actions may be needed within the wastewater treatment plant, the biosolids management program, or both.

While odors primarily fall into the nuisance category in the public’s mind (and nose), they also may raise public health concerns (i.e., if it smells this bad, it must be bad for my health). Discussing the odors related to biosolids management early on, explaining the absence of health effects, showing how an operation deals with odor incidents, and creating avenues of communication (e.g., hotlines, response teams, advisory committees that include neighbors) is key to gaining public understanding and support.

In the case of agricultural application, the transitory nature of biosolids operations and the context of other farming practices can sometimes serve to mitigate public concerns about odor and other potential nuisances. This usually will not be true if the biosolids processing and treatment are inadequate and result in highly odorous material. Another major factor with land application odors is the fact that most such programs operate in communities located at some distance from the treatment plant. Additional discussion of the odor issue in land application is contained in Odor Control in Land Application Programs, Chapter 11 of this manual.

The pathogen and vector attraction reduction (disinfection) processes required by biosolids regulations are designed to reduce (but not eliminate) odor potential. Further odor reduction may be accomplished by decreasing the amount of organic material in the biosolids or by otherwise preventing its decomposition by soil microbes (e. g., adding alkaline material). In most cases, biosolids managers must provide a greater degree of treatment (disinfection) than is required to meet pathogen and vector attraction reduction regulatory standards if they plan to meet the

aesthetic standards needed for acceptance by neighbors and the public.

In the case of land application, odors from decomposition of adequately treated biosolids are generally much less noticeable and persistent than odors from the decomposition of raw organic materials, such as animal manure. Applying biosolids at crop nutrient rates using the management practices required by regulations also reduces odor potential. It should be noted, however, that biosolids odor is qualitatively different from that of other commonly used nutrient materials, and this unfamiliarity must be addressed for people to accept biosolids application.

Unfortunately, meeting regulatory requirements for protecting human health and the environment does not guarantee adequate odor control. This concept is difficult for many biosolids managers to accept, and often even more difficult to address with decision-makers who control funding and want to minimize costs. Persuading those decision-makers to commit the additional resources to address a non-regulatory issue can be challenging.

Having an odor management plan that the regulatory community supports -- with public input -- can enhance public acceptance. The plan identifies odor sources, odor management systems for each source, corrective actions if problems arise, and public communications linkages. This plan can be incorporated in a facility's Environmental Management System, and is a tool that helps facility employees and biosolids managers identify "checkpoints" and practices that will enable them to better address community needs as well as demonstrate their commitment to good practice.

### **1.4 Developing Effective Communication**

Every facility/project needs to have a public acceptance strategy and the resources to carry it out. Staff at the wastewater treatment plant, the biosolids management facility, and use/disposal sites should be involved in the effort outreach (helping to create the public acceptance mindset), which can be divided into Communications Approaches and Communication Tools.

#### **1.4.1 Communication Approaches: Proactive Reactive**

Communication generally falls into one of two categories: proactive and reactive. Proactive strategies focus on building a positive public perception for biosolids, which in turn leads to public acceptance for the program. Reactive methods are often used during difficult or crisis situations.

##### *Practice Strategies*

One of the basic principles of proactive communication is the need to recognize and be sensitive to community questions and concerns. Regardless of the management option being used, the "good neighbor" approach is essential. If some impact is felt from the facility or practice, local citizens will be much more accepting of that impact if they already have a positive relationship with the biosolids practitioner. To establish such rapport, biosolids staff and managers should know and understand their local communities' views and issues. All staff members should be imbued with the concept that they have a real obligation to be aware of and sensitive to the communities they may affect.

To respond to community questions and concerns, biosolids managers should be prepared to address:

- Understanding of wastewater and biosolids treatment processes
- Measures taken to establish and maintain quality control
- Properties of biosolids
- Regulatory requirements
- Nuisance potential
- Protection of public health and the environment
- Local history and experience with biosolids or related issues (e. g., solid waste)

Each facility/project should assess the issues that are likely to be important to their community when developing public outreach. In all cases, this outreach effort needs to be made as early as possible and appropriate communication methods initiated with the various segments of the community's members. Every project should aim to become accepted and credible within every community affected by the project. Such acceptance depends on:

- Establishing local alliances
- Responding to specific concerns
- Providing empathetic staff as contact point(s)
- Providing credible information to community members
- Willingness to listen, not just talk
- Offering open and honest dialogue
- Providing ways for the community to continue to participate in the project

A successful communications approach must reflect an understanding of human nature and motivational factors, especially with regard to actual and perceived risks. Biosolids managers should do more than just present scientific data to address the public's concerns related to risk. Openness and personal credibility play a big part in determining whether the public believes the messages about low risk from biosolids. A respected independent source can be invaluable in establishing credibility. Invest the time to identify and understand these issues before a "crisis" occurs so that facility/operational staff can respond appropriately. Use that understanding to improve program management and public acceptance efforts.

### *Reactive Strategies*

Reactive strategies are necessary because no matter how much groundwork is laid and outreach is done, there will be situations that happen in a crisis mode, as well as ones that cannot be anticipated or predicted. Reactive strategies are much more effective, however, when strong proactive approaches have been developed and carried out, and a trusting relationship established.

Predictable "crises" may include a biosolids transport vehicle turning over on the highway or an odor incident. Biosolids managers can plan approaches to react to these situations. Less predictable crises will need a more general response plan, with the details to be developed according to the specific situation at hand. For example, for any situation

that involves questions about public health, the response team may include a local physician who knows about biosolids and understands possible public health risks and exposure. The key is to have a crisis response plan that can be carried out immediately, and staff people trained to respond to community concerns and the media.

**1.4.2 Communication Tools**

An effective community outreach program must be active, not passive. Opportunities abound to present information to the community, and successful biosolids programs take advantage of these. Presentations to local groups, participation in community events, facility/operations tours, distributing educational information, and media outreach are some ways to develop community awareness and acceptance. In many cases, some type of state or local regulatory requirement also provides an opportunity (through a public meeting or notification process) to interact with the public. Biosolids managers should make every effort to use these opportunities to provide factual information and assure communities that communication links will be maintained.

**Table 1.1 lists suggested components (tools) of a public information program.**

Media contact	news releases and informational materials describing biosolids management practices in general as well as project specifics
Written and Audiovisual Materials	detailed manuals, specific project information, brochures, question-and-answer pamphlets, news reprints and slide presentations (3, 4, 5, 6)
Public Meetings	public information, regulatory, and special interest groups
Tours	at sites and in conjunction with the treatment of wastewater to discharge clean effluent
Regulatory Liaison	to provide regulators with technical and operational information beyond the minimum required for the permitting process; regulators should also be included in non-regulatory meetings, field days, tours and other community outreach programs

All of the components require resources, and biosolids managers must include and be prepared to defend their need for funding such efforts as part of their organization's budget allocations.

Some audience-specific communication tools include:

- Biosolids users: Provide information regarding their type of biosolids management (as written material, videotapes, orally or otherwise as appropriate), and keep them up-to-date as you become aware of issues and questions that may arise and be asked of them by their neighbors, community members, the media or the general public.
- General public: Offer tours, demonstrations and field days. Develop outreach

- programs for schools and public events such as community festivals.
- **Public officials:** Be sure to educate public officials about your biosolids management operation. In times of crisis, you do not want people to whom the public looks for answers to have no knowledge of your program. When not informed, these individuals can be primary sources of misinformation.

Sponsor special tours, demonstrations and field days for public officials. Make sure you give them a brief -- and understandable -- summary of your program's system costs and benefits. Educate officials about biosolids management practices so they are aware of potential impacts that their decisions may have on your program changes in (e.g. zoning status from agricultural to residential).

Develop checklist(s) of officials you need to reach and update it regularly; schedule meetings or other contacts with officials on a predetermined frequency; evaluate effectiveness of these efforts (this can be a component of an Environmental Management System (EMS) -- see discussion below).

Educational materials should be updated as necessary, and reflect specific issues and concerns in the community. Treatment plants that manage biosolids by incineration or disposal will likely need materials focused on a more specific audience (plant neighbors), and may feel less need to work directly with the general public. However, these facilities should maintain some avenues of communication both for general educational purposes (on wastewater treatment) and for specific problems that may arise (e.g. odors or spills). Laying the groundwork for public support also makes it easier should the need arise to manage biosolids -- even if only for the short term -- in a different way. If that alternative involves any kind of approval and/or permitting process that includes the public, it is wise to have established communication channels prior to any operational mishap or public relations crisis.

### **1.5 Environmental Management System Connections**

Public outreach can be improved in several ways by adopting the Environmental Management Systems (EMS) approach, which if selected, should be integrated into the overall effort to improve public understanding and support for a biosolids management program. An EMS, because it is voluntary on the part of biosolids generators, offers a unique opportunity to set forth the commitments made to implement practices that go beyond just meeting regulatory requirements. The "transparency" of the EMS approach is vital to public understanding and support for biosolids programs.

An EMS benefits the public for a number of reasons. First, this approach can "institutionalize" the mindset in program managers and staff, no matter what aspect of the operation they are involved in. These individuals also can work within their organization to include public acceptance efforts as line items in the wastewater treatment plant's budget.

Second, an EMS can help build the public's confidence in the biosolids management program by providing documented systems that demonstrate how performance goals are achieved.



Third, an EMS can be a vehicle for members of the public to have input into the program with regard to their concerns. It can serve as a tool for bringing facility managers, plant neighbors, community organizations and others together to establish realistic and acceptable operational parameters.

Fourth, an EMS sets a level of operational performance for staff and contractors. Creating a mechanism for the public and local officials to have input into performance standards will boost confidence in third party oversight and verification mechanisms as well as understanding and support for regulatory requirements.

Fifth, the formal review component of an EMS provides an excellent opportunity to share information with decision-makers within and outside an organization. It also can be used as the basis for providing information to the media, legislators, local officials, and organizations that are allies of a biosolids program. Information about environmental and other benefits can be incorporated in this information-sharing process.

Lastly, and perhaps most importantly, the independent third party verification included in an EMS offers a tremendous opportunity to insure that someone outside the wastewater treatment/biosolids agency organization itself is carefully "minding the store". If your community and public understand this and are given the opportunity to participate in the EMS process, you will have an exciting and invaluable way to demonstrate to them that their issues and concerns are being addressed in your biosolids program.

Educational resources for community outreach and communication are contained in the references to this chapter and in various state and regional biosolids publications. Additional sources may be found in the references contained in other chapters of this Manual. Information from these references can be used directly or adapted as needed in response to specific community needs.

### **1.6 Message Development**

Biosolids management projects often encounter apprehension and sometimes opposition from the public for a variety of reasons (Forster, D. Lynn 1986; Forste, J.B. and Machno, P.S. 1994). The attitudes that fuel such opposition are now recognized as a significant factor in developing biosolids use programs. Appropriate and effective communication is essential to adequately address concerns relating to biosolids. The benefits of good biosolids management as well as specific environmental, health and agricultural considerations must all be addressed for a biosolids management program to succeed.

The community attitudes that constrain biosolids programs are important considerations to be addressed along with federal, state or local regulations that govern biosolids. Concerns about health risk, nuisances and environmental quality are often coupled with political and attitudinal considerations that are not based on either science or regulation. Much of the information addressing the issues associated with biosolids management has been developed for land application (beneficial use) options. However, the data and methods used to assess risk were applied to disposal and incineration methods as well. Biosolids managers employing these

methods readily can use the communication principles and, with some modification as needed, the messages used to address land application issues discussed in this chapter as part of their public acceptance efforts.

The ways in which biosolids managers can affect the beliefs and opinions of community neighbors depend, to a large degree, on the attitudes that both parties bring to the table. Advocates and opponents alike have preconceived ideas and priorities that must be reconciled. The following discussion on risk communication and the examples provided focus on the attitudes of the parties involved, the methods by which they communicate with one another, and the messages they convey to one another. The communication process is a two-way street, and biosolids managers are negotiating for acceptance as well as providing information.

### **1.6.1 Risk Communications**

To transfer information and be responsive to questions and concerns, biosolids managers must adopt methods (both operational and communications-related) that address the critical components essential to developing positive links to their communities. Biosolids managers often find themselves in a defensive posture due to their reliance on technical and scientific data in their attempts to address public concerns and fears. They are usually more familiar with risk assessment and risk management than with the skills that enable them to communicate effectively about these subjects. Risk communication has become more significant in recent decades as the public became more interested in business and government activities that affected them, and more demanding of their right to know about and participate in those activities. In many instances, the concerned public has influenced risk management decisions that may not have been scientifically sound or in society's best interest. Nevertheless, the reality of public participation in decision-making means that biosolids managers must become more active in risk communication if they want to avoid wasteful decisions that affect their bottom line.

To achieve a positive outcome, biosolids managers must engage in an interactive process with their public and examine some of their management decisions based on input from the public during the communication process.

It is also critically important that facility operations and management practices be sensitive to the issues that are important to local communities. To address these issues, present your management practices and demonstrate their safety when conducted under existing regulations. Frequently, this demonstration involves discussion of the science of risk assessment, particularly the risk assessment process used in developing the 40CFR Part 503 Rule (Part 503 Rule). Refer to Appendix A for additional information on the Part 503 Rule. Critics often focus on what they perceive to be deficiencies in rulemaking -- a criticism that can be leveled at virtually any environmental regulatory program. Policy choices inevitably play a role in establishing environmental regulations, and because of the unprecedented complexity of the Part 503 Rule standards, some individuals may question the conclusions. However, the vast majority of qualified scientific opinion supports the conclusions that are the basis of the Part 503 Rule. Biosolids managers must understand and effectively communicate their confidence in the scientific integrity of biosolids regulations and practices.

Public outreach efforts must also recognize that scientific data and information about risk assessment do not necessarily result in public acceptance, since perceived risk is just as important (or more so) to the concerned individual than actual risk. The perception of risk has repeatedly been shown to be very different from actual or scientifically determined risk. Issues of control, fear of industrial contaminants, lack of familiarity, and inflammatory press can and do shape public perception of risk. While the process and findings of scientific risk assessment should be understood and communicated, do not expect science alone to win over people who have emotional reactions and concerns about biosolids management. However, perceptions about many subjects can and do change in time -- remember when wetlands were just swamps to be drained? Accurate, credible communication efforts that give people an opportunity to be heard and understood can help change their opinions and perceptions.

Public acceptance efforts must include an ongoing method for maintaining the flow of information and keeping communication lines open among all interested parties. Concerns about health, odor, groundwater contamination, decline in property values and other legitimate issues can be anticipated and defused in a well-managed public acceptance program. Biosolids managers must continually set forth the beneficial aspects of their biosolids program.

The messages conveyed by outreach programs must be credible, understandable to each audience, and responsive to their concerns. In the case of biosolids, credibly addressing risks relies on the extensive data compiled by scientists during the last several decades and used to develop the Part 503 Rule. Efforts to communicate with concerned individuals, groups and institutions should include discussion of the quality standards for safe biosolids management, which are based on protective assumptions about the impact of biosolids on the environment, animals, crops, and humans. However, as noted earlier in this chapter, these messages must be presented with an empathetic approach that acknowledges and speaks to the underlying emotional issues, even if these issues appear to have no valid scientific basis. Careful and genuine listening will enable you to discern what people are really saying and thinking, and respond credibly to their concerns. Biosolids managers should understand thoroughly the information they provide in response to citizens' concerns and be prepared to explain this information in as much detail as their audience needs.

### **1.6.2 Information Examples with Land Application**

The most common concerns related to land application of biosolids are water quality; synthetic organic compounds; pathogens, and trace metals. The examples given below provide suggested perspectives that can help to address concerns expressed by communities. The challenge is to present such information in easily understood terms tailored for the specific audience you are addressing while retaining scientific integrity and credibility. Try to avoid oversimplifying, while accurately conveying the basic principles relating to each issue. These examples should be modified to suit specific audiences and must be accompanied by a basic understanding of the scientific issues.

### *Water Quality*

Water quality protection in a land application program addresses the most likely potential source of water pollution from applying biosolids as a nutrient source: the nitrogen contained in the biosolids. Nitrate, the mobile form of nitrogen, is released slowly from organic material such as biosolids and therefore moves with soil water more slowly than does soluble nitrate from chemical fertilizers. For agricultural use, application rates are based on the calculated amount of nitrogen the crop will use, coupled with estimates of the decomposition rate of organic nitrogen contained in biosolids to forms available to crops (mineralization). Nitrogen taken up by crops is not available for leaching to groundwater or surface runoff and the basic agronomic principle of matching as closely as possible biosolids applications to the nitrogen need of the crop assures protection of groundwater.

Biosolids also are managed to prevent undesirable levels of phosphorus buildup in soils. Unlike nitrogen, such levels are not identical with the amounts taken up by crops, since phosphorus becomes less mobile over time through soil reactions. Biosolids are also managed to prevent undesirable levels of phosphorus buildup in soils. Unlike nitrogen, the soil levels at which phosphorus becomes mobile are generally much higher than the amounts needed to feed crops and those environmentally significant levels represent the appropriate limits. In addition, the phosphorus contained in biosolids is generally less soluble (bioavailable) than that contained in animal manures and chemical fertilizers, and thus less likely to cause surface water enrichment.

With respect to most trace metals potentially present in biosolids, water quality is protected by the low mobility of these pollutants in soils. The concern in this case is based on possible transfer to plants, animals and humans, since these components of biosolids remain in the upper layer (plow layer) of the soil.

Applying biosolids can actually help improve water quality. The natural organic matter in biosolids helps bind soil particles to improve soil structure, making it more resistant to erosion. Adding biosolids to soil also increases the soil's ability to retain water. The same characteristics that can improve soil structure also prevent the movement of biosolids applied to the surface (for example, on pastures where biosolids are not incorporated). Analysis of runoff water from pastures has shown that surface-applied biosolids are less likely to pollute than are animal manure or chemical fertilizers.

### *Organic Compounds*

The possible presence of organic compounds is sometimes a public concern when biosolids are applied to land. Based on nationwide United States Environmental Protection Agency (USEPA) surveys of treatment plants, the maximum concentrations of organic pollutants potentially of concern in biosolids are below amounts found to produce a toxic effect when applied to the land. By way of comparison, when contained in biosolids applied at agronomic rates, these compounds will typically be applied in amounts 10 to 100 times lower than the amounts applied at recommended rates for agricultural pesticides. They also would have to be directly ingested to have any potential effect on consumers, since plants do not absorb them to any significant degree.

While not each and every individual organic compound potentially present in biosolids has been extensively tested on agricultural land, information on the behavior of various classes of compounds (i.e., those that are chemically similar and behave in similar ways in the environment) can be used to assess their impacts. This information can be coupled with data on the concentrations of the compounds that are of potential concern through various environmental exposure routes to establish risk. For the compounds potentially of concern in biosolids, independent scientists conducted detailed risk assessment as part of the development of the Part 503 Rule. When evaluated in light of actual concentrations found in biosolids, a negligible level of risk was found.

### *Pathogens*

Risk of disease (like the concern for ingesting organic priority pollutants) is negligible when treated biosolids are applied to land. Processes to reduce pathogens (typically digestion or lime stabilization) are required before any biosolids can be applied to land. These disinfecting processes do not sterilize biosolids. However, disease-causing organisms are reduced to such low levels that they do not present risk of infection or disease, especially when combined with the required crop management practices for land-applied biosolids.

If some pathogens remain in biosolids following the required stabilization processes, they die off in the soil environment, and their movement through soils is very limited. Good management practices in applying biosolids (e. g., setback distances) also serve to prevent runoff of surface water that might contain pathogens.

Not only has there never been a demonstrated instance of human or animal disease resulting from biosolids that are recycled in accordance with regulations, but epidemiological evidence with real people living where biosolids are applied verifies that this practice does not represent a health risk (USEPA 1985).

***Example:** The 14-pathway risk assessment approach contained in the Part 503 Rule includes specific consideration of the plant uptake of metals that could result in either phytotoxicity (damage to the plants themselves) or result in concentrations that would be undesirable in the human food chain. The risk assessment assumes that metal uptake is directly proportional to cumulative application rates of biosolids. This results in a very conservative assessment because field data establish that the relationship is, in fact, nonlinear (that is, uptake plateaus over time as shown in Figure 1.1. Assumed vs. Actual Metal Uptake from Biosolids Amended Soils). Since the actual uptake is lower than the assumed rate used as the basis for regulation, the Part 503 Rule overestimates metal uptake and thus provides a greater degree of protection.*

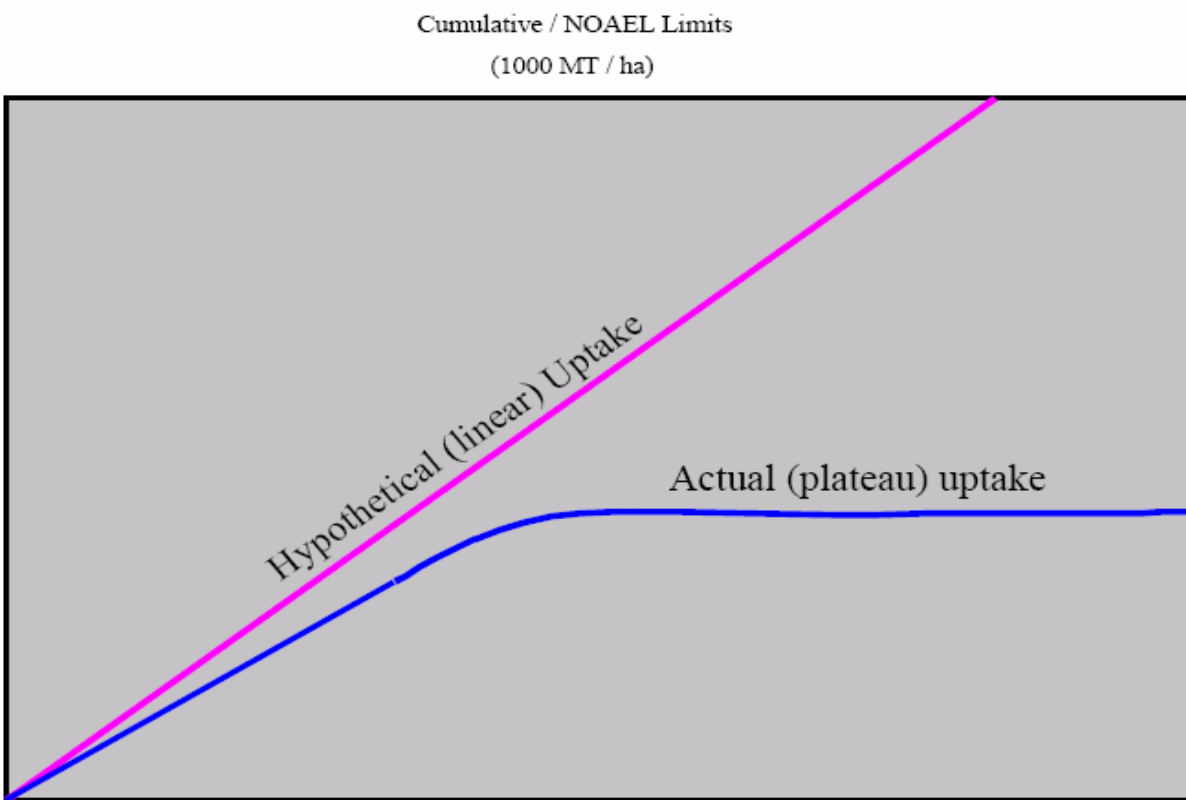
*Using a linear model for plant uptake is one of the many conservative factors built into the risk assessment used to develop metal limits for the Part 503 Rule. Discussion of other risk assessment pathways may be found in Chapter 3 of this manual and in the technical support documents developed for the Part 503 Rule.*

## *Trace Metals*

Perhaps the best known consideration in applying biosolids to land is the management of trace metals contained in biosolids. As mentioned in the discussion on water quality above, these metals are regulated based on well-known behaviors in soils, and to prevent uptake by crops to protect the food chain. Regulatory standards establish the amounts of trace metals that may be applied to soil to allow unrestricted future use of each site. In addition, the amounts of metals in biosolids-treated soils have been established by regulation to protect individuals that might actually consume biosolids from land application sites (by soil adherence to crops or directly).

For the Part 503 Rule, USEPA established management practices and numerical limits (standards) to safeguard public health and the environment by examining the probability of individuals' exposure to pollutants from biosolids. These standards were based on data provided by researchers throughout the United States. The standards also include special populations at greater risks (e.g., small children playing in gardens where biosolids have been applied). Exposure assessment (mathematical) models projected the effect on an individual receiving maximum dose throughout an average life span of 70 years. All the models contain assumptions that are highly conservative (protective).

**Figure 1.1 Plateau Effect**



### 1.6.3 Presenting Messages Effectively

Factual and technical messages should be presented creatively and compellingly if they are to resonate with communities and the general public. Fundamental to this approach is the need to listen carefully and empathetically to questions, concerns and doubts. There are a number of ways to accomplish such listening, but all require an approach that is more people-oriented than the methods typically used in the past.

*Biosolids managers should insure that they and their staff members who are responsible for community outreach have the necessary understanding and skills to deal with people who are uninformed and may have been exposed to negative points of view about biosolids.*

Establishing an atmosphere of mutual respect from the beginning is the most effective way to win people's trust, and requires honesty and sensitivity.

### 1.6.4 Developing Outreach

As biosolids programs are becoming more publicly visible, interest in such programs is intensifying. Public meetings, field days, and media coverage all can help to provide the informational outreach needed to operate a program. These efforts are even more important given the greater likelihood that inaccurate, negative information will reach more people than in the past.

Outreach materials and ongoing efforts to achieve public acceptance should include such messages as environmental benefit, agricultural benefit and the protection of the environment, health and safety embodied in existing practices and regulation. Achieving public acceptance includes outreach efforts to the general public, and specifically developing local community support from the outset. In many cases, such support will only be forthcoming if biosolids programs are managed to go beyond the minimum (i.e., regulatory) requirements. One example of such an approach is to include voluntary water well monitoring as part of a land application program. Not only does this effort serve to reassure farmers and neighbors, the information acquired can be very useful in addressing any future questions and concerns about water quality.

*"Going beyond the minimum" will only succeed if it is based on the need of the community as seen by the community, not just from the biosolids managers' perspective.*

The Environmental Management System (EMS) approach of voluntarily implementing practices that are community-sensitive is especially important for effective outreach. Such practices may include communication as well as operational commitments, and

should be developed individually in response to each community's needs and desires. Two-way communication and effective listening are means by which mutually acceptable goals for biosolids management can be determined. Meeting with citizens' groups and other regular points of contact can be very effective in such communication efforts.

To ensure ongoing and up-to-date scientific information is available for outreach efforts, methods for compiling data and exchanging information on beneficial use issues are

critical. Research in related areas should be evaluated for its relevance to the issues surrounding biosolids management. Efforts to gain new insights and data should be accompanied by a commitment to provide this information to the community and to interested members of the general public.

Some specific areas to address in an outreach program are local concerns; aesthetics – including odors; traffic; storage; and quality assurance.

### *Addressing Local Concerns*

It is critical that everyone involved in biosolids projects be responsive to the underlying concerns many people have, regardless of their scientific validity. They must be particularly sensitive to the impacts of local nuisance factors that may be associated with biosolids (e. g., truck traffic and odors). Even if people's fears and concerns are not based on scientific evidence, they are nonetheless real and must be respected to get at the root of issues that can impede success and address them effectively. The listening and communication skills discussed in this chapter are most important in addressing local concerns.

Regional biosolids organizations that have been formed in several parts of the country can facilitate exchange of information and experiences in various geographic areas, and provide mutual support. By sharing the same concerns, issues, and solutions among biosolids managers, regulators and citizens, a common understanding can replace skepticism and misinformation. The efforts of regional groups offer an opportunity to neutralize and prevent opposition with community-sensitive outreach, credible science, and good operational practices.

### *Addressing Aesthetic, Considerations*

One of the most important factors in a biosolids management program is the prevention of aesthetically unacceptable or nuisance conditions. While these factors may have no environmental or health effects, they are critical to achieving public approval. Truck traffic, dust, and especially odors must be managed and minimized, as discussed in Chapters 8 and 11 of this Manual, and in section 1.3, above, in this Chapter.

It is particularly important that biosolids managers be aware of the complexity of human responses to odorous chemicals. As our control over environmental aspects of biosolids management increases, we are faced more and more with questions about more subtle aspects of environmental exposure to odors. Human responses to various chemical concentrations consist of both physiologic responses (direct, measurable physical or chemical changes) and indirect, cognitive responses (influenced by the brain) that are difficult to quantify. In order to address complaints from workers and/or neighbors, biosolids managers will need to have better understanding of the interaction of direct as well as indirect, induced responses in individuals. Research to address such issues is ongoing (10), and the results should be helpful in responding to public concerns and developing communication methods that can describe odor responses in ways that enable people to modify their perception, and therefore their physiologic reaction to odors associated with biosolids. This approach must of necessity be integrated with the efforts



made to develop technological solutions to controlling odor emissions. This combined approach offers the greatest chance for successfully addressing odor issues in biosolids management.

Biosolids managers must become aware of this variability in human odor responses and develop their odor control programs accordingly.

Since individuals vary greatly in their response -- and even in their ability to detect -- odors it is impossible to establish a one-size-fits-all odor standard. Scientific understanding and better methods for quantifying odors

objectively will help in this effort, but ultimately standards relating to odor will be determined by acceptability to the public.

Increased public sensitivity means that the processing and management techniques for biosolids must be accompanied by the communications skills described in this chapter in order to achieve public understanding of the meaning and significance of odors. Since odor duration is often a significant factor in determining public acceptability, measures such as immediate incorporation or subsurface injection of biosolids can be employed in some cases. Attention to atmospheric conditions such as temperature, humidity, and air inversion patterns may provide a way to schedule operations to minimize odors. Selecting sites for application that are more remote from neighboring homes and businesses also can help to reduce odor impacts. All of these measures, however, must be accompanied by the commitment to processing the biosolids to the degree necessary to address community sensitivity. Although we may not be able to reduce odors to zero, we can improve performance to a point that satisfies our particular public.

### *Traffic Considerations*

Traffic considerations should be addressed during the planning phase of any biosolids operation. The larger the project, the more sensitive this issue can become. Biosolids managers should provide as much flexibility as possible in scheduling truck traffic to avoid prolonged or excessive impact on neighborhoods. Scheduling hours of operations to minimize impacts on the community is important for most projects. Having alternate traffic routes is especially important when using secondary or less -- traveled roads. For many agricultural programs, using traffic control measures (e. g., signs and flags) minimizes the impact of the temporary increase in traffic entering and leaving farm roads. In addition, a brush or water truck can be used to remove soil tracked onto roads at farm entrances.

The bottom line, as with most aesthetic concerns, is the need to be aware of the sensitivities of other people, and to make every effort to accommodate those sensitivities in your operations.

### *Storage Considerations*

More intensive methods may be needed to address the concerns of neighbors and the public around areas where large amount of biosolids remain before being used or disposed. Treatment processes may need to be modified to meet the aesthetic standards

appropriate for biosolids management.

A good example of a processing modification is the need to increase alkaline addition for lime-treated biosolids in order to keep pH elevated to a level (10.5 or higher) that prevents decomposition (and therefore odor) during and after storage periods. Simple laboratory tests can be conducted to determine percentages of liming potential in the biosolids that are linked to minimizing odors and other nuisance potential over time.

***Biosolids managers should be prepared to make the operation and budgetary commitment to adopt process modifications necessary to prevent nuisance potential from storage of biosolids.***

Additional discussion of storage considerations is contained in chapter 6 (Transportation) of this manual and in reference 3 of that chapter.

### *Quality Assurance*

A compliance system is a core component of a successful biosolids management program. This includes:

- Collecting, recording and reporting all required information to demonstrate conformance with permit conditions, regulations and biosolids quality requirements
- Developing procedures and mechanisms (e. g., checklists) to ensure that operations will conform to permit conditions and the additional internal requirements that address community concerns
- Providing information about the quality assurance program to the public in a readily understandable format.

The specific requirements and procedures that maintain quality assurance are described in greater detail in the various operational chapters of this Manual, and are contained in an Environmental Management System. The level of detail and manner of presentation should be developed to meet your specific situation. The important point to remember is that making quality assurance information (including the operation of your pretreatment program) available to the public will go a long way toward demonstrating that their concerns are being met in an organized, documented and credible manner.

## **1.7 Maintaining Support**

Every biosolids management program should develop a support system that is based on the surrounding community and its needs as communicated to the biosolids program manager and staff.

For agricultural programs, the farming community is an obvious first source of public support. Agricultural organizations, individual farmers, and cooperative extension agents can provide strong local support if their concerns and issues are being addressed. Their support is also valuable in developing the understanding and approval of neighbors and local officials. The value of biosolids as a significant resource must be recognized and articulated by farmers or

others who use them for the practice to remain viable.

Appropriate field management that involves coordination with individual farming practices is essential to maintain support for the agricultural use of biosolids. Land applicators should pay careful attention to the timing, methods of application and housekeeping details during operations to insure that they meet agricultural producers' needs as well as the needs of generators. To accomplish this, a highly motivated staff with experience in such disciplines as agriculture, natural resources and environmental science can interact with individual farmers and their organizations/associates. The staff's role in the permitting and monitoring requirements for land application as well as their responsiveness to farmer's needs provide the necessary link between the biosolids generator, field operations and local communities.

The following activities can provide support for agricultural programs:

- Arranging field operational demonstrations
- Sponsoring local programs (e.g., agricultural appreciation days)
- Providing biosolids nutrient information to cooperative extension agents
- Funding research and extension publications
- Presenting information at meetings for the farming community
- Providing participating farmers with the results of soil testing, field application reports, and actual cost savings from biosolids as compared to current fertilizer prices

The activities described above should be modified (as dictated by the local situation) for other methods for using and disposing biosolids. Facilities that process biosolids and projects where the material is applied (such as agricultural operations) require different approaches to achieving local acceptance. In both cases, however, open communication and responsiveness are essential to develop alliances and support.

Detailed discussion of research findings on attitudes, effective messages and elements required for an effective communications plan may be found in Reference (1) of this Chapter.

To expand the base of local support for biosolids projects, it is important to maintain contact with key individuals in the local communities including:

- Administrators and managers
- Elected officials
- State legislative representatives
- Environmental organizations
- Community associations
- Civic groups
- Media representatives

The effort to gain and maintain public acceptance is an integral part of any biosolids management project throughout its lifetime. Needs and concerns differ from project to project, but community acceptance can never be taken for granted. In the face of increased public involvement and demands, more detailed and specific management and operational practices for biosolids are likely to be needed in the future. Biosolids managers will be faced with continuing and significant challenges. Developing the skills to interact successfully with the public is perhaps the greatest of those challenges.

## References

Forste, J.B. and Machno, P.S., (1994), “*Public Acceptance of Biosolids—What’s in a Name?*”, Proceedings from The Management of Water and Wastewater Solids for the 21st Century: A Global Perspective, Water Environment Federation

Forster, D.L. et al, (1986), Institutional Constraints on Residuals Use in Utilization, Treatment and Disposal of Waste on Land

Monell Chemical Senses Center, (March, 2000), “*Volatiles, Health and the Environment*”. Special Colloquium 2000, Philadelphia, PA

United States Environmental Protection Agency, (June, 1994), “*Biosolids Recycling: Beneficial Technology for a Better Environment*”, (USEPA/832-R-94-009)

United States Environmental Protection Agency, (May, 1985), *Ohio Farm Bureau Development Corp. Demonstration of Acceptable Systems for Land Disposal of Sewage Sludge*

United States Environmental Protection Agency, (October, 1983), “*Process Design Manual for Land Application of Municipal Sludge*”, (USEPA/625/1-83-016)

United States Environmental Protection Agency, (September, 1994), “*A Plain English Guide to the USEPA Part 503 Biosolids Rule*”, (USEPA/832/R-93/003)

United States Environmental Protection Agency, (September, 1995), “*A Guide to the Biosolids Risk Assessment for the USEPA Part 503 Rule*”, (USEPA/832-B-93-005)

Water Environment Federation, (1994), Biosolids Recycling: Factsheets, videotapes (by geographic region) and brochure

Water Environment Federation, (July, 1993), *Powell Tate Communications Plan on Biosolids / Research Findings*

## Chapter 2 – Federal and State Regulations

---

### 2.1 Federal Regulations

The major requirements of the 40 CFR Part 503 Rule (Part 503 Rule) are contained in the subheadings of this chapter. Biosolids managers should familiarize themselves with the information under each of these major requirements and develop their programs to address them.

This chapter lists the basic requirements; readers are referred to the appropriate use/disposal chapters of this Manual for more detailed methods and "rules of thumb" for meeting specific requirements.

#### 2.1.1 History and Background

The USEPA has made recommendations for the use and disposal of biosolids for decades -- including two separate rulemakings in 1979 (USEPA 1979) and 1993 (USEPA 1993). The intervening years have seen further development and refinement of the approach currently in force. The Part 503 Rule is a complex, risk-based assessment of potential environmental effects of pollutants that may be present in biosolids (USEPA 1995), coupled with treatment and management practices designed to protect human health from illnesses that could potentially result from untreated and/or mismanaged use or disposal of biosolids. The basic provisions of the Part 503 Rule are presented in this chapter, with references for further details and discussion of these provisions.

The 1979 Interim Final Rule (40 CFR Part 257) governing biosolids was issued under the authority of the Solid Waste Disposal Act as amended by the Resource Conservation and Recovery Act (RCRA) of 1976 as well as Section 405(d) of the Clean Water Act (CWA). This 257 Rule was an interim final regulation that partially fulfilled the requirement of the CWA to provide guidelines for the disposal and utilization of biosolids. Because it was issued as a federal solid waste regulation, the 257 Rule resulted in many states regulating biosolids under their solid waste programs. In fact, this rulemaking stated that facilities that did not meet the criteria of the 257 Rule would be classified as "open dumps". As specified by the CWA, the criteria contained in the 1979 regulation were designed "to avoid a reasonable probability of adverse effects on health or the environment from disposal of sludge on land" (USEPA 1979). The criteria applied only to the placement of biosolids on land. All such practices were required to address environmentally sensitive areas and diseases (pathogen control) in addition to protecting food chain crops from the effects of cadmium and PCBs. The evaluation of lead, pesticides and persistent organics was deferred to future rulemaking because information available to the agency at the time was believed to be inadequate to support specific standards.

Many of the assumptions and the data used to develop the 1979 limits were unnecessarily conservative and/or based on an incomplete understanding of the mechanisms of metal uptake and accumulation in crops. Nevertheless, this rule (along with recommendations for cumulative loading limits developed by the U.S. Department of Agriculture) provided the federal regulatory basis for biosolids land application programs in the United States

for more than a decade. Even as it was published, USEPA and the scientific community identified gaps and limitations in the 257 rule and began efforts to develop a more comprehensive risk-based rule encompassing more of the pollutants of concern.

Under Section 405(d) of the CWA, USEPA identified, based on available information, pollutants that may be present in biosolids in concentrations that might affect public health and/or the environment. Then, for each identified use or disposal method, USEPA specified acceptable numerical limits and management practices for biosolids that contain these pollutants. Following more than 15 years of research and development, USEPA proposed the “Standards for the use or disposal of sewage sludge” (40 CFR Parts 257, 403 and Part 503 Rule) in 1989 and published the Final Rule on Feb. 19, 1993 (2), after extensive comments and detailed peer review (4, 5, 6).

### **2.1.2 Standards for the Use or Disposal of Biosolids**

The 40 CFR Part 503 Rule sets standards for final use or disposal when biosolids are applied to agricultural and non-agricultural land (including products sold or given away), placed in or on surface disposal sites or incinerated. The Part 503 Rule does not specify operating methods or requirements for biosolids entering or leaving any particular treatment process. The Part 503 Rule does include a provision that requires a person disposing of biosolids in Municipal Solid Waste Landfills (MSWLF) or using biosolids as a cover material at MSWLF sites must ensure compliance with 40 CFR Part 258. Treatment works that use an MSWLF to dispose of their biosolids must insure that the material is non-hazardous (as determined by the Toxicity Characteristics Leachate Procedure, or TCLP) and passes the Paint Filter Liquid Test. They may also be subject to other state or local landfill requirements.

The standards contained in the final Part 503 Rule consist of general requirements, pollutant limits, management practices, operational standards and requirements for frequency of monitoring, record keeping and reporting.

The pollutant limits, management practices and other requirements developed for Part 503 Rule were specific to the use or disposal method employed. The use or disposal methods included in the proposed rule were:

- Application to agricultural or non-agricultural land
- Distribution and marketing (referred to in the final Part 503 Rule Regulations as sale or giveaway of biosolids)
- Disposal in on surface disposal sites
- Incineration

The Part 503 Rule Regulations contain five subparts:

***Subpart A:*** General Provisions

***Subpart B:*** Land Application

***Subpart C:*** Surface Disposal

***Subpart D:*** Pathogens and Vector Attraction Reduction

***Subpart E:*** Incineration

### *General Provisions*

The general provisions of the rule establish standards consisting of general requirements, pollutant limits, management practices, operational standards, and monitoring, record keeping and reporting for the final use or disposal of the solids generated by the treatment of domestic biosolids or of domestic septage. The regulations do not cover solids from an industrial biosolids treatment facility or those generated during water treatment.

Biosolids grit and screenings are not subject to the Part 503 Rule regulations as they have completely different characteristics than biosolids and must be disposed in accordance with appropriate requirements (e.g., 40 CFR Part 257 when disposed on the land).

Part 503 Rule is self-implementing, i.e., enforceable even before a specific federal permit is issued. Thus a responsible person must become aware of the Part 503 Rule regulations, comply with them, perform appropriate monitoring and record keeping and, if applicable, report information to the permitting authority even when a permit is not issued. These standards are also directly enforceable against any person who uses or disposes of biosolids through any of the practices addressed in the final regulations. An enforcement action can be taken against a person who does not meet those requirements, regardless of whether a permit has been issued.

Compliance with the regulatory standards has been required for all facilities since January 19, 1995. For detailed discussion of specific biosolids requirements, the reader is referred to Chapter 40 CFR Part 503 Rule (USEPA 1993) and the technical support documents (USEPA 1992) accompanying the final rule.

In the final regulation, USEPA uses the term “land application” in a restrictive sense to delineate clearly between different regulatory requirements. Since biosolids are not only disposed on land, but in many cases also used to condition the soil or provide nutrients, the Part 503 Rule uses the phrase “land application” only when referring to biosolids used for their beneficial properties. When biosolids are disposed of by placing them on the land, the Part 503 Rule refers to this practice as “surface disposal.”

Provisions under the Part 503 Rule also address the compliance period, permits and direct enforceability, relationship to other regulations, more stringent permitting requirements and exclusions.

Many requirements in the regulations apply to the “person who prepares” biosolids -- referring to the person or entity that effectively controls the quality of the biosolids or the material derived there-from that is ultimately either used or disposed. For example, in situations where a treatment works generates biosolids that are blended with other sources of biosolids, the person blending is the one who prepares the biosolids since s/he controls the quality of the material that is ultimately used or disposed. This preparer could be the person who oversees generation of biosolids during the treatment of domestic biosolids or a person who derives a material from biosolids.

## 2.2 General Requirements – 40CFR Part 503.12

Bulk biosolids subject to this section must include the:

- Transfer of sufficient information (Notice and Necessary Information) among the preparer, land applier, landowner and permitting authority
- Tracking of cumulative pollutant loading limits from biosolids that do not meet the concentrations contained in Table 3, § 503.13, (shown in Table 2.1, below)
- Movement of biosolids across state lines

### 2.2.1 Land Application

If the land applier is not the same person who prepared the biosolids, the preparer is responsible for providing documentation to the land applier on the quality of the biosolids before they may be applied to land. This information is provided on a Notice and Necessary Information (NANI) form.

Before land application, the land applier will need to obtain the following (either from the preparer or independently):

- Pollutant concentrations
- Nitrogen concentrations
- Class of pathogen reduction level achieved
- Vector attraction reduction option achieved, if any

The land applier also must provide the landowner/farmer with any information needed to comply with land application requirements (e.g., site restrictions). It is also advisable to provide the landowner/farmer with the biosolids quality information including nitrogen content and the amounts of other nutrients applied to the soil through the biosolids application.

As a practical matter, the permitting process for a land base will entail interaction with the landowner/farmer in obtaining information typically required by state regulatory agencies (e.g., maps, cropping information, soil test results).

#### *Pollutant Limits*

The Part 503 Rule provides two approaches to limiting trace metals: one specifies the amounts of trace metals that are allowed in biosolids; the other limits the cumulative amounts of these metals *added* to soils through biosolids application. Cumulative limits for metals are the amounts that can be added to the preexisting background amounts in soils. The cumulative pollutant loading rates (CPLRs) are based on a risk assessment performed by the USEPA, using data from decades of field research. The assessment evaluated 17 potential pathways and the risk to human, plant and animal life. Fourteen apply to land application on managed or unmanaged land.

The numerical standards for biosolids that are not subject to cumulative soil loading limits are directly related to the loading rates for trace metals through the various exposure assessment pathways. USEPA derived these "Pollutant Concentration" numbers from calculations using the risk -- based cumulative soil loading and applying certain



conservative assumptions. Such biosolids are known as Pollutant Concentration (PC) biosolids (Table 3 of § 503.13). Since Pollutant Concentrations are based on the cumulative loading rates established by the risk assessment calculations and include the same conservative safety factors, they provide the same degree of protection to human health and the environment as do the cumulative pollutant loading rates for soils. Table 2.1 (below) shows the maximum concentrations of metals in biosolids that, if not exceeded, allows the biosolids to be applied without maintaining records of cumulative applications. PC biosolids (with trace element concentrations less than or equal to those contained in Table 2.1) are a high quality material that will require minimal record keeping, depending upon the type of pathogen reduction treatment used.

**Table 2.1 Pollutant Concentration (PC) Biosolids (Table 3 of § 503.13)**

Pollutant	Allowable Concentration (mg/kg monthly average)
Arsenic (As)	41
Cadmium (Cd)	39
Copper (Cu)	1,500
Lead (Pb)	300
Mercury (Hg)	17
Nickel (Ni)	420
Molybdenum (Mo)	To be determined*
Selenium (Se)	100
Zinc (Zn)	2,800

\*As of November, 2000

Table 2.2 shows the maximum allowable concentrations of these metals in any biosolids that are applied to land along with the corresponding cumulative pollutant loading rate (CPLR) for each metal. If any trace element contained within biosolids exceeds the amount shown in column 2 of Table 2.2, the material cannot be land applied. Biosolids with metal concentrations greater than those in Table 2.1 and less than or equal to those in column 2 of Table 2.2 may be applied to the land up to the amounts shown in column 3.

**Table 2.2 Maximum Allowable Metal Concentrations and Loading Rates (Tables 1 & 2 of § 503.13)**

Pollutant	Concentration Mg/kg dry wt.	CPLR Loading	
		Kg/ha	lb/ac
Arsenic (As)	75	41	36.5
Cadmium (Cd)	85	39	35
Copper (Cu)	4,300	1,500	1,339

Pollutant	Concentration Mg/kg dry wt.	CPLR Loading	
		Kg/ha	lb/ac
Lead (Pb)	840	300	267
Mercury (Hg)	57	17	15
Molybdenum (Mo)	75	N/A	
Nickel (Ni)	420	420	375
Selenium (Se)	100	100	89
Zinc (Zn)	7,500	2,800	2,500

As a result of several amendments to the Part 503 Rule, cumulative loading and PC limits for Molybdenum were deleted from the rule pending reevaluation of research data. Chromium was deleted because risk-based limits were extremely high and not relevant to existing biosolids quality. Ceiling limits for Selenium were raised to 100 based on new data, as shown in the tables above. In addition, USEPA clarified that ceiling concentration limits apply to all land -- applied biosolids.

For bulk biosolids subject to CPLRs, the land applier must notify the permitting authority in the state where the biosolids will be applied of his/her intent to apply to a particular site before the initial land application. Such notification must include the location of each land application site and the name, address, telephone number and a National Pollutant Discharge Elimination System (NPDES) permit number (if applicable) of the land applier. In addition, before beginning land application on a site, a land applier must consult the permitting authority to determine whether past applications of biosolids subject to CPLRs have been made after July 20, 1993. If no biosolids subject to CPLRs were applied after that date, the land applier must then begin keeping records of cumulative pollutant loadings for each of the ten regulated metals. Multiple land appliers on a single site must make their application data available to one another and coordinate the tracking of cumulative loadings to ensure that CPLRs are not exceeded. If biosolids subject to CPLRs were applied after July 20, 1993, the land applier is responsible for finding out the amount of each regulated metal that was applied and subtracting those loadings from the allowable limits.

When a land applier determines that bulk biosolids not meeting the Class A pathogen and PC metal concentrations are to be land applied in a state other than where they were generated, the land applier should notify the preparer, who is then responsible for notifying the permitting authority in the state where biosolids are to be applied before initial application to any site. In the case of interstate application of biosolids subject to CPLRs, the land applier as well as the preparer must send prior written notice to the permitting authority in the state where the application of biosolids will occur.

### *Pathogen and Vector Attraction Reduction*

The land application subsection contains operational standards and methods for pathogen and vector attraction reduction. The operational standards set the pathogen requirements for various uses of biosolids. Class A pathogen requirements or Class B pathogen requirements with site restrictions must be met when biosolids are to be applied to agricultural land, forest, public contact sites or reclamation sites. Class A pathogen requirements must be met if the biosolids product is to be applied to lawns or home gardens, or if it will be sold or given away in bags or bulk. This portion of the subsection also specifies which vector attraction reduction requirement must be met for the various uses.

The Part 503 Rule establishes requirements for reducing pathogenic organisms or indicator organisms such as fecal coliforms in biosolids applied to the land. It also includes requirements for destroying or reducing the characteristics of biosolids that might attract birds, insects, rats and other animals (so-called “vectors”). Based on “vector” exposure to the pathogenic organisms potentially present in biosolids and potential spread of disease from these disease vectors to humans, the rule requires measures for reducing the attraction of vectors to biosolids. These vector attraction reduction measures include reduction or destruction of the odor-causing properties of biosolids that lure insects and animals by covering with soil, or injecting/incorporating the biosolids into the soil.

The pathogen reduction requirements (Class A and Class B) are operational standards. All biosolids intended for land application must meet at a minimum, the Class B pathogen reduction requirements.

To be a Class A biosolids, the material must meet one of the following criteria:

- Fecal coliform - a density less than 1,000 Most Probable Number (MPN) per dry gram of total solids; or
- Salmonellae - density of less than 3 MPN per 4 dry grams of total solids.

In addition, the material must meet one of the following requirements:

- Time/Temperature relationships
- Alkaline treatment and subsequent air drying
- Demonstration through testing of enteric virus and helminth ova prior to and after pathogen treatment with documentation that the process operating conditions convert non-class A levels to Class A levels. Ongoing testing for enteric virus and helminth ova is not required as long as the treatment process is then operated in accordance with the parameters that have achieved the Class A status
- Ongoing testing for enteric virus and helminth ova to demonstrate that levels meet Class A criteria
- Process to Further Reduce Pathogens (PFRP) or a PFRP-equivalent process

To be a Class B biosolids, the material must meet one of the following standards:

- Less than 2,000,000 MPN of fecal coliform per gram of total dry solids
- Less than 2,000,000 Colony Forming Units (CFU's) of fecal coliform per gram of

total dry solids.

- A Process to Significantly Reduce Pathogens (PSRP) or PSRP equivalent.

Any biosolids that meet the Class B pathogen reduction requirements and are intended for land application also must comply with the site restrictions included in the land application subsection.

In addition to the pathogen reduction requirements for land application, one of the vector attraction reduction (VAR) requirements shown below in Table 2.3 (below) must be met. Management practices also are required for Class A biosolids if they exceed any of the pollutant concentrations of Table 2.3 in the Part 503 Rule or do not meet one of VAR options 1-8.

**Table 2.3 Vector Attraction Reduction Methods**

<ol style="list-style-type: none"><li>1. Volatile Solids Reduction by a minimum of 38 percent</li><li>2. Volatile Solids Reduction additional testing for anaerobic digestion</li><li>3. Volatile Solids Reduction additional testing for aerobic digestion</li><li>4. Specific Oxygen Uptake Rate (SOUR) equal to or less than 1.5 milligrams of oxygen per hour per gram of dry solids at 20 degrees Celsius (°C)</li><li>5. Aerobic process for a minimum of 14 days at a temperature of greater than 40°C and an average temperature greater than 45°C</li><li>6. pH of 12 or higher by alkaline addition, and the maintenance of at least pH 12 for two hours without addition of more alkaline material; then pH 11.5 or higher for an additional 22 hours</li><li>7. A total solids concentration equal to or greater than 75 percent for a material that does not include unstabilized solids generated in a primary treatment process prior to mixing with other materials</li><li>8. A total solids concentration equal to or greater than 90 percent for a material that contains unstabilized solids generated in a primary treatment process prior to mixing with other materials</li><li>9. Injection of liquid biosolids below the land surface</li><li>10. Incorporation of biosolids that have been surface applied or placed on a surface disposal site within 6 hours after application to or placement on the land</li><li>11. Biosolids placed in an active disposal unit shall be covered with soil or other material at the end of each operating day</li><li>12. The pH of domestic septage shall be raised to 12 or higher by alkaline addition and, without further alkaline addition, remain at 12 or higher for 30 minutes.</li></ol>
---

The twelve VAR options specified in the Part 503 Rule are treatment options (1-8 and 12) and barrier options (9, 10, and 11). Treatment options are undertaken by the biosolids preparer, and in such a case, the land applier has no requirements relative to vector attraction reduction once he has been notified by the preparer that this requirement has been met. If such a treatment option is not performed by the preparer, the land applier must implement and certify compliance with one of the barrier options of injection below the soil surface or incorporation into the soil (Dominak, Robert P. 2000; USEPA 1989) within 6 hours following surface application.

The VAR alternatives a community uses depend on the method in which the biosolids are to be applied. Subsurface injection and incorporation apply only to biosolids that are applied to agricultural land, forest land, public contact or reclamation sites.

Amendments to the Part 503 Rule specified that 1) pH readings must be reported at the standard temperature of 25 degrees Celsius to avoid errors; and 2) fecal coliform densities for Class B can be met at any time after achieving pathogen reduction.

### *Operational Standards*

If biosolids are treated by a Class B process, site restrictions must be imposed to allow time for natural processes to further reduce pathogen levels. Site restrictions for Class B address: 1) public access to the site and 2) crop harvest and grazing of animals at the site.

Public access must be restricted for at least 30 days on all land application sites that receive Class B biosolids; this is usually accomplished by selecting sites on farmland in rural areas, remote lands or fenced areas. If the site is used frequently by the public or the potential for public contact is high, such access must be restricted for one year after Class B biosolids are applied. Such land would include parks, playgrounds and golf courses.

Besides public access, other site restrictions also may apply depending on the use of the site. If food crops are grown, certain waiting periods must be observed prior to harvest and waiting periods must be observed on sites where feed and fiber crops, as well as turf, are grown and where animals are grazed. Table 2.4 summarizes the site restrictions associated with application of Class B biosolids in order to achieve the same level of protection to public health and the environment as is provided by Class A biosolids treatment.

**Table 2.4 Site Restrictions for Class B Biosolids Application**

- Public access to land with a high potential for public exposure is restricted for one year after biosolids application
- Public access to land with a low potential for public exposure is restricted for 30 days after biosolids application
- Food crops, feed crops or fiber crops are not harvested for 30 days after biosolids application
- Food crops with harvested parts that touch the biosolids/soil mixture and are totally above the land surface (e.g., melons, cucumbers) are not harvested for 14 months after application of biosolids
- Food crops with harvested parts below the surface of the land (e.g., root crops such as potatoes, carrots, radishes) are not harvested for 20 months after application when the biosolids are not incorporated into the soil or remain on the soil surface for four or more months prior to incorporation into the soil
- Food crops with harvested parts below the surface of the land are not harvested for 38 months if the biosolids are incorporated into the soil less than four months after biosolids application
- Animals are not grazed on a site for 30 days after biosolids application\*
- Turf shall not be harvested for one year after biosolids application if it is placed on land with high potential for public exposure or on a lawn unless otherwise specified by the permitting authority.

\* In 1999, amendments to the Part 503 Rule clarified that the Class B grazing restriction applies to intentional grazing of domestic animals, not inadvertent grazing of wildlife.

The site restrictions to control public access or crop harvest and grazing animals must be implemented by either the land applier or the landowner/farmer. At a minimum, the land applier must provide the landowners/farmers with a list of these restrictions and inform them that they must be met for each site where Class B biosolids are applied. If the land applier intends to implement the restrictions, they must certify that they have been met and maintain this certification in their records for a five-year period. If it is agreed that the landowners/farmers will implement the appropriate restrictions, the land applier must provide them with a list of the restrictions and certify that they were appropriately informed.

#### *Management Practices*

The land application subsection also includes a number of management practices required for the land application of biosolids and the distribution of biosolids-derived products in bags or in bulk.

Biosolids may not be applied within 10 meters of waters of the U.S., and certain site restrictions may apply, depending on the level of treatment to reduce pathogens and the intended use of the land.

Management practices applicable to the land application of biosolids address the following:

- Threatened or endangered species
- Flooded, frozen or snow-covered land
- Distance to waters of the United States
- Agronomic rates

*Threatened or Endangered Species:* Bulk biosolids subject to the management practices of the Part 503 Rule may not be applied to the land if an adverse effect on threatened or endangered species or their designated critical habitat is likely to occur. An “adverse effect” includes any direct or indirect action that reduces the likelihood that a threatened or endangered species will survive or recover from an impact. The critical habitat is any location where a threatened or endangered species may live or grow during its life cycle. Threatened or endangered species are listed in 50 CFR 17.11 and 17.12, published by the U.S. Department of Interior, Fish and Wildlife Service (FWS).

The normal tillage, cropping and grazing practices, mining, forestry and other activities that involve turning the soil and impacting vegetation are not likely to cause any adverse impact on endangered species and may be beneficial because of the enhanced nutrient status and soil building which the application of biosolids imparts. Therefore, the application of biosolids to land would not normally be considered to have an adverse impact on threatened or endangered species or their habitat. If there is some specific reason to believe otherwise, a land applier should evaluate whether any threatened or endangered species or habitats at the site could potentially suffer a negative impact.

*Flooded, Frozen or Snow-Covered Land:* While bulk biosolids may be applied to flooded, frozen or snow-covered lands, this practice must not result in bulk biosolids entering wetlands or other waters of the United States unless specifically authorized by a permit under Sections 402 or 404 of the Clean Water Act. By insuring that proper runoff prevention and/or control measures exist to prevent biosolids from entering the waters of the U.S., the land applier is allowed to apply biosolids to flooded, frozen or snow-covered areas. Many state programs include such measures as slope restrictions, buffer zones, tillage requirements, crop residue or other means of insuring that biosolids will not migrate to wetlands or waters of the U.S. The land applier should be familiar with the details of such requirements and, in some cases, seasonal restrictions that relate to this requirement.

*Distance to Waters of the United States:* Bulk biosolids may not be applied to agricultural land, forest or reclamation sites within 10 meters (approximately 33 feet) of any waters of the U.S. unless otherwise specified by the permitting authority. The permitting authority (USEPA or a delegated state) may give approval for application within 10 meters of waters of the U.S. for site-specific conditions or to enhance the local environment.

Revegetating a stream bank suffering from severe erosion is an example of the situation where the permitting authority could reduce or eliminate this requirement. Additional management practices are sometimes required by states to minimize runoff and ponding

of biosolids. These management practices would be specific to a particular situation and land appliers should familiarize themselves with state and regional requirements that relate to this issue.

*Agronomic Rate:* Biosolids must be applied at a rate equal to or less than the agronomic rate unless otherwise specified by the permitting authority. The agronomic rate is the dry weight application designed to provide the amount of nitrogen needed by the crop or vegetation while minimizing the amount of nitrogen that passes below the root zone to groundwater. For reclamation sites, the permitting authority (USEPA region or a state that has been delegated authority to administer the Part 503 Rule) may specifically authorize application of biosolids above the agronomic rate. Such an application usually occurs only once to improve the soil physical properties and supply sufficient nitrogen, organic matter and other nutrients to establish vegetation. Land appliers should obtain approval for such an application rate from the permitting authority.

For non-PC (Table 3 -- Non-Pollutant Concentration) biosolids sold or given away in a bag or other container, the only management practice required is the provision of a label or information sheet indicating the appropriate annual application rate specified in Table 2.4 of 503.13. The applier is then required to read and correctly follow these instructions.

*Monitoring, Record Keeping and Reporting* The record keeping and reporting requirements of the Part 503 Rule are mandated throughout the United States; other individual permitting requirements may vary from state to state. Federal and state regulations and guidance documents should be consulted to develop a system to comply fully with all applicable requirements. For land application under the Part 503 Rule, the number and stringency of requirements depends upon the quality of the biosolids and circumstances under which they are being applied. Land appliers are those who apply biosolids as a soil conditioner and/or to fertilize crops or vegetation grown in the soil.

Under the Part 503 Rule, this term includes those applying large quantities of bulk biosolids to agricultural land as well as those applying smaller quantities which may be distributed in bags for use on a lawn or home garden. The definition of “land applier” is therefore very broad and not all land appliers are required to comply with the same provisions of the Part 503 Rule.

The preparer of biosolids must monitor their quality and supply the land applier with biosolids quality information, It is the responsibility of the land applier to obtain information from the preparer. The land applier also could conduct independent verification by additional testing on the pollutant concentrations in bulk biosolids. USEPA -- approved procedures contained in the Part 503 Rule must be used to test biosolids. The following references provide detailed guidance on the collection and analysis of biosolids samples:

- *POTW Sewage Sludge Sampling and Analysis Guidance Document* (USEPA 1989, and updates)
- *Standard Methods for the Examination of Water and Wastewater*, 20<sup>th</sup> Edition (APHA, 1998)
- *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*, USEPA



Publication SW-846 (USEPA, 1986)

- *Environmental Regulations and Technology: Control of Pathogens and Vector Attraction in Sewage Sludge*. USEPA Pub. No. 625/R-92/013, Center for Environmental Research Information, Cincinnati, OH 45268. Rev. 1999.

The preparer may, by contractual arrangement, designate the land applier as the party responsible for sampling and/or testing the preparer's biosolids. In that case, the land applier also will need to keep records documenting those results and provide them to the preparer.

All preparers must keep records on biosolids quality regardless of what that quality is. Land appliers are only required to keep records biosolids quality if they change its original quality and, therefore, meet USEPA's definition of a preparer.

The requirements for biosolids quality are usually the responsibility of the person who prepares the biosolids, not the land applier. However, such quality plays a significant role in determining land application requirements and is relevant to the discussion of the compliance requirements for land appliers. Biosolids meeting the most stringent limits for pollutant concentrations, pathogen and vector attraction reduction are considered comparable to commercial fertilizer products and therefore are not subject to any additional requirements for compliance under the Part 503 Rule. Additional requirements are imposed on biosolids that do not meet one or more of the preceding requirements to ensure the same level of protection for human health and the environment is met in all cases.

If the applier changes the quality of the biosolids prior to application, such a change may also influence the number of requirements with which they must comply. Monitoring data which establishes and certifies biosolids quality is provided by the person who prepares the biosolids (often the generator), who is then responsible for meeting the preparation requirements before the biosolids can be land applied. If the land applier then alters the quality in the biosolids received from the preparer, the land applier becomes a preparer and assumes responsibility for monitoring and certifying biosolids quality with respect to pollutant limits, level of pathogen reduction and level of vector attraction reduction.

If the biosolids have met the three criteria referred to above and are then mixed with other substances not subject to the Part 503 Rule (e.g., fertilizer materials, bulking agents), the person performing that mixing operation is not required to reevaluate the product's final quality. In other instances, however, where biosolids quality is considered to have been changed (for example when bulk biosolids from several sources that do not meet the above three criteria are mixed prior to land application or when a source that does meet these three requirements is mixed with a source that does not), the resulting quality of the mixtures must be determined in order to correctly land apply.

The frequency of monitoring, record keeping and reporting requirements in the Part 503 Rule depends on the quantity of biosolids used or disposed by a treatment facility. The pollutants for which a treatment facility must monitor their biosolids depend on the use or

disposal method employed; record keeping and reporting requirements also are specific to each use or disposal method.

The frequency of monitoring required in the land application subsection is presented in Table 2.5. Record keeping requirements for the various scenarios also are contained in this subsection. The level of record keeping varies depending upon the characteristics of the material and the degree of pathogen reduction.

**Table 2.5: Monitoring Frequency Required**

Amount of Biosolids Produced per 365 Day Period*		Frequency of Monitoring
Dry Metric tons	Dry English tons	
0 to 290	0 to 320	Once per year
290 to 1,500	320 to 1,654	Once per quarter (four times per year)
1,500 to 15,000	1,654 to 16,540	Once per 60 days (six times per year)
greater than or equal to 15,000	greater than or equal to 16,540	Once per month (twelve times per year)

\*Either the amount of bulk biosolids applied to the land or the amount of biosolids received by a person who prepares biosolids that are sold or given away in a bag or other container for application to the land.

More detailed information regarding monitoring requirements may be found in reference (2) of this section.

Amendments to the Part 503 Rule adopted in 1999 allow the permitting authority to reduce the monitoring frequency (to no less than annually) after at least two years of monitoring biosolids quality. The certification requirements for preparers and land appliers contained in the Part 503 Rule also were modified to require the record keeper to certify that the information verifying compliance has been collected properly.

*Septage Management*

Finally, the land application subpart addresses the application of domestic septage (8). Septage can be managed separately or as biosolids. If handled as septage, the material must be raised to a pH of 12 or greater for 30 minutes. It must be land applied at a hydraulic loading rate determined by crop nitrogen requirements and a conversion factor provided within the regulation. If the material is to be managed in another manner, it will be regulated as biosolids.

**2.2.2 Surface Disposal**

The surface disposal subpart applies to the placement of biosolids in a disposal unit.

These disposal units include biosolids -- only monofills, dedicated disposal surface application sites, on-site disposal at a biosolids treatment facility and impoundments or lagoons. This subpart does not regulate the storage of biosolids, including solids that accumulate in a biosolids treatment lagoon. Such a lagoon is considered a storage facility, not a disposal unit. The regulation allows biosolids to be stored for up to two years prior to having to meet the requirements of the surface disposal subpart.

The subpart for unlined disposal sites requires the following pollutant concentrations:

- Arsenic -- 73 mg/kg
- Chromium -- 600 mg/kg
- Nickel -- 420 mg/kg

These concentration limits vary depending upon the distance of the disposal site from the property line. In addition, the regulation requires that the site be monitored to ensure that the groundwater is not contaminated by nitrate breakthrough. Material placed in the surface disposal area must meet either Class A or Class B pathogen reduction requirements or be covered daily. One of the VAR requirements 1 through 11 also is required for surface disposal.

### 2.2.3 Incineration

Prior to promulgation of the Part 503 Rule, biosolids incinerators were subject to federal emission standards for particulate matter and mercury. The particulate standards differed based on whether the facilities were constructed or modified before or after June 11, 1973. Biosolids incinerator owners/operators were allowed one or two years from promulgation of the Part 503 Rule (February 1993) to achieve compliance.

The Part 503 Rule establishes current (October 2000) requirements for biosolids incinerators. It includes emission limits, operational standards, management practices, and monitoring and record keeping requirements for biosolids incinerators. The Part 503 Rule pertains to the feed system, the incinerator itself and the exhaust gases from the stack (USEPA 1992). It does not apply to hazardous waste incinerators or to incinerators that co-fire biosolids with other wastes. The USEPA does not consider up to 30 percent municipal solid waste “auxiliary fuel” as “other waste”.

The Part 503 Rule required site-specific emission limits for five metals: arsenic, cadmium, chromium, lead and nickel, facilities that incinerated biosolids had to conduct performance tests to determine the percentage of the five regulated metals contained in their feed solids that are emitted to the atmosphere. Using these data, along with air dispersion modeling and formulas established by USEPA, site-specific metal limits for each POTW that incinerates biosolids were developed.

The monitoring frequency for facilities that incinerate biosolids is based on the quantity processed annually.

Additional emission limits for incinerators under the Part 503 Rule are:

1. A beryllium limit of 10 grams per 24 hours (NESHAPS); and

2. A Total Hydrocarbon (THC) limit of 100 PPM, as propane, corrected to 7% oxygen and 0 % moisture, on the basis of a monthly average. (The THC measurement serves as a surrogate for potentially toxic organic compounds.)

Since 1994, USEPA has allowed owners/operators of biosolids incinerators the option of complying either with this THC limit or a more stringent carbon monoxide (CO) limit of 100 PPM with the same corrections applied.

To comply with the Part 503 Rule, owners/operators identified a need to find ways to reduce biosolids incinerator emissions. Testing established the following:

1. Lowering temperatures within an incinerator's burning zone reduced emissions of the regulated metals
2. Increasing incinerator exhaust gas temperatures decreased THC and particulate emissions
3. Installing internal or external afterburners also can decrease THC and particulate emissions
4. Lowering the levels of regulated metals in the feed solids will reduce emissions (this can be accomplished through the POTW's pretreatment program).

Current (2000) emissions from U.S. biosolids incinerators are typically well below federal regulatory limits (Dominak, Robert P. 2000).

### 2.3 Risk Assessment

In preparing the Part 503 Rule, USEPA used “reasonable worst-case assumptions.” Each of these has a margin of safety associated with it, depending on the accuracy of data and information supporting it. For example, if EPA had insufficient data from biosolids/field studies on metals uptake in crops (the most accurate data), they used data from biosolids/pot studies or salt/pot studies. Data from salt/pot studies are not representative of conditions in the field, and such studies drastically overestimated actual field results.

The risk assessment establishes concentrations and loading rates for 10 elements found within biosolids. The risk assessment was not restricted to these ten elements, however. In March 1984, USEPA developed a list of 200 pollutants to be considered. The pollutants were drawn from the Clean Water Act Toxic Pollutant List. By May 1984, the USEPA, working with a group of scientists, reduced the number to 50 pollutants for further study. In 1985, USEPA's Science Advisory Board approved the general risk assessment methodology, including the algorithms, exposure routes and functions. Between 1985 and 1992, additional review and data gathering resulted in the final list of organic and inorganic materials to be regulated by the Part 503 Rule.

For land application, 14 organic and 10 inorganic materials were evaluated. Following the risk assessment, the resulting concentrations for the organics evaluated were compared to those found in biosolids. The concentrations in biosolids were generally orders of magnitude below those determined allowable through the risk assessment. For this reason, organics were not included in the final Part 503 Rule. For surface disposal, 10 organics and six inorganics were evaluated, and for incineration, 78 organics are regulated under the total hydrocarbon, along with seven

inorganics.

In the final Part 503 Rule regulations (USEPA 1993; USEPA 1995), USEPA evaluated the risk to highly exposed individuals and populations from pollutants found in biosolids using different exposure assessment pathways. In evaluating the standards for the final Part 503 Rule, the Agency established criteria based not only on cancer risk but also on a series of other health and environmental effects. These included the overall incidence of other serious health effects within the exposed population as a whole (including average exposed and highly exposed individuals and within special subpopulations, such as children). USEPA also evaluated effects on plants and animals, estimated uncertainties and margins of safety, considered the scientific evidence for human health and environmental effects, and other quantified or unquantified health and environmental effects associated with use and disposal of biosolids before selecting the final standards.

The Part 503 Rule was unique not only with respect to the complexity of the task at hand, but the extensive review and input that was received by the Agency on the technical standards. Experts from both inside and outside USEPA reviewed the scientific literature and provided additional data and scientific and technical input which enabled the Agency to expand and refine the standards during the time following the comment period and before promulgation of the final standard. Reviewers included the USEPA Science Advisory Board, the Cooperative State Research Service, the Regional Research Technical Committee (the W-170 Committee), representatives of academia and other scientific/technical entities with specific experience in the areas covered by the Part 503 Rule (5,6,7,10).

### *Exposure Pathways*

USEPA evaluated 14 pathways of potential exposure to pollutants in biosolids for the final Part 503 Rule. The Part 503 Rule distinguishes between biosolids applied to the land for a beneficial purpose and biosolids disposed of on the land. Table 2.6 summarizes the pathways.

USEPA evaluated potential exposure when biosolids are used as a fertilizer or soil conditioner in one of two ways: agricultural and non-agricultural land application. Agricultural land application includes use to produce food or feed crops commercially by agricultural producers on pasture and rangeland and also by a home gardener. Non-agricultural land includes forest, reclamation and public contact sites. The descriptive term “surface disposal” in the final Part 503 Rule includes biosolids disposed on land either in piles or in biosolids-only landfills, which also are referred to as monofills. For surface disposal, USEPA evaluated two pathways of exposure. Incineration was evaluated by a single pathway of exposure -- inhalation.

<b>Table 2.6 Pathways</b>
Final exposure Assessment Pathways Evaluated
Land Application (Beneficial Use)
Biosolids-soil-plant-human (Pathway 1)
Biosolids-soil-plant-home gardener (Pathway 2)
Biosolids-soil-child (Pathway 3)*
Biosolids-soil-plant-animal-human (Pathway 4)
Biosolids-soil-animal-human (Pathway 5)
Biosolids-soil-plant-animal toxicity (Pathway 6)
Biosolids-soil-animal toxicity (Pathway 7)
Biosolids-soil-plant toxicity (Pathway 8)**
Biosolids-soil-soil biota toxicity (Pathway 9)
Biosolids-soil-soil biota-predator of soil biota toxicity (Pathway 10)
Biosolids-soil-airborne dust-human (Pathway 11)
Biosolids-soil-surface water-contaminated water-fish toxicity-human toxicity (Pathway 12)
Biosolids-soil-air-human (Pathway 13)
Biosolids-soil-groundwater-human (Pathway 14)
<u>Surface Disposal</u>
Biosolids-soil-air-human (Pathway 13)
Biosolids-soil-groundwater-human (Pathway 14)
<u>Incineration</u>
Biosolids-incineration particulate-air-human (Pathway 13)
<u>Footnotes:</u>
*Most limiting pathway (regulatory limit) for arsenic, cadmium, lead, mercury and selenium.
** Most limiting pathway (regulatory limit) for copper, nickel and zinc.

All of the land application pathways, with the exception of Pathways 3, 5 and 7, anticipate incorporation of biosolids into the top 15 centimeters (6 inches) of soil. Pathways 3, 5 and 7 anticipate biosolids will remain on top of the soil. Because of this, the result of the risk assessment for all pathways other than 3, 5 and 7 are in the form of a loading rate in kilograms per hectare. The results for pathways 3, 5 and 7 are in the form of a concentration in milligrams per kilogram, dry weight.

A review of the pathways shows how they address the impact of biosolids on edible crops, the impact of direct ingestion by humans or grazing animals, phytotoxicity to plant life and the impact on aquatic life, soil biota and soil biota predators. They also address the safety of farmers and the public by evaluating airborne dust along with the impacts on surface and groundwater quality.

A more expanded description of the risk assessment pathways developed for the Part 503 Rule is contained in Appendix A; for more information about the development of the risk assessment in

easy-to-read format, reference 3 of this chapter is particularly recommended.

### 2.4 Biosolids Quality Information

Data on biosolids quality from reports provided to regional USEPA offices may be found at [www.epa.gov/region08/water/wastewater/biohome/biohome.html](http://www.epa.gov/region08/water/wastewater/biohome/biohome.html); the Biosolids Data Management System.

### 2.5 Proposed Dioxin Standards

USEPA proposed revisions to the Part 503 Rule in December 1999, primarily to establish numerical limits for dioxins (chlorinated dibenzo-p-dioxins, or CDDs; chlorinated dibenzofurans or CDFs; and dioxin-like coplanar polychlorinated biphenyls, or PCBs) in biosolids that are land -- applied. The proposed standards were based on a risk assessment performed by USEPA with respect to land application, surface disposal and incineration. The risk to a highly exposed individual was found to be less than one in 1,000,000 for the latter two practices and the Agency decided not to impose numerical standards on either of them.

For land application, USEPA considered 15 exposure pathways (one more than the original Part 503 Rule's pathways), and performed a risk assessment on eight. The assessment yielded two pathways of concern: a rural family member consuming livestock that has incidentally consumed biosolids, and the nursing infant of a highly exposed mother. The limits proposed are established to protect against exposure via these two pathways. Details of the assessments and the proposed standards are contained in the December 23, 1999 Federal Register and comments were received until February 22, 2000. The revisions expected to be finalized in 2001.

The proposed standards vary with the levels of dioxins contained in the biosolids. Biosolids exhibiting a level of dioxins less than 30 PPT (parts per trillion or 0.00003 mg/kg) toxic equivalency units (teqs) -- calculated using relative toxicity factor currently in use in the U.S. would be required to be monitored every 5 years following an initial two-year cycle. Biosolids containing between 30 and 300 PPT (0.0003 mg/kg) TEQs would have to be monitored annually. Biosolids with TEQers over 300 PPT could not be land -- applied under the proposed revision to the Part 503 Rule.

USEPA also proposed monitoring, record keeping and reporting requirements for dioxins in land -- applied biosolids. Small POTWs (<1 mgd), preparers managing less than 290 dry metric tons (319 English tons) per year, and septage would be excluded from the proposed requirements. The standards discussed above are subject to change based on comments received and the outcome of USEPA's broad dioxin reassessment effort currently underway. Biosolids managers should have their material analyzed for dioxins and have the TEQ calculated. They also should keep abreast of the development of the USEPA standards for dioxin limits under the Part 503 Rule, as well as the results of the dioxin reassessment. It is very likely that changes will be made to the currently proposed biosolids regulations with respect to dioxins in biosolids.

### 2.6: State Regulations: Who's In Charge?

The self-implementation element of the Part 503 Rule establishes a regulatory baseline. States' standards, at a minimum, must follow the Part 503 Rule. They can, however, be more restrictive than the Part 503 Rule, e.g., have a lower pollutant limit for a particular metal. The majority of states follow the Part 503 Rule pollutant limits and pathogen and VAR requirements, but many have more detailed requirements regarding management practices.

When USEPA promulgated the Part 503 Rule, it was counting heavily on states to become delegated as the permitting authority. The permitting and enforcement of the technical standards in the Part 503 Rule can be accomplished by a state through a NPDES (National Pollutant Discharge Elimination System) permit and Part 123 state program requirements, or 40 CFR Part 501 State Sludge Management Program regulations. In the absence of delegation of the biosolids program to the states by USEPA, a dual system is common, with NPDES permits containing biosolids requirements, and state programs continuing to issue biosolids permits. Under such a dual approach, permittees have the obligation to monitor and report to both the USEPA Regional office and the state agency. Delegation of the federal program has proceeded slowly; as of this writing, only a handful of states have been delegated to administer some or all of the Part 503 Rule requirements. If the USEPA region is the permitting authority in a non-delegated state, it cannot impose more restrictive requirements than the Part 503 Rule (except on a case-by-case basis, which rarely occurs).

Once a state is delegated, it can run the program through its water quality, solid waste, natural resources or other program, depending on the state's law.

Most, if not all, states require specific management practices that are not contained in the Part 503 Rule, based on each state's regulatory history, and public demand for operational practices. Several states use the term "exceptional quality" biosolids. This term was coined to describe biosolids that do not exceed the pollutant concentration (Table 3) limits, meet Class A pathogen requirements by any of the alternative methods listed and achieve one of the first eight vector attraction reduction options listed in the Part 503 Rule. Biosolids managers should determine the current status of permitting in the state(s) where they intend to operate, and establish internal systems to obtain and conform to specific state and federal requirements.

Some states have developed regulations that allow the issuance of a General Permit or its equivalent for the state as a whole or for each facility. Each land application project must conform to the conditions of the General Permit.

Biosolids managers should examine both the Part 503 Rule and individual state technical requirements and include all such requirements in their internal management system to ensure complete regulatory compliance. Appendix B of this document provides federal and state contact information, including electronic mail addresses, for agencies responsible for regulating biosolids management. The states' web sites may contain their biosolids regulations; in some cases, permit applications also are available electronically.



### 2.7 Local Government Regulations

In terms of permitting, the majority of biosolids management programs are permitted through state agencies. However, local governments also may impose their own requirements. For example, a city or county health agency can put limitations on the quantity and types of materials processed at a site; a zoning board may restrict certain land use practices; an air quality district may set a limit on odor or dust emissions; and an overall governing body may restrict truck traffic, noise and other public nuisance factors. Biosolids managers will need to become familiar with any local ordinances or regulatory requirements that will apply to or affect their facility or biosolids management program.

More recently, a growing number of jurisdictions have adopted local ordinances or passed bans that primarily affect land application programs for biosolids. Several states report that their state laws override any local bans or ordinances.

## References

Dominak, R.P., (February, 2001), *"Incineration: Current Practices and Future Direction for Biosolids Incinerators"*, Proceedings of the Residuals and Biosolids Management Conference, February, 2001

United States Department of Agriculture, (1989), *"Peer Review – Standards for the Disposal of Sewage Sludge U.S. Environmental Protection Agency Proposed Rule 40 CFR Parts 157 and 503"*

United States Environmental Protection Agency, (February, 1993), *"Standards for the Use or Disposal of Sewage Sludge,"* Fed. Regist., 58,32,40 CFR Part 503 Rule.

United States Environmental Protection Agency, (November, 1993), *"Technical Support Document for Land Application of Sewage Sludge"*, (USEPA 822/R-93-001a)

United States Environmental Protection Agency, (September, 1993), *"Domestic Septage Regulatory Guidance: A Guide to the USEPA 503 Rule"*, (USEPA 832-B-92-005)

United States Environmental Protection Agency, (September, 1994), *"A Plain English Guide to the USEPA Part 503 Biosolids Rule"*, (USEPA/832/R-93/003)

United States Environmental Protection Agency, (September, 1995), *"A Guide to the Biosolids Risk Assessment for the USEPA Part 503 Rule"*, (USEPA/832-B-93-005)

United States Environmental Protection Agency, (1979), *"40 CFR Part 257, Criteria for Classification of Solid Waste Disposal Facilities and Practices"*, Federal Register 44(179): 53438-53464

United States Environmental Protection Agency, (1989), *"Review of Proposed Sewage Sludge Incineration Rules"*, 40 CFR Part 257 and 503, (USEPA-SAB-EEC-89-035)

United States Environmental Protection Agency, (1992), *"Response to Public Comments on the Proposed Part 503 Sewage Sludge Use and Disposal Regulations and the National Sewage Sludge Notice of Availability"*, Washington, D.C

## Suggested Reading:

United States Environmental Protection Agency. Part 503 Implementation Guidance. USEPA Office of Water (4203) EPA 833-R-001. October 1995.

## Chapter 3 - Wastewater Treatment Overview

---

The treatment of wastewater, the processing of solids generated and use or disposal of biosolids must be considered as a system designed to produce two products: clean water that can be reused or released into the environment, and biosolids. Wastewater treatment facility processes have a significant impact on biosolids characteristics. Careful consideration must be given when evaluating changes to either the liquid or solids handling system as one impacts the other. If changes are done correctly, the processes will complement each other.

This manual addresses wastewater treatment as one location on the biosolid value chain. The four primary processes (sections) within this location (chapter) are pretreatment and pollution prevention, liquid stream as it relates to solids management; solids generation; and septage handling.

This chapter is not intended to fully explain each of the process associated with wastewater treatment, but rather to highlight the relationship between influent characteristics, wastewater treatment and biosolids management. The processes associated with wastewater treatment that relate to biosolids management include:

- Pretreatment and pollution prevention programs
- Liquid stream impact on solids management
- Primary solids generation
- Secondary solids generation
- Tertiary solids generation
- Solids processing side stream characteristics
- Septage handling

### 3.1 Pretreatment and Pollution Prevention Programs

Influent characteristics are crucial to wastewater treatment and solids management. Waste diversion and pretreatment programs are designed to remove pollutants at their source, protecting the public investment in a wastewater treatment facility. Pretreatment also reduces the potential for process upsets and enhances biosolids characteristics.

Pretreatment programs were established by the USEPA in 1978 (requirements were set forth in 40CFR Part 403), requiring industrial users to limit the discharge of certain pollutants. The regulation addresses metals within wastewater along with organic chemicals. Pollution prevention programs are designed to reduce or eliminate the discharge of certain contaminants.

In addition to protecting the wastewater treatment facilities, pollution prevention often results in savings to the industry implementing the programs. The implementation of pretreatment and pollution prevention programs have had a significant positive impact on the characteristics of biosolids generated. Table 3.1 compares the results of two surveys conducted

*The implementation of pretreatment and pollution prevention programs have had a significant positive impact on the characteristics of biosolids generated.*

to assess the characteristics of biosolids. The 40-city study was conducted in 1979 and 1980. The study summarizes the results of sampling and analysis performed on solids generated at 40 publicly owned wastewater treatment facilities. In 1989, during the development of the 40CFR Part 503 Rule regulations, the USEPA sponsored a second survey of biosolids. The second survey, the National Sewage Sludge Survey, summarizes the results of testing conducted at over 200 wastewater treatment facilities. (USEPA 1990).

**Table 3.1 Pretreatment Impacts – National Trends**

Element	40-City Study (1980) mg/kg dry weight	National Sewage Sludge Study (1989) mg/kg dry weight
Arsenic	9.9	6.7
Cadmium	69	6.9
Chromium	429	119
Copper	602	741
Lead	369	134.4
Mercury	2.8	5.2
Molybdenum	17.7	9.2
Nickel	135.1	42.7
Selenium	7.3	5.2
Zinc	1,594	1,202

While dated, the results of the two surveys illustrate the trends occurring within biosolids characteristics. A review of the table indicates that in almost every case, the characteristics found in the National Sewage Sludge Survey are significantly less than those in the 40-city study. In two cases, copper and mercury, the results from the National Sewage Sludge Survey are greater than those from the 40-city study. The copper concentrations are most likely the result of increased use of copper plumbing in new homes. There is not a clear explanation for the increase in the mercury concentration. It may be the result of changes in analytical techniques and an increase in the number of samples collected in the NSSS. The USEPA is in the process of implementing a Biosolids Data Management System (BDMS) that collects biosolids quality data reported by wastewater treatment facilities. The database can be accessed through [www.epa.gov/region08/water/wastewater/biohome/biohome.html](http://www.epa.gov/region08/water/wastewater/biohome/biohome.html).

In addition to industrial contributions, the waste stream from individual residences can impact wastewater treatment and biosolids characteristics. Educating the public about the impacts of household hazardous waste on the treatment facility, along with making household hazardous waste recycling and disposal convenient, can result in a marked improvement in biosolids characteristics.

### 3.2 Liquid Stream Impact on Solids Management

The liquid stream processes in a wastewater treatment facility can impact both solids characteristics and the types of solids handling processes that are appropriate. While it is unlikely that an organization will change its entire wastewater treatment process to improve solids handling, both the liquid and solid stream processes need to be considered when contemplating a change.

*The type of liquid stream treatment process employed impacts the amount, dry weight, and volume of solids generated.*

The type of liquid stream treatment process employed impacts the amount, dry weight, and volume of solids generated. To illustrate, consider use of a primary clarifier as part of a conventional activated sludge process and the absence of a primary clarifier in an extended air process. A primary clarifier removes solids from wastewater by gravity settling. Primary solids are a benefit to certain solids management processes including anaerobic digestion and mechanical dewatering. They are not a benefit to other processes such as dissolved air flotation thickening and aerobic digestion.

In addition, the impact a solids handling process can have on the liquid stream should be considered. For example, mechanical dewatering with a belt filter press generates significantly more sidestream volume than centrifuge dewatering. The impact of these sidestreams on the liquid stream process should be considered when evaluating these alternatives.

### 3.3 Solids Generation

Understanding solids generation within the facility helps optimize the operation of subsequent solids handling processes. The most effective method to establish the treatment efficiency of primary, secondary, and tertiary processes is to measure wastewater characteristics entering and leaving each process. For solids production, the total suspended solids and the biochemical oxygen demand are typically monitored. If historical data is not available, limited analysis and some “rules of thumb” can be used to establish an estimate of solids generation.

#### 3.3.1 Primary Solids Generation

Primary clarifiers, the principle means of wastewater treatment in the U.S. prior to the passage of the Clean Water Act, remove suspended solids within the wastewater by the use of gravity. They also reduce the organic load, measured as biochemical oxygen demand (BOD), which enters the secondary treatment process.

*The most effective way to determine the performance of a primary clarifier is to monitor the influent and effluent total suspended solids and biochemical oxygen demand.*

Efficiently designed and operated primary clarifiers can remove 50 to 70 percent of the suspended solids that enter the process. During the removal of these suspended solids, 25 to 40 percent of the 5-day BOD is also removed. (Metcalf & Eddy, 1991).

The most effective way to determine the performance of a primary clarifier is to monitor the influent and effluent total suspended

solids and BOD. This will allow the organization to closely estimate the removal efficiency of their process.

Recording the surface overflow and weir overflow rate in addition to the removal rates will allow the organization to predict the performance at various hydraulic loading rates.

### 3.3.2 Secondary Solids Generation

The secondary process includes a fixed film or suspended growth biological treatment along with secondary clarification. Parameters that will impact secondary solids generation include:

- Presence or absence of primary clarification
- Type of secondary treatment process employed
- Secondary clarifier loading rates

Similar to primary solids generation, it is necessary to establish the characteristics of the influent and effluent to understand the solids and organic removal through the process. To establish performance, an organization needs to determine the solids generated per unit of organics removed. This is typically referred to as the pounds of solids generated per pound of BOD removed (lb/lb BODr). This generation rate is best determined over time with actual operating data. If data is not available, a generation rate of 0.75 to 0.85 lb/lb BODr can be used for facilities that do not nitrify. Nitrification increases the solids generation rate. If the facility does nitrify, the solids generation will approach 1.0 lb/lb BODr. In addition to the biological solids generated through secondary treatment, the suspended solids entering and leaving the secondary treatment process should be monitored. The suspended solids removed in the secondary treatment process should be added to the biological solids to determine the total secondary solids. [(3) WEF Design of Municipal Wastewater Treatment Plants WEF MOP, 8]

### 3.3.3 Tertiary Treatment and Solids Generation

Advanced secondary and tertiary treatment impacts the solids generated during wastewater treatment, but the manner in which the performance is monitored and the solids generation is estimated will not change. Nitrification will increase the biosolids generated in the secondary treatment process. Chemical addition for phosphorus removal will enhance settling and increase the generation of primary and/or secondary solids. Biological nutrient removal also impacts the volume and characteristics of the solids generated.

*It is important to estimate the characteristics of any sidestreams that will be generated from a new unit process.*

### 3.3.4 Impact of Sidestreams on Solids Generation

Sidestream generated from solids handling unit process have an impact on the liquid stream of a wastewater treatment facility and subsequently the solids generation. It is important to estimate the characteristics of any sidestreams that will be generated from a new unit process. The sidestreams can be “modeled” to determine their impact on the

hydraulic and organic capacity of a wastewater treatment facility.

The characteristics of the sidestreams should be considered when determining where they will enter the stream. Because a number of solids handling processes have extremely high solids capture rates, it may not be necessary to introduce the sidestream upstream of a primary clarifier, thereby maintaining as much reserve hydraulic capacity in the primary treatment process as possible.

### 3.3.5 Solids Generation for Lagoon Systems

A number of small wastewater treatment facilities employ lagoon treatment technology. These systems include either a facultative or aerated lagoon. In the majority of these systems, wastewater that has undergone preliminary treatment is discharged directly into a lagoon. Lagoon systems typically include baffles or a series of lagoons to minimize the opportunity for short-circuiting. All solids (suspended and biological) generated within the lagoon treatment system remain within the lagoon and are periodically removed. The method to estimate the solids generation within the lagoon system is similar to that of an extended aeration activated sludge process, starting with monitoring the suspended solids and BOD entering and leaving the lagoon system. Due to the endogenous respiration that occurs within the solids settled in the lagoon, the solids generation rate per pound of BOD removed is significantly lower than that experienced in an extended air activated sludge system. It should be anticipated that 40 percent of the volatile solids estimated within the lagoon solids will be destroyed through endogenous respiration, resulting in a solids generation rate of approximately 0.5 lb/lb BOD<sub>r</sub>.

## 3.4 Septage Handling at a Wastewater Treatment Facility

Cotreatment of septage with wastewater at a municipal treatment facility is a viable option for septage management. Septage, however, has several significant effects on the conventional wastewater treatment process. It exerts a load on both the liquid and solids stream treatment systems, with resulting increases in solids production and operating costs. It can also have an effect on facility performance and, ultimately, on the quality of effluent and biosolids produced. The latter effect depends on a number of factors, including the proportion of septage loading being treated compared to total facility loading, and the manner in which septage is introduced into the treatment facility.

### 3.4.1 Characteristics of Septage

The characteristics of septage are similar to wastewater, though significantly higher in strength. In addition to the organic loading, septic tanks concentrate rags, plastics, and other nondegradable materials, which can cause operational and aesthetic problems at the wastewater treatment facility and in the resulting biosolids. Odors may be the most significant factor to consider when dealing with septage.

Septage strength varies, but can be characterized based on an average composition. Septage can be managed as high strength wastewater or as a dilute solid. Data collected at the King County, Washington East Division Reclamation Plant since the mid-1970s

*Septage can be managed as high strength wastewater or as a dilute solid.*

indicate total solids concentrations averaging approximately 23,000 mg/L, with suspended solids averaging 22,000 mg/L. The concentration of oil and grease average approximately 1,400 mg/L. Total BOD values have averaged approximately 7,400 mg/L, whereas soluble BOD values have averaged approximately 800 mg/L. The solids concentration is approximately 100 times greater, and BOD approximately 30 times greater, than for domestic wastewater being received at this facility. [(2)WEF MOP 24, 1997)].

### **3.4.2 Incorporation with the Liquid Stream**

A number of factors must be considered when deciding to add septage to the liquid stream process. These include where in the process the septage will be introduced; how it will be introduced; and its impact on both the liquid and solids stream unit operations. The solids and organic loading to the WWTF from the septage must be considered in each unit process, including the size of the facility, the unit process sequence, and the manner in which the septage is fed into the facility.

#### *Primary Treatment*

Because septage has a much higher solids content than typical domestic wastewater, the effects of septage discharges on liquid stream processes such as primary treatment are more significant from a solids loading viewpoint than from a hydraulic viewpoint. Because the solids contained in the septage have already been removed by settling in the septage system, they should be effectively removed during the primary treatment process. These additional solids subsequently would be discharged to the solids stream process for additional treatment and management. Because the loading is predominantly solids, it is important to ensure that the solids collection and pumping capacity for the primary solids are adequate to handle the increased loading that septage represents. Peak loading conditions will be of the greatest concern.

#### *Secondary Treatment*

While most of the BOD in the septage is associated with the solids, there is some BOD that will be discharged to the secondary process. This will result in higher aeration requirements and an increase in secondary solids production. The actual effect will be dependent on the specific facility because factors such as type of aeration diffuser, mean cell residence time (MCRT) at which the system is operated, and ambient temperature can affect both air demand and solids production.

Odors associated with septage must be addressed to reduce the potential for odor complaints at the facility. Even if odors have been addressed at the receiving station, it is possible to have additional odors released during liquid stream processing.

### **3.4.3 Septage Treatment and the Solids Process Stream**

It may be possible to discharge the septage directly to the solids process stream to reduce effects on the liquid stream processing facilities. For this approach to be successful, it is important that a mechanism be present, either as a part of the septage receiving station or as a part of the solids processing system, to remove grit and screenings. Failure to provide this treatment will result in grit and materials such as rags and plastics in the final



biosolids product and can have such adverse effects on the solids processing units as ragging and accumulation of grit, which require periodic draining and cleaning of process units. Some agencies have reported success with the use of a rotary screen device; however, the screened materials represent an additional sidestream that requires disposal.

### *Solids Processing*

Consideration also must be given to the effects of the septage on the solids processing units when determining the point in the process at which the solids will be introduced. As an example, unless the septage is prethickened, it may not be desirable to feed it directly into a digestion process because of the dilution and resulting reduction in solids retention time. Similarly, the direct introduction of the septage solids to the dewatering processing system could have adverse effects on the resultant biosolids quality and may create compliance issues with regard to vector -- attraction reduction and pathogen reduction requirements.

### *Solids Stream Effects*

The solids stream effects of septage are primarily related to the solids loading on the processing units and the resultant increase in biosolids production. It is probable that the loading will be comparable to that assumed for the solids stream loading under the previous liquid stream treatment scheme.

### *Liquid Stream Effects*

Although the septage stream would be discharged to the solids processing area under this treatment scheme, the liquid fraction would still need to be treated in the liquid stream processing unit as a portion of the solids recycle stream.

## References

Metcalf and Eddy, Inc., (1991), *Wastewater Engineering, Treatment, Disposal and Reuse*, Third Edition McGraw-Hill, Inc., New York, N.Y

United States Environmental Protection Agency, (November, 1990), USEPA 40 Code of Federal Regulations Part 503 National Sewage Sludge Survey; Availability of Information and Data, and Anticipated Impacts on Proposed Regulations; Proposed Rule

Water Environment Federation, (1992), *“Design of Municipal Wastewater Treatment Plants”*, Manual of Practice No.8, Alexandria, Va.; Am. Soc. Civ. Eng., Manual and Report on Engineering Practice No.76, New York, N.Y.

Water Environment Federation, (1997), *“Septage Handling”*, Manual of Practice No.24

## Chapter 4 – Solids Stabilization Systems

---

Stabilization is an extremely important process in any biosolids management program. Stabilization processes provide a number of benefits, which include:

- Reduction of pathogens
- Reduction of odor potential
- Providing uniform product characteristics

Each are key to a successful program.

This chapter provides an overview of a number of biosolids stabilization processes including:

- Anaerobic Digestion
- Aerobic Digestion
- Alkaline Treatment
- Composting
- Air Drying
- Thermal Drying

Some of these processes yield a marketable product. Others are employed prior to incineration or disposal. Each process is described and discussed in general terms. While detailed descriptions of each process can not be included in a manual like this, suggestions for operational controls and recommendations for additional information are provided.

While it is not necessary to incorporate each operational control into an Environmental Management System, it is important to consider them in the evaluation or implementation of a process. Considering each operational control as part of the planning process will result in the development of stabilization processes that compliment an agency's biosolids management program.

### 4.1 Stabilization Considerations

A number of general rules should be considered when evaluating stabilization processes. These "rules" apply to a number of processes.

*Rule #1: Bigger is generally better.* In almost all stabilization processes, bigger is better. Stabilization processes must be capable of successful operation under various loadings and conditions. Adequate capacity to process maximum monthly solids generation is essential. Capacity also should be available to provide flexibility within the overall program. Be certain to provide adequate capacity in a new system or be confident of the capacity of an existing facility before it becomes a key component of a biosolids management program.

In digestion processes, consider more than detention time. The total solids and volatile solids loading also must be considered. In addition, feed rates, temperature, and mixing play important roles.

*Rule #2: Operate to meet downstream goals.* While bigger is often better, stabilization systems should be operated to meet design conditions, not to utilize all the capacity available. As an example, a facility with excess capacity in its auto thermal thermophilic digester, operated well below the design loadings and achieved remarkable volatile solids reduction. Unfortunately, the “over digestion” resulted in a material that would not dewater. Microscopic examination found that there was “nothing left to dewater”. Reducing the detention time to match design parameters corrected the dewatering problem.

*Rule #3: Combining stabilization processes can add value.* In some instances combining processes can result in an enhanced operation and product. For example, composting can be used successfully to stabilize raw solids and produce a material that meets Class A pathogen reduction requirements. A number of facilities, however, elect to digest solids prior to composting. Potential advantages include reduced odor potential during the composting process and enhanced product quality. This is also the case with drying processes. Indirect drying of unstabilized biosolids will result in an odorous product. While indirect dryers can meet pathogen reduction and vector attraction reduction goals, a product with an odor can not be marketed.

*Rule #4: Consider use when selecting a stabilization process.* The use of the biosolids should be known when selecting a stabilization process. This, however, is not always the case and may place certain limitations on facilities selecting a beneficial use alternative. For example, if lime treatment is practiced to meet Class B pathogen reduction requirements, the potential for odor following long periods of storage is significant. Minimize storage periods or add additional lime to reduce the odor potential. To further reduce odor, incorporate biosolids as soon as possible following application.

*Rule #5: Drying is exactly that, drying.* While discussed in this section, drying technologies do not guarantee stabilization. Air drying and thermal drying remove water from biosolids. Drying raw solids can result in a product with significant odor. A number of indirect drying facilities have produced a non-marketable product. The facilities were forced to curtail operations or reduce throughput to match digestion capacity. Some direct drying facilities have successfully produced pellets using unstabilized biosolids. A key to their success is keeping the biosolids aerobic prior to dewatering and drying.

### 4.2 Anaerobic Digestion Systems

Anaerobic digestion is a multi-stage biological process that contains three basic stages: (WEF Manual of Practice, FD-9, 1995)

- *Stage One:* organics, cellulose, proteins, lignin, and lipids are converted to soluble fatty acids, alcohol, carbon dioxide, and ammonia.
  - *Stage Two:* products of the first stage are converted to acetic acid, propionic acid hydrogen, carbon dioxide, and other low molecular weight organic acids.
- Stage Three:* Methane Production. Two groups of methane forming bacteria are responsible for the third stage of anaerobic digestion. One group converts hydrogen and carbon dioxide to methane. The second group converts acetate to methane and bicarbonate.

There are three types of anaerobic digestion systems: Low-Rate, High-Rate and two stages. Most systems implemented today are high-rate.

### *Low-Rate Anaerobic Digestion*

Low-rate digesters, the oldest anaerobic stabilization systems, also are referred to as standard-rate or conventional anaerobic digesters. The low-rate digester consists of a cylindrically shaped tank with a sloping bottom and a flat or domed roof. Mixing is not provided in low-rate systems, causing stratification within the digester.

Methane gas accumulates in the headspace of the tank and is drawn off for storage or use. Scum accumulates on the supernatant surface. The supernatant is drawn off and returned to either the primary clarifier or to the secondary treatment process. Supernatant typically contains high concentrations of ammonia and phosphorus. Stabilized biosolids settle to the bottom of the digester for removal and further processing.

Low-rate digestion is characterized by: Intermittent Feeding; Low organic loading rates; No mixing ; and Detention times of 30 to 60 days. An external heat source may or may not be provided to increase the digestion rate. Due to the long detention time and subsequent large volume requirements, this type of digestion has traditionally only been employed at small wastewater treatment facilities with capacities below one million gallons per day. Use of low-rate systems has decreased significantly in recent years.

### *High-Rate Anaerobic Digestion*

Several improvements to anaerobic digestion were developed in the 1950s, resulting in the high-rate anaerobic digestion system. A high-rate system is characterized by: Heating; Auxiliary mixing; Thickening; and Uniform feeding. High-rate digesters attempt to maintain ideal environmental conditions to maximize efficiency of the anaerobic microorganisms.

### *Two-Stage Anaerobic Digestion*

Two-stage digestion is a high-rate system that divides the functions of fermentation and solids-liquid separation into two digesters operated in series. The first digester is a high-rate stabilization system, while the second is for solid-liquid phase separation. The second digester typically does not have mixing or heating facilities unless it is also used to provide standby digester capacity. The secondary digester also provides storage capacity within the system. The series type operation of the two digesters serves to minimize any potential of short-circuiting.

Anaerobically digested biosolids may not settle well in the second digester. This will result in a supernatant with a high concentration of suspended solids. Reasons for poor settling characteristics include incomplete digestion in the primary digester, which can cause gas generation in the secondary digester resulting in floating solids, and small particles that do not settle well. Small particles are associated with secondary or tertiary solids. Primary- and waste-activated solids thickened to more than four percent total solids typically will not separate in the second digester.

#### 4.2.1 Critical Control Points / Operational Controls

Regardless of the system type, there are a number of controls that must be considered. They include:

- Solids Loading Rate
- Operating Volume
- Detention Time
- Temperature
- Mixing
- pH
- Volatile Acids/Alkalinity
- Nutrients
- Gas Production
- Scum and Foam Production
- Failure Indicators

These operational controls should be considered when addressing system performance and capacity. Each parameter is discussed separately.

*Most systems implemented today are high rate systems, which include heating, mixing and uniform feed rates*

##### *Solids Loading Rate*

The solids retention time, hydraulic residence time, volume and solids concentration determine the solids loading rate to a digester. Biologically volatile solids (VS) are the most important element to control in the process.

The Water Environment Federation's (WEF) Anaerobic Digestion Manual of Practice, (MOP16) Second Edition (1987) (WEF Manual of Practice, 16, 1987) states that most high rate anaerobic digesters are loaded at a rate of approximately 8 percent VS per day. This loading is added to the total VS in the digester prior to feeding. In addition to VS loading, MOP 16 recommends that daily Total Solids loading should not exceed five percent of the total solids within the digester.

*High rate digesters with mixing and heating are characterized by volumetric loadings between 0.1 and 0.2 pounds volatile solids per day per cubic foot (lbVS/day/cu.ft.)*

Volumetric loading is defined as the mass of VS added to the digester each day divided by the operating volume of the digester. The WEF Wastewater Residuals Stabilization Manual of Practice (MOP FD-9) (1995) [(3) WEF Manual of Practice, FD9, 1995] states that high rate digesters with mixing and heating are characterized by volumetric loadings between 0.1 and 0.2 pounds volatile solids per day per cubic foot (lbVS/day/cu.ft.). The WEF Design of Municipal Wastewater Treatment Plants Manual of Practice, MOP 8 (1992) further defines volumetric loadings during peak conditions at 0.12 to 0.16 lbVS/day/cu.ft.

### *Operating Volume*

The digester's operating volume impacts the hydraulic residence time and the volumetric loading to the system. The operating volume is a percentage of the digester's total volume. Operating volumes range from 75 to 95 percent of the total volume. The type of mixing system used impacts the operating volume and the volume of grit and scum that has accumulated within the digester. The best way to increase the operating volume is to improve mixing. Keeping grit and scum in suspension will maximize the operating volume.

### *Detention Time*

The WEF Wastewater Residuals Stabilization Manual of Practice (MOP FD-9) states that anaerobic digestion systems have been based on solids retention time (SRT), volatile solids loading and volume per capita. Some rules of thumb for detention time include:

- Typical SRTs for high rate digestion at mesophilic temperatures range from 15 to 20 days.
- For anaerobic digesters with no internal recycle, the SRT is equal to the hydraulic residence time (HRT).
- A minimum SRT for high rate mesophilic digestion is 10 days. (MOP FD-9)
- For stability, ease of control, to account for the accumulation of grit and scum and to allow for imperfect mixing, most digesters operate at 15 day retention time or more. (MOP FD-9)

*Minimum SRT is essential to the digestion process to ensure that the necessary microorganisms are being produced at the same rate as they are removed from the system each day*

A minimum SRT is essential to the digestion process to ensure that the necessary microorganisms are being produced at the same rate as they are removed from the system each day (MOP FD-9).

### *Mixing*

Proper mixing increases digestion rates by allowing food and nutrients to reach the cells and by removing wastes from the cells. Improper mixing can cause a portion of the digester to be overloaded. Overloading will result in the production of foam. The WEF Design of Municipal Wastewater Treatment Plants, Manual of Practice (MOP 8) (1991) states that typical mixing system designs are based on achieving a turnover time of 30 to 45 minutes. Some systems have been based on turnover times as high as 3 to 4 hours.

*Full-scale trials have shown that digestion capacity can increase by raising the digester's temperature into the thermophilic range. Thermophilic operation also increases the degree of pathogen reduction and improves solids dewatering.*

### *Temperature*

The heating system is a critical component of the anaerobic digestion system. If the temperature in an anaerobic digester fluctuates, no group of methane formers can achieve a large stable population. A smaller population results in a reduced degree of stabilization

and lower rate of methane production. The temperature within the digester should not fluctuate more than 1° to 2°F. To minimize digester heating requirements, some facilities preheat solids prior to feeding the digesters. Temperature fluctuations also can be minimized by feeding the system at frequent intervals.

Anaerobic digestion usually occurs in the mesophilic range (35°C). Full-scale trials have shown that digestion capacity can increase by raising the digester's temperature into the thermophilic range. Thermophilic operation also increases the degree of pathogen reduction and improves solids dewatering. Disadvantages of thermophilic digestion include increased energy requirements, reduced supernatant characteristics, greater odor potential and reduced process stability.

### *pH*

To provide a healthy environment for methane forming microorganisms, the pH for normal operation should be between 6.6 and 7.2. If the pH falls below 6, un-ionized volatile acids become toxic to methane forming microorganisms. Above pH 8, un-ionized ammonia becomes toxic to methane forming microorganisms.

### *Volatile Acids and Alkalinity*

In the first stage of anaerobic digestion, raw solids are converted to volatile organic acids. The formation of these acids must be closely monitored. Volatile acid formation without adequate alkalinity will result in a pH reduction. Volatile acid formation is controlled by the amount of volatile solids fed to the process. Volatile acid concentration in a well operating anaerobic digester range between 50 mg/L and 300 mg/L. Values below 500 mg/L usually indicate good digestion. With anaerobic digestion, the major acid-base system that impacts pH is the carbonate system. When total volatile acids in a well-balanced digester are low, bicarbonate alkalinity is approximately equal to total alkalinity.

Anaerobic digesters should have a bicarbonate alkalinity concentration between 2,500mg/L and 5,000mg/L to neutralize volatile acids and prevent a reduction in pH. A well-established heated digester has a total alkalinity between 2,000 and 2,500 mg/L. Bicarbonate alkalinity above 2,000mg/L indicates a well-digested product. An alkalinity between 1,500 mg/L and 3,000mg/L is recommended to prevent digester souring.

An acceptable alkalinity concentrations range from, 1,500 mg/L to 5,000 mg/L. The alkalinity within the digestion system will be impacted by the characteristics of the wastewater treated and the solids generated. The alkalinity of the digester contents should be monitored for trends which will indicate proper operation or the onset of upset conditions.

*If the ratio exceeds 0.8, pH depression and inhibition of methane production occurs, indicating process failure.*

The volatile acid-to-alkalinity ratio indicates if the digester has enough buffering capacity for the volatile acids being produced. As the volatile acid-to-alkalinity ratio increases, pH decreases. While individual values reveal current conditions, process



control is best accomplished by closely monitoring this ratio's rate of change. Ratios above 0.4 indicate upset and the need for corrective action.

### *Nutrients and Trace Elements*

The major nutrients required for anaerobic digestion are nitrogen and phosphorus. An average cell contains approximately 12.5 percent nitrogen and 2 percent phosphorus. Sodium, potassium, calcium, magnesium, chloride, and sulfate ions are also required for proper digestion.

### *Digester Gas Production*

The amount of digester gas produced is an indicator of system performance. Typical production ranges between 12 and 18 cubic feet per pound of VS destroyed. This parameter is often used to determine when the digester is capable of operating at its capacity.

Digester gas composition also should be monitored. Methane content of the gas should be between 55 and 75 percent. The sum of methane and carbon dioxide should constitute approximately 95 percent of the digester gas produced. Anaerobic digestion also produces small amounts of nitrogen, hydrogen sulfide and hydrogen. These gases represent approximately 1 to 5 percent of the gases produced.

### *Digester Scum and Foam*

Foaming often occurs in anaerobic digesters during initial start-up, when there is an organic overload, or when an imbalance in the digester occurs. Digester foaming can be the result of the following:

- High concentration of grease
- Inadequate mixing
- Excessive mixing
- High percentage of waste activated solids
- Solids thickened by dissolved air flotation
- Large fluctuations in digester temperature
- High carbon dioxide content
- High alkalinity
- Low feed solids concentration
- High organic content in the feed solids.

Because of the number of potential causes, digester foaming is difficult to control.

Control measures include:

- Grease Control - Grease and scum should be removed from the process train. While some facilities do, the literature recommends that grease and scum not be introduced into the digesters.
- Mixing - Inadequate or excessive mixing can result in foaming. Practice continuous mixing that results in the turnover of the digester at least once per hour.
- Temperature Fluctuations - Minimize temperature fluctuations by extending digester feed cycles. A 2° to 3° F temperature fluctuation can result in foaming.

- Excessive Carbon Dioxide Concentration - Excessive carbon dioxide concentrations are often experienced during start up or during conditions of upset. Scrub digester gas to remove carbon dioxide.

### *Failure Indicators*

Failure of the anaerobic digestion system occurs when the microbiological reactions become imbalanced. Often acid forming microorganisms outproduce the methane forming microorganisms, which consume acid. The imbalance may be the result of:

- Methane organism inhibition
- Organic overload, which results in the acid formers outproducing the methane formers.
- Washout of the slower growing methane formers.

A digestion system failure can have a major impact on a biosolids management program. Failure to meet pathogen reduction requirements results in the inability to practice a beneficial use program. Partial digestion can have a negative impact on the ability to dewater solids. Suddenly a facility can be faced with a poorly dewatered material that cannot be land applied or a poorly dewatered material entering a subsequent process such as composting, alkaline stabilization, or incineration.

### **4.3 Aerobic Digestion Systems**

The aerobic digestion process provides the destruction of degradable organic components and the reduction of pathogenic organisms within biosolids by aerobic, biological mechanisms. Aerobic digestion is a suspended-growth biological treatment process similar to the extended aeration process.

*Aerobic digestion is a suspended growth biological treatment process similar to the extended aeration process.*

The objectives of aerobic digestion include production of a stable product by oxidizing organisms and other biodegradable organics, reduction of mass and volume, reduction of pathogen organisms, and conditioning for further processing. The aerobic digestion process is its relatively simple operation. As long as the environment is maintained comparable with an activated-sludge system, the aerobic digestion process is essentially self-sustaining.

The primary disadvantage typically attributed to the aerobic digestion process is the relatively high energy requirement associated with oxygen transfer. Developments in the process, such as increased oxygen transfer efficiency using fine bubble diffusion and operation at thermophilic temperatures, have reduced energy requirements. Other disadvantages include reduced efficiency during cold weather and relatively poor dewaterability of the solids after digestion.

The primary purpose of the aerobic digestion process is to produce biosolids that are stable and amenable to various beneficial use alternatives. Historically, volatile solids reduction have been used to monitor system performance. Research suggests that the reduction in volatile solids during the digestion process may not be a valid indication of stabilization [(4) Hartman et al., 1979, and Matsch and Drnevich, 1977)]. Other parameters, such as the residual rate of oxygen demand, pathogen levels, odor-producing potential, specific oxygen uptake rate, or oxidation-

reduction potential, may be more indicative of stabilized aerobically digested biosolids.

*Aerobic digestion of primary solids or a mixture of primary and waste-activated solids is not recommended*

### 4.3.1 Critical Control Points / Operational Controls

There are a number of controls that should be considered in the design and operation of aerobic digestion systems. They include:

- Feed Characteristics
- Operating Temperature
- Oxygen Transfer and Missing
- Detention Time
- Method of Operation
- Tank Design
- Aeration and Mixing Equipment
- Supernatant Quality
- Foaming
- PH Reduction
- Dewatering

#### *Feed Characteristics*

Aerobic digestion typically is used to stabilize waste-activated solids. While the process has been used to stabilize primary and biological mixtures, the associated detention times and oxygen requirements are increased substantially. Aerobic digestion of primary solids or a mixture of primary and waste-activated solids is not recommended.

Because the mechanisms of the aerobic digestion process are similar to the activated-sludge process, the same concerns regarding variations in influent characteristics and levels of biologically toxic materials apply, although a dampening effect will occur as a result of upstream treatment processes. The accumulation of metals in wastewater treatment may result in toxicity in the aerobic digester. The metals precipitated or absorbed are resolubilized at the reduced pH, potentially to toxic concentrations.

The solids concentration of the material entering the system is important in the design and operation of an aerobic digestion process. Thickening prior to aerobic digestion will result in longer solids retention times, smaller digester volume requirements, less decanting, and subsequently increased levels of volatile solids destruction.

*Thickening prior to aerobic digestion will result in longer solids retention times, smaller digester volume requirements, less decanting, and subsequently increased levels of volatile solids destruction.*

### *Operating Temperature*

The operating temperature of the aerobic digestion system is the critical parameter in the process. A disadvantage to the process is the variation in process efficiency that results from changes in operating temperature. The changes are closely related to ambient temperatures because most aerobic digesters use open tanks.

*Operation of aerobic digestion systems in the thermophilic zone of more than 40°C has become popular.*

Aerobic digesters are typically operated in the mesophilic temperature range, from 20° to 40° C. If the temperature falls below 20° C, the rate of digestion is significantly slowed. Operation of

aerobic digestion systems in the thermophilic zone of more than 40° C has become popular.

### *Oxygen Transfer and Mixing*

The biological reaction that occurs during aerobic digestion requires oxygen for the respiration of cellular material in biosolids. Proper operation of the system also requires adequate mixing. Because the introduction of oxygen to maintain the biological process typically provides a mixing action, these parameters are interrelated.

In aerobic digestion systems that treat waste-activated solids, the need for adequate mixing typically will govern the capacity of the oxygenation equipment. Actual mixing requirements typically range from 0.5 to 4.0-hp/1000 cu ft of digester volume. This value will vary depending on the type of mixing device.

In theory, 1.5 to 2.0 pounds of oxygen are required per pound of volatile solids removed in the aerobic digestion process. If the system is inhibited by nitrification, the oxygen requirement increases significantly. Experience indicates that a minimum of 2.0 pounds of oxygen per pound of volatile solids destroyed are required for aerobic digestion.

*Experience indicates that a minimum of 2.0 pounds of oxygen per pound of volatile solids destroyed are required for aerobic digestion.*

*Aerobic digestion studies indicate that a total aeration time, including time in a suspended growth wastewater treatment process, of 35 to 50 days is required to consistently meet a specific oxygen uptake rate (SOUR) of less than 1.5 mg O<sub>2</sub>/g·h.*

### *Detention Time*

The volume of an aerobic digestion system is governed by the detention time necessary to achieve stabilization, which historically has been measured as a desired reduction in volatile solids. The detention time to achieve 40 to 45 percent reduction in volatile solids ranges from 10 to 12 days at an operating temperature of approximately 20° C (Metcalf and Eddy, Inc., 1979). New designs must focus on pathogen reduction as the controlling factor. Aerobic digestion studies indicate that a total aeration time, including time in a suspended growth wastewater treatment process, of 35 to 50 days is required to

consistently meet a specific oxygen uptake rate (SOUR) of less than 1.5 mg O<sub>2</sub>/g·h. (Maxwell et al., 1992). The total required aeration time was impacted by operating temperature and biodegradability of the waste-activated solids.

### *Method of Operation*

The two primary modes of operation for aerobic digestion systems are batch and continuous. The primary difference between the two modes is the manner in which supernatant is removed from the process.

In the batch mode of operation, the aerobic digesters are fed directly from the clarifiers. The filling operation continues for a period of time depending on the wasting rates. The aeration and mixing equipment operates during the filling period that typically occurs for one to two days, or in extreme cases for as long as 2 to 3 weeks. After the tank is full, the aeration and mixing continues until the stabilization process is complete.

After the stabilization is completed, the aeration equipment is turned off and the biosolids settle. Supernatant forms at the surface and is removed. Digested biosolids are removed from the tank on a regular basis; however, some biosolids are always left in the tank to serve as a seed for the next batch. The frequency of supernatant and biosolids removal is determined by the feed requirement and the desired solids retention time. Multiple supernatant draw-off points should be provided for operational flexibility. The batch mode typically is selected for small-capacity digestion systems because of the relative simplicity of operation.

The continuous digestion mode allows regular operation without interrupting the aeration and mixing equipment. Decanting, filling, and aeration are continuous. Baffles and a supernatant withdrawal chamber (stilling well) or separate settling tank are common features of the continuous mode of operation. Including stilling wells in the digestion tank is typically unacceptable because of the mixing-induced turbulence carried into the well (WEF, 1992). Floating solids may occur from denitrification occurring in the stilling wells and contribute to poor supernatant quality.

The design of separate settling basins for continuous mode aerobic digestion is similar to the design of gravity thickeners or flotation thickeners for waste-activated solids. Solids loading rates ranging from 5 to 10 lb/d/sq ft of gravity thickener surface typically are used. Higher rates of 10 to 20 lb/d/sq ft are allowable with dissolved air flotation thickeners. Provisions should be included for rapid biosolids withdrawal and baffling/skimming to remove any accumulated floating solids. Thickened biosolids withdrawn from a batch digestion process or the continuous digestion process typically range from 2 to 4 percent solids with gravity thickeners and 4 to 6 percent solids from flotation thickeners or gravity belt thickeners.

### *Tank Design*

Aerobic digesters are typically uncovered, unheated tanks of steel or concrete construction. Recent installations have included covers to maintain temperature within the process.

A minimum of two tanks should be provided in aerobic digestion systems to permit draining and equipment repair. Multiple units are important in batch operation systems to provide digester capacity during the supernatant formation cycle. Aerobic digestion tanks have been designed with circular, and rectangular geometry. Bottom slope in the tanks typically ranges from 1:12 to 3:12 to facilitate biosolids removal. Side water depths are similar to those provided for activated-sludge systems, but more generous freeboards are provided (3 to 10 ft) to contain excessive foaming that may occur.

### *Aeration and Mixing Equipment*

Several types of equipment have been used successfully to meet the aeration and mixing requirements of aerobic digestion systems. These include diffused air, mechanical surface aeration, and mechanical submerged turbines.

Diffused air system diffusers are typically located near the tank bottom and along one side to produce a spiral or cross-roll pattern, although floor-mounted grid systems can also be used. Air flow rates of 15 to 20 cfm/1000 cu ft are required for aeration. Air flow rates of 20 to 40 cfm/1000 cu ft are required to provide adequate mixing.

*As long as the environment is maintained comparable with an activated-sludge system, the aerobic digestion process is essentially self-sustaining.*

### *Supernatant Quality*

Both the batch and continuous modes of operation result in the supernatant being discharged back to the WWTF. The volume and the characteristics of the supernatant and its impact on the WWTF must be addressed.

### *Foaming Problems*

Foaming problems are common in aerobic digestion systems. Foaming is typically caused by high organic loading rates during warm weather. Water sprays often are used to control foam. Antifoaming chemicals may be added to the spray water in response to more severe foaming problems.

Filamentous microorganisms also can cause foaming. Control methods include adding oxidizing chemicals to destroy the filamentous bacteria, and creating temporary anaerobic conditions by turning off the aeration equipment in the digester (WEF Operation of Municipal Wastewater Treatment Plants Manual of Practice-11, 1990). The most effective method to control foam in a digester is to remove the filamentous microorganisms from the liquid stream treatment process.

Foaming also may occur in the spring and fall as the microorganisms reacclimatize to summer or winter temperatures.

### *pH Reduction*

If the aerobic digestion process is provided with sufficient oxygen and detention time, ammonia will nitrify and form nitrates. This nitrification process may result in a decrease in pH and alkalinity as a result of the acid formed during the process. If the aerobic

digester has separate aeration and mixing equipment, it is possible to denitrify by operating only the mixing equipment during the fill cycle. Although the pH reduction should be monitored and the buffering capacity of the system checked as a normal operational control parameter, it seems that the organisms in the aerobic digestion process will acclimate to the lower pH as long as the level does not drop suddenly and does not continue to decrease below and pH of approximately 5.5 (Metcalf and Eddy, Inc., 1979).

#### *Dewatering*

Mechanical dewatering of aerobically digested biosolids is difficult. The dewatering characteristics show a definite deterioration with increasing solids retention time. Optimal dewaterability seems to occur after 1 to 5 days of aeration with a marked deterioration in dewaterability with increased aeration times (USEPA, 1979).

The dewaterability of aerobically digested biosolids also is affected by the degree of mixing provided during the digestion process. High degrees of mixing destroy the structure of the solids floc with a subsequent adverse effect on dewaterability. The design of mechanical dewatering facilities following aerobic digestion should incorporate conservative criteria developed during field-testing.

*The design of mechanical dewatering facilities following aerobic digestion should incorporate conservative criteria developed during field-testing.*

### **4.3.2 Process Variations**

Several variations to standard aerobic digestion have been investigated. The more notable variations are pure oxygen aeration and autothermal thermophilic digestion.

#### *Pure Oxygen Aeration*

This modification of the aerobic digestion process substitutes pure oxygen for air. Pure oxygen systems are relatively insensitive to changes in ambient air temperatures because of the increased rate of biological activity and the exothermic nature of the process. While one variation of this modification uses open tanks, aerobic digestion using pure oxygen typically is performed in closed tanks similar to those used for the pure oxygen activated-sludge process.

A disadvantage of this approach is the process cost associated with oxygen generation. Pure oxygen aerobic digestion typically is cost effective only when used in conjunction with the comparable activated-sludge process. The use of pure oxygen also decreases the amount of carbon dioxide that would be added in the standard air-oxygenated system. Consequently, neutralization may be required to offset the reduced buffering capacity of the system.

#### *Thermophilic Aerobic Digestion*

Extensive research has been conducted to optimize the aerobic digestion process. Optimization efforts include containing the released heat and operating the process in the thermophilic zone of biological activity. This modification is known as autothermal

thermophilic aerobic digestion (ATAD).

The advantages of thermophilic operation include a decrease in detention times required to achieve volatile solids reduction and the production of an essentially pathogen-free end product.

Operation in the thermophilic range inhibits nitrification. This reduces the oxygen requirement compared to systems where nitrification occurs.

As a result of the reduction in the aeration gas volume required, the normal heat loss from the aerobic digestion system is reduced. This results in a retention of heat generated during the process. Covering and insulating the digestion tanks increases the quantity of heat retained, and helps to maintain the process in thermophilic range.

The ATAD process is self-regulating with respect to temperature. This occurs as a result of a decrease in the digestion rate at elevated temperatures. The decrease in biological activity reduces the quantity of heat released during the exothermic reaction with a resultant decrease in the process operating temperature. The process is relatively stable, recovers quickly from minor process upsets, and is not affected by relatively wide variations in outside air temperature.

Similar to conventional aerobic digestion, the product of the ATAD process can be difficult to dewater. Care must be taken not to “over digest” the biosolids, break down the cell structure and yield a material that will not dewater well.

### 4.4 Alkaline Treatment Systems

The addition of alkaline chemicals as a method of stabilization has been practiced at wastewater treatment facilities since the 1980s. Quicklime (CaO) and hydrated lime (Ca(OH)<sub>2</sub>) are the traditionally used alkaline additives.

A number of advanced alkaline stabilization technologies have emerged that use either chemical additives in addition to or instead of lime, or involve special equipment or processing steps. These processes all claim advantages over traditional lime stabilization, including enhanced pathogen control and a more marketable product.

*Alkaline material can be used in processes to meet Class B or Class A pathogen reduction requirements.*

Lime is the most widely used and one of the lowest cost alkaline materials available in the wastewater industry. Lime has been used for reducing odors, increasing pH in stressed digesters, removing phosphorus in advanced wastewater treatment, treating septage, and solids conditioning prior to or following mechanical dewatering.

Alkaline materials can be used to stabilize biosolids. Alkaline material can be used in processes to meet Class B or Class A pathogen reduction requirements. Each product has particular characteristics associated with it. Traditional lime stabilization can be used to meet Class B



pathogen reduction requirements. A number of the advanced alkaline stabilization technologies have been developed to meet USEPA's Class A pathogen reduction requirements.

Potential uses for alkaline-treated products include:

- Ag-lime substitute
- Reclamation
- Landfill cover (daily, intermediate, and final)
- Topsoil blends
- Slope stabilization

The alkaline stabilization process is a simple one. An alkaline chemical is added to raise the pH of the solids. Adequate contact time is provided to allow pathogen reduction. At a pH of 12 or higher, with sufficient contact time and adequate mixing, pathogens and microorganisms are either inactivated or destroyed. Chemical and physical characteristics of the biosolids produced also are altered by the reactions with the alkaline material.

To meet Class B stabilization requirements, the pH of the feed/chemical mixture must be above 12 for 2 hours and subsequently maintained above 11.5 for 22 hours to meet vector attraction reduction requirements by alkaline addition. To meet the Class A stabilization, the elevated pH is combined with elevated temperatures (70°C for 30 minutes) or other USEPA-approved time/temperature processes. As long as the pH remains above 10, microbial activity and the associated production of odorous gases is greatly reduced or eliminated (USEPA, Process Design Manual For Sludge Treatment and Disposal, 1979). However, other odorous gases, including ammonia and trimethylamine, are produced as a result of the high pH and temperature conditions.

*Odorous gases, including ammonia and trimethylamine, are produced as a result of the high pH and temperature conditions.*

Several alkaline treatment alternatives are available. Each has advantages and disadvantages. It is important to evaluate and select a process that produces the desired product on a facility-specific basis.

### *Liquid Lime (Prelime) Stabilization*

Liquid lime or prelime stabilization involves the addition of a lime slurry to liquid biosolids to meet Class B stabilization requirements. Due to the volume of material handled per dry ton of system capacity, this practice is limited to smaller WWTFs or those with relatively short haul distances to land application sites.

Conditioning with lime before dewatering is a second method of liquid lime stabilization. Lime typically is combined with other conditioners, such as aluminum or iron salts, to achieve enhanced dewatering. This method is primarily used with recessed chamber, plate and frame, filter presses. Treatment is complementary in these situations because the lime dose for conditioning typically exceeds the dose required for pathogen reduction.

### *Postlime Treatment*

Postlime stabilization involves the addition of quicklime, hydrated lime or other dry alkaline

materials to dewatered cake. Postlime treatment can be used to meet either Class B or Class A pathogen reduction requirements. Postlime treatment has been practiced since the 1960s (Stone et al., 1992). The lime typically is mixed with the cake using a pug mill, plow bender, paddle mixer, ribbon blender, screw conveyor, or similar device. The degree of mixing is critical to the process.

The use of hydrated lime is typically limited to smaller facilities. Quicklime is less expensive and easier to handle than hydrated lime. The heat of hydrolysis released in slaking the quicklime when it is added to the dewatered solids can also enhance pathogen destruction.

### *Alternative Alkaline Materials*

There are a number of alkaline treatment alternatives using materials in addition to or in place of lime. Most of the alternatives rely on additives such as cement kiln dust (CKD), lime kiln dust (LKD), Portland cement (PC), or fly ash.

Other alternatives include the addition of other chemicals, a higher chemical dose, and supplemental drying. These processes alter the characteristics of the feed material and, depending on the process, increase the stability, decrease the odor potential, reduce pathogens, and enhance the product. Many of the processes are proprietary and are marketed through private firms.

Some advanced processes use the exothermic reaction of quicklime with water to achieve temperatures greater than 70°C. When this temperature is maintained for more than 30 minutes, the material meets Class A pathogen reduction requirements. This process must be carried out under controlled conditions to achieve inactivation of pathogens. Varying the process additives and mix ratios can produce a range of biosolids-derived materials.

One process combines advanced alkaline stabilization with accelerated drying. This involves the addition of quicklime, CKD, or other alkaline admixtures and other subsequent processes to create stresses on the pathogens with pH, temperature, ammonia, salts, and dryness (Burnham et al., 1992).

Another process includes elevating the temperature to 55°C for a 12 hour period. The process allows the heat generated by the chemical reaction to further reduce pathogens. Yet another process involves alkaline addition followed by mechanical drying in windrows to generate a product with a total solids concentration of between 50 and 60 percent. The product can be used as an agricultural liming agent, soil conditioner, or as landfill cover.

*Because of the interdependency between product quality and process design, the importance of defining process and product goals is extremely important.*

#### 4.4.1 Critical Control Points / Operational Controls

The controls associated with alkaline treatment systems are impacted by the technology used and the desired product characteristics. Consideration include:

- Feed characteristics
- Contact time, pH, and temperature
- Alkaline chemical types and dosages
- Solids concentration of feed/chemical mixture
- Storage
- Pilot testing

##### *Feed Characteristics*

The quantity and characteristics of the solids to be processed determines the overall sizing of the alkaline treatment equipment. Variable performance of thickening or dewatering equipment is an important consideration when sizing equipment because poor dewatering performance significantly increases equipment sizing.

*The chemical added must provide enough residual alkalinity to maintain a high pH until the product is used or disposed.*

##### *Contact Time, pH, and Temperature*

Contact time and pH are directly related. The pH of the mixture must be maintained at the required level for an adequate time to destroy pathogens. The chemical added must provide enough residual alkalinity to maintain a high pH until the product is used or disposed of because the high pH prevents growth or reactivation of odor-producing and pathogenic organisms.

The drop in pH, referred to as pH decay, occurs in the following sequence. Atmospheric carbon dioxide or acid rain, which forms a weak acid when dissolved in water, is absorbed, then gradually consumes the mixture's residual alkalinity, allowing the pH to gradually decrease. Eventually, the pH drops to less than 11 and biological activity resumes. The renewed activity will cause the pH decay to continue. It also will result in odor generation. The length of time an alkaline stabilized material will be stored or on the surface of the ground must be considered when determining alkaline dose and the potential for pH decay.

##### *Alkaline Chemical Types and Dosages*

The types and dosages of the alkaline chemicals to be added are important design criteria. The characteristics of the chemicals (lime, CKD, PC, and LKD) should be consistent. Different types or sources of additives result in different product texture and granularity. Lime is available from numerous sources, ranging from a high calcium lime made from oyster or clam shells to a relatively low calcium dolomitic lime. Major considerations in selecting the type of chemical to be used include availability, mixing characteristics, end product requirements and economics.

The required dosages of the specific chemicals depend on the feed material type (primary, waste activated, or trickling filter solids) and characteristics, including organic content, the feed solids concentration, desired product, and type and quality of

the alkaline material being used.

The range of liquid lime stabilization dosages required to maintain a pH of 12 for 30 minutes is presented in Table 4.1 (USEPA, 1979). Numerous researchers have confirmed these dosages (Ramirez and Malina, 1980).

**Table 4.1 Lime dosage required for liquid lime stabilization pH 12 for 30 minutes at Lebanon, Ohio (USEPA, 1979).**

Type of Solids	Average Solids Concentration, %	Average Lime Dosage, lb calcium hydroxide/lb dry solids	Average pH	
			Initial	Final
Primary and WAS	4.3	0.12	6.7	12.7
Waste-activated	1.3	0.30	7.1	12.6
Anaerobically digested combined	5.5	0.19	7.2	12.4

Chemical composition of the feed material also impacts the required chemical dose. This composition depends on the type of solids and the process used for wastewater treatment. Solids concentration also impacts the chemical dose.

*Solids Concentration of Feed/Chemical Mixture*

The solids concentration of the feed material and feed/chemical mixture are important design considerations. Minimum solids concentrations may be required to meet regulatory requirements for landfilling or extended storage, for example. Solids concentration will affect the materials handling characteristics for mixing, transportation and application/disposal equipment. For proper mixing, the dewatered cake must have a solids concentration between 18 and 25 percent.

The solids concentration of the initial feed/chemical mixture also affects any supplemental drying step in advanced alkaline stabilization processes. Through the addition of the alkaline additive, chemical reactions occur that increase the solids content of the mix due to the alkaline solids, chemical binding, and evaporation of water in the feed material. The alkaline material, particularly quicklime, produces a fast reaction resulting in a temperature increase within a matter of minutes. Thorough mixing of the feed and alkaline material is important to achieve the target solids content, reduced pathogens and residual odors in the product.

High chemical doses can be used to achieve the desired total solids concentration without supplemental drying. In almost all cases, excessive chemical costs make this practice prohibitively expensive.

Other bulking materials can be added to increase the product’s total solids concentration and improve handling characteristics. Potential bulking materials include fly ash, wood ash, sawdust, sand, and soil.

Mechanical mixing enhances drying, blends materials, and releases trapped ammonia,

resulting in a more homogeneous product. The final design should reflect the best balance between the chemical dosage and the amount of subsequent drying required.

### *Storage Requirements*

The size of storage facilities should be tailored to the actual needs of each treatment facility and should include intermediate storage and product storage.

- *Intermediate Storage.* Some advanced alkaline stabilization processes require additional facilities for the heating step to achieve Class A stabilization requirements. The objective of this step is to contain the heat produced from the exothermic reaction, reducing the chemical dosage by reducing the heat loss. Intermediate storage facilities can include insulated steel, live bottom hoppers, concrete bunkers, or an uninsulated stockpile.
- *Product Storage.* Final storage of the alkaline stabilized product is also an important design consideration. Adequate storage capacity is required where markets are seasonal or have not been established. The volume of storage required depends on the type of end use or the distribution and marketing methods. Sufficient storage should be provided if product curing is required and to accommodate road and weather conditions and fluctuations in the product marketing and distribution schedule. Provide adequate storage to allow peak production for the longest anticipated time without a market. Adequate storage allows management to meet quality requirements and market demands.

### *Pilot Testing*

Pilot testing also allows the evaluation of different operating procedures and product characteristics.

*Since the characteristics and consistency of feed vary from site to site, bench and pilot-scale testing should be performed to determine the optimum chemical dosages and mixer performance.*

## 4.5 Composting Systems

Composting is a stabilization process that prepares biosolids for use as a soil conditioner. The composting process destroys pathogens and results in a material similar to soil humus. Well-stabilized compost can be stored indefinitely and has minimal odor even when rewetted. Products meeting certain criteria may be distributed to the general public. Compost may be used in agriculture to improve soil properties.

Raw, digested, or chemically stabilized solids may be composted. Composting is a relatively simple process that can be performed outdoors in most climates. To operate the process more efficiently, control odors, and reduce operating costs, many facilities are constructed under cover, within buildings, or in mechanized “in-vessel” systems.

A number of composting systems are available and generally fall into the following categories:

- Open
- Enclosed
- Static (Non-mixed)
- Dynamic (Mixed)

All composting systems can be described using these four categories. Aerated static pile composting is an open/static system. Aerated windrow composting can be described as an open/dynamic system. In-vessel systems can also be described using these categories. Horizontal agitated bin systems are enclosed/dynamic systems. In-vessel silo systems are described as enclosed/static systems.

### 4.5.1 Critical Control Points / Operational Controls

The primary controls that govern the composting process are:

- Properties of the initial mix
- System aeration
- Detention time and mixing

While each of these factors can vary slightly depending on the composting alternative implemented, they all must be carefully considered during system design and process optimization. The operational controls outlined in this section are based on the research performed by Dr. Tim Haug (Haug, R.T., 1980). In addition to the initial mix ratios, aeration, and detention time, mixing is often incorporated into the system operation. These components can be used in process design and system optimization. While aerated static pile composting examples are used, these optimization components are equally important in all types of composting; enclosed or open, static or dynamic.

#### *Initial Mixture*

The initial mixture of biosolids and amendment or biosolids, amendment and recycle is extremely important. An initial mixture with an adequate total solids concentration will provide porosity for proper air distribution and structural integrity for pile construction.

*A number of variables must be taken into consideration while developing the initial mix quantities and the material flow diagram. These include:*

- *Biosolids, total solids, and volatile solids concentration*
- *Amendment total solids and volatile solids*
- *The desired initial mix total solids concentration*
- *The desired total solids concentration of the product*

Equations developed by Dr. Haug calculate the energy requirement to remove the moisture necessary to achieve the desired product solids and compare it to the energy potential, through biodegradable volatile solids, in the biosolids. If the energy within the biosolids is not adequate to achieve the desired product total solids concentration, an energy amendment must be added. Once the energy balance is achieved the anticipated initial mix total solids are determined. If the addition of energy amendment alone has not

resulted in the specified initial mix total solids, then additional structural amendment or recycled compost is added to achieve the desired total solids concentration.

As shown on Figure 4.1, the first example anticipates composting anaerobically digested biosolids. In this case, the biodegradable volatile solids contained within the biosolids are not adequate to achieve the desired product total solids, so an energy amendment is added. Once the energy balance has been met, additional amendment is added to achieve the desired initial mix total solids concentration. Woodchips are commonly used as structural amendment to maximize the porosity of the initial mixtures.

Unstabilized “raw” biosolids will have a higher volatile solids content. In this example, presented in Figure 4.2, it is anticipated that the volatile solids will be approximately 85 percent. In addition, the raw solids often dewater well and are expected to reach a total solids concentration of 24 percent. Because of the high volatile solids and cake solids, no energy amendment is required. However, a structural amendment is required to meet the desired initial mix total solids concentration of 40 percent.

The importance of representative data cannot be over emphasized. The solids content of the dewatered cake needs to be determined prior to establishing the initial mix ratios. A microwave oven can be used to quickly determine the total solids. The microwave oven reduces the time required to dry a sample from approximately three hours to twenty minutes.

In addition to total and volatile solids, the nutrients in the initial mix -- the carbon to nitrogen ratio (C:N) -- is an indicator of nutrient balance. A C:N ratio of 30:1 (30 parts carbon to 1 part nitrogen) is a good target. (Hoitink, H.A.J. and Kerner, H.M., 1993)

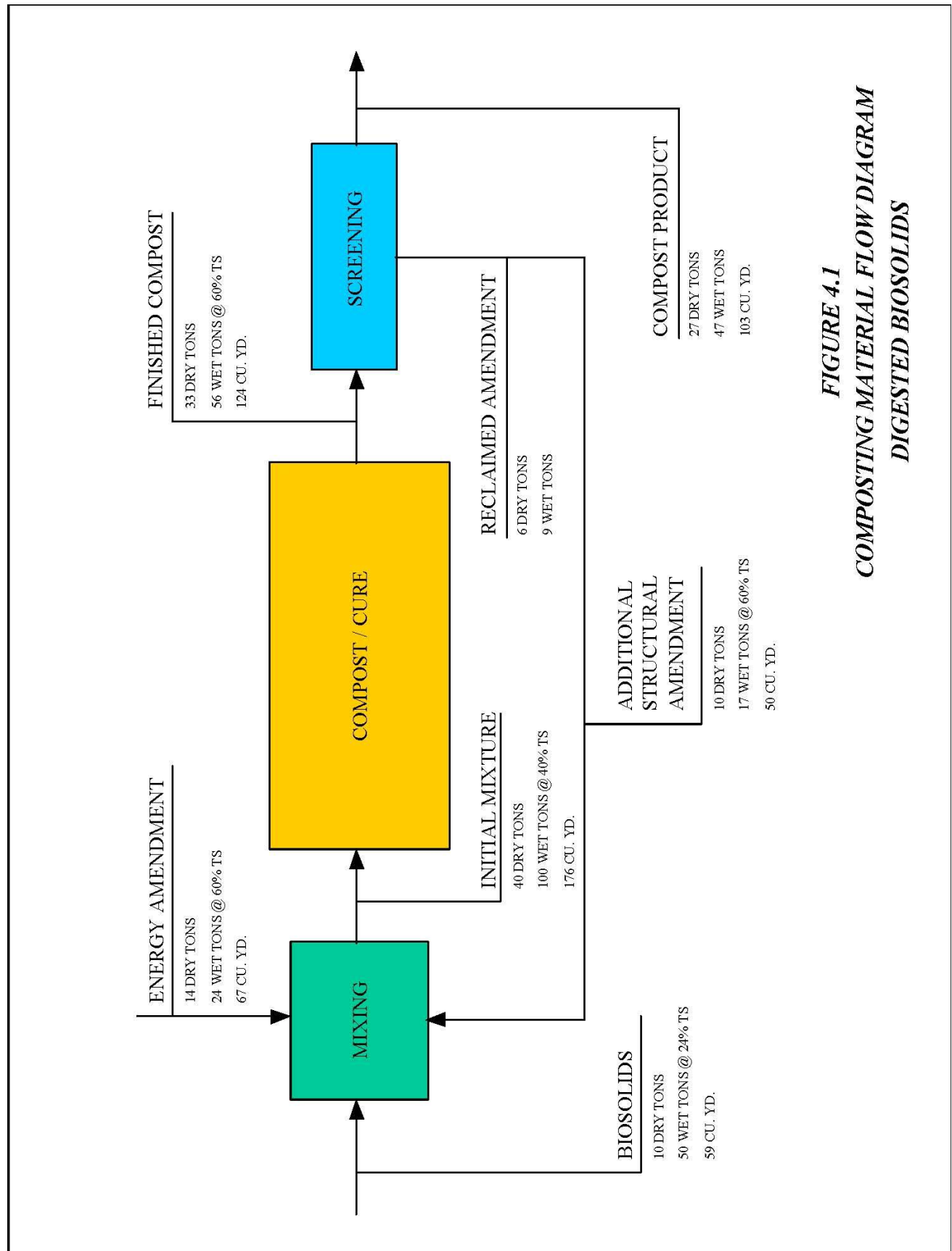
### *Aeration*

Aeration is extremely important in the composting process, performing three main functions:

- Provides oxygen for microbiological growth
- Removes moisture
- Controls temperature

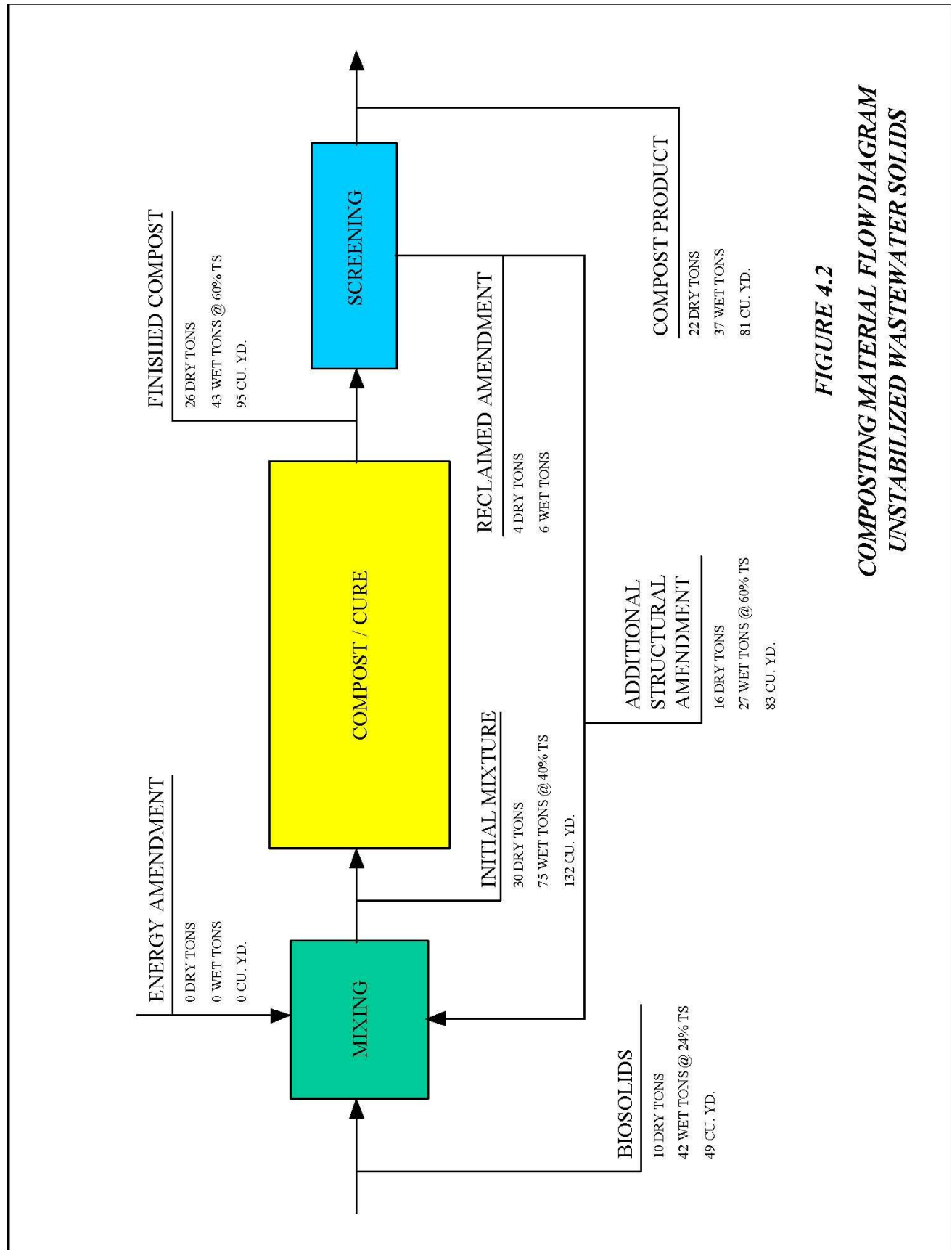
Aeration systems can be designed so that each fan can be operated in the positive mode, pushing air up through the pile, or negative mode, pulling air down into the pile. It is recommended that systems be operated in a negative mode until the temperature within the compost piles rise to between 55°C and 65°C. Once temperatures are within this range, the airflow should be reversed to positive to control the temperature, optimize stabilization and remove moisture through evaporative cooling.

As discussed by Dr. Haug, the aeration required to provide oxygen to the microorganisms within the compost is a fraction of that required to remove moisture and control temperatures. Following active pile construction, while the blowers are operating in the negative mode, the timers which operate the blowers are set to provide aeration between ten and twenty percent of the time.



**FIGURE 4.1**  
**COMPOSTING MATERIAL FLOW DIAGRAM**  
**DIGESTED BIOSOLIDS**





**FIGURE 4.2**  
**COMPOSTING MATERIAL FLOW DIAGRAM**  
**UNSTABILIZED WASTEWATER SOLIDS**

Once the pile temperature exceeds 55°C, the aeration mode is reversed. Air is drawn from the atmosphere and forced up through the piles. In the positive mode, the aeration system maintains the temperature between 55° and 65°C, allowing for continuation of compost stabilization while gradually removing moisture and increasing the total solids concentration. In the positive mode, the blowers may operate between 50 and 60 percent of the time. Temperatures should be monitored frequently and the timers on the fans adjusted accordingly.

### *Detention Time and Mixing*

The amount of time the initial mix is subjected to the composting process will impact the degree of product stability. While detention time has been a design and operating criteria, the actual time required to achieve a stable product has not been universally accepted.

Liquid stream processes in a wastewater treatment include design and operating parameters for hydraulic detention time (HRT) and solids residence time (SRT). The hydraulic retention is based on a single-pass liquid retention time. The solids residence time takes into account the volume of material recycled as part of the process. For a system without recycle the HRT and SRT are equal (Haug 1980).

The HRT and SRT are impacted by the conditions under which the process will operate and by the characteristics, total and volatile solids, within the initial mixture. Enclosed, mechanically mixed systems do not require the same composting period as an open static system.

A minimum solids retention of 60 days is recommended to produce a stable compost. A stable compost will not reheat or result in phototoxicity. Composting systems typically provide from 18 to 24 days in the active composting process followed by 30 to 45 days of compost curing.

To insure stability, it is recommended that the SRT be provided within the active composting and curing processes. The required storage and subsequent further stabilization should not be included in the SRT determination.

Following active composting, the compost is transferred to a curing area. This relatively simple step is extremely important in the composting process (Murray 1988). The curing process provides time for further stabilization and in some processes one of the few opportunities for mixing. The mixing performs three main functions:

- Restimulates heat production
- Exposes new surfaces to microorganisms
- Increases total solids concentrations

The mixing action which occurs during restacking stimulates further stabilization and eliminates areas of air channelization exposing new surfaces of material to the organisms within the piles.

### 4.6 Air Drying Systems

Air drying of stabilized, dewatered biosolids for additional stabilization and volume reduction is gaining popularity in regions with semi-arid climates. Air drying is viable in areas with dry climates, high evaporating rates and limited precipitation. Two methods of air drying are the “Two Summer Method” and the Rapid Drying Method.

#### 4.6.1 Two Summer Method

The USEPA Region VIII Office, located in Denver, Colorado, has developed requirements for facilities implementing air drying. The process is referred to as the “Two Summer” Method. The following requirements include recommendations made by the USEPA Pathogen Equivalency Committee (PEC). These are essentially the operational controls for this method.

- Biosolids must meet Class B requirements before being placed in storage piles for long-term treatment and must be stored over two summers (a minimum of 15 months).
- Biosolids must have a total solids content of at least 14 percent, but no more than 35 percent when the piles are formed.
- Piles shall be formed into windrows at least 3.5 feet high, but no more than 6.0 feet in height.
- During the first summer, the total solids in the pile should not exceed 60 percent.
- The average temperature of the pile must exceed 20°C for 12 months of the storage period (not necessarily consecutive months).
- The pile shall be turned at least three times (at evenly spaced intervals) during each summer period.
- Finished biosolids must not contain more than one viable helminth ova per four grams of total solids (dry weight basis) and must meet the fecal coliform limits (<1000MPN/gram of total solids) or the Salmonella limits (<3MPN/4 grams of total solids).
- Biosolids must be monitored for helminth ova once for each batch.
- At each turning of the pile, biosolids shall be monitored for volatile solids and total solids. The average pile temperature must be monitored monthly.
- Biosolids are not required to be monitored for enteric viruses if all other conditions listed for long-term treatment are followed.

Some of the current monitoring requirements may be reduced (e.g., helminth ova testing) as additional information about the process is collected and studied.

#### 4.6.2 Rapid Drying Method

In addition to the Two Summer Method, a number of facilities are investigating rapid air drying. The rapid drying method consists of applying stabilized, dewatered biosolids cake to an uncovered paved pad in a single two or three inch lift. The cake dries over a 7 to 10 day period and is turned using a mechanical auger. After drying, the air dried material is stockpiled prior to use.

Another approach to rapid drying consists of stockpiling cake prior to air-drying. After a

given period of time, the cake is applied to a pad and dried using the same process previously discussed. The merits of both approaches are being evaluated as part of a project sponsored by the Water Environment Research Federation.

The rapid drying method typically requires a smaller footprint than the Two Summer Method. General operational controls the rapid drying method include:

- Biosolids must meet Class B pathogen reduction requirements prior to being air dried.
- Biosolids should have a total solids content suitable for material handling.
- Biosolids should be placed in a single 2 to 3 inch thick lift and allowed to dry over a 7 to 10 day period.
- The lift should be turned at least three times during the drying period.
- Finished product must not contain more than one viable helminth ova per four grams of total solids (dry weight basis) and must meet the fecal coliform limits (<1000 MPN/gram of total solids) or the Salmonella limits (<3 MPN/4 grams of total solids).
- Biosolids shall be monitored for volatile solids and total solids before and following the drying process.
- Air dried material should be stockpiled prior to distribution. Dewatered cake may be stockpiled prior to air drying.
- To meet Vector Attraction Reduction requirements the air dried product, without unstabilized primary solids, must exceed 75 percent total solids.

### 4.7 Thermal Drying Systems

Thermal drying involves the application of heat to evaporate water from biosolids. Thermal drying reduces the moisture content to a level below that achievable by conventional mechanical dewatering methods. Advantages of thermal drying include reduced volume and further pathogen reduction. Thermally dried biosolids can be marketed as a fertilizer or soil conditioner. They are also acceptable for landfill disposal or incineration.

The drying rate depends on the internal mechanism of liquid flow and the external mechanism of evaporation. Understanding these mechanisms is necessary when investigating the drying characteristics, choosing the correct dryer, and determining the optimal drying conditions. While the internal and external mechanisms occur simultaneously, either mechanism may limit the drying rate.

The three general stages of thermal drying are as follows:

#### *Warm-up Stage*

The temperature and the drying rates increase to the steady-state conditions of the constant-rate stage. The time required for warm-up stage varies. Little drying occurs during this stage.

### *Constant-Rate Stage*

Interior moisture replace the external moisture as it evaporates from the saturated surface of the dewatered solids. The transfer of heat to the evaporating surface controls the drying rate. The constant-rate stage, typically the longest stage, results in most of the drying. The drying rate, essentially independent of the internal mechanism of liquid flow, depends on three external factors:

- Heat- or mass-transfer coefficient;
- Area exposed to the drying medium; and
- Temperature and humidity difference between the drying medium and the wet surface of the sludge.

### *Falling-Rate Stage*

The external moisture evaporates faster than it can be replaced by internal moisture. As a result, the exposed surface is no longer saturated, latent heat is not transferred as rapidly as sensible heat is received from the medium, the temperature increases, and the drying rate decreases. The drying rate at the transition point between the constant-rate and falling-rate stage is called the critical moisture.

Thermal drying systems can be grouped into direct and indirect categories. Each category -- and are discussed below.

#### **4.7.1. Direct Dryer**

Direct (convection) dryers include the flash and the rotary dryers.

##### *Flash Dryer*

The flash dryer, or pneumatic conveyor dryer, consists of a furnace, mixer, cage mill, cyclone separator, and vapor fan (USEPA, Process Design Manual for Sludge Treatment and Disposal, 1979). The mixer blends wet feed with dried product to achieve a mixture with 40 to 50 percent moisture (Metcalf and Eddy, Inc., 1979, and Niessen, 1988). The feed mixture discharges to a windbox on the cage mill. In the windbox, hot furnace gases at a temperature of 650<sup>o</sup> to 705<sup>o</sup> C (1,200<sup>o</sup> to 1,300<sup>o</sup> F) disperse the feed and rapidly evaporate moisture (USEPA, 1979). The cage mill mechanically agitates the solid-gas mixture to maximize the surface area contacting the hot gases and complete the drying process. The dry biosolids, with a moisture content of 8 to 10 percent, are pneumatically conveyed to a cyclone that separates the biosolids from the spent drying gases (USEPA, 1979).

Flash-dried biosolids are extremely dusty, creating the potential for fires and explosions. Dust also may complicate handling, storage, and marketing. Pelletization of the dried biosolids can improve the marketability, but at additional capital and operations and maintenance expense. The flash dryer, a complex system with several heat exchangers and numerous material handling processes, is vulnerable to severe abrasions by dried biosolids, especially the cage mill and cyclone separator, and fouling of the heat exchanger surfaces.

### *Flash Dryer Operational Controls*

Operation controls that should be considered for a flash dryer include:

- Moisture content – Maintain the moisture content of the feed below approximately 40 to 50 percent to ensure that the gas stream will readily disperse the feed without agglomeration and sticking on the conveyor walls (Williams-Gardner, 1982).
- Particle size – Detention time in the flash dryer typically only lasts a few seconds. Hence, the drying process is mainly a surface phenomenon that demands small particles to allow essentially instantaneous heat and mass transfers from interiors to exteriors.
- Gas velocity – The gas velocity sufficient to carry the largest particle to the cyclone separator typically ranges between 65 and 100 ft/sec (USEPA, 1979).
- Agitation – The cage mill must agitate the feed sufficiently to break up small clumps, exposing new surface areas and creating enough turbulence for dispersal and entrainment of particles in the hot gas stream.
- Air pollution control – Cool gases from the cyclone are preheated to approximately 760° F through heat exchange with combustion gases from the furnace. Then the cyclone gases, mixed with the combustion gases to attain a minimum temperature of 650° C (1,200° F), pass through the deodorizer preheater to the wet scrubber for particulate removal (Niessen, 1988). Preheater temperatures of 760° C (1,400° F) or higher may be required for effective odor control. Exhaust gases from the wet scrubber may require further treatment to reduce air emissions before exiting the stack.

### *Rotary Dryer*

The rotary dryer consists of a cylindrical steel shell, rotated on bearings, typically mounted with its axis at a small slope from the horizontal. Rotary dryers include both single-pass and multiple-pass systems.

In a rotary drum system a mixer blends wet feed with previously dried biosolids, reducing the moisture content of the feed material to 30 to 40 percent and dispersing the cake and beginning the formation of pellets (Niessen, 1988). The blended feed continuously enters the upper end of the rotary dryer along with hot furnace gases at temperatures ranging from 260° to 480° F (Niessen, 1988, and USEPA, 1979). The feed mixture and hot gases are conveyed, typically cocurrently, to the discharge end of the dryer. This creates a thin sheet of falling particles, which directly contact the hot gases and dry rapidly. The exhaust gases exit the dryer at 65° to 105° C (150° to 220° F) and travel to air pollution control equipment for odor and particulate removal (Niessen, 1988).

### *Rotary Dryer Operational Controls*

Operational controls that should be considered for a rotary dryer include:

- Moisture content – Maintain the moisture content of the feed below 30 to 40 percent by blending previously dried biosolids with the wet feed. This will ensure that particles do not stick to the conveyor, flights, and interior dryer walls.
- Length of drum – The length of the rotary drum typically ranges between 4 and

10 times the drum diameter for single-pass dryers and 2.5 and 3 times the drum diameter for multiple-pass dryers (Perry and Green, 1984).

- Drum rotation and slope – The rotary drum typically rotates at 5 to 8 rpm for single-pass dryers and 10 to 12 for multiple-pass dryers (USEPA, 1979). The drum slope is typically 2 to 6 percent. Multiple-pass dryers are not sloped.
- Flight geometry – The design of the axial flights depends on the handling characteristics of the material. Many dryers are designed with flat radial flights without any lips for the first 30 percent of the dryer and with flights with 45- to 90deg lips for the remaining sections of the dryer. Sometimes with cocurrent gas flow, flights are at the end of the dryer to reduce the entrainment of dried particles in the exit gas.
- Gas velocity – Gas flow through the drum may be either cocurrent or countercurrent to the feed flow. Gas velocities typically are limited to 4 to 12 ft/sec. Gas velocity also must be controlled to obtain an adequate gas retention time and efficient heat transfer between the gas and feed.
- Air pollution control – Air pollution control typically includes treatment for particulate removal and for odor control by wet scrubbers or thermal oxidation.

### *Indirect Dryers*

Indirect (conduction) dryers include the paddle, hollow-flight, disc, and multiple-effect evaporation dryers.

### *Paddle, Hollow-Flight, or Disc Dryer*

These dryers consist of a stationary horizontal vessel or trough with a jacketed shell through which a heat-transfer medium, typically steam, circulates. The vessel contains a rotating agitator assembly with a series of agitators, discs, flights, or paddles, mounted on a rotating shaft. The rotor and agitators allow the heat-transfer medium to circulate through the hollow core. Therefore, the agitators not only transport the feed through the unit, but also provide an additional heat-transfer surface that contacts the feed.

Wet feed continuously flows into the vessel, and the agitator surface, pitched at a slight angle, conveys the solids through the dryer. In some dryers, the agitators are arranged on the shaft to intermesh, thereby producing the maximum possible relative movement between the heated surfaces and the feed to enhance drying. They are susceptible to damage from physical contaminants that may be contained in the feed. In other dryers, stationary agitator ploughs or breaker bars are located between the rotating agitators to enhance mixing and prevent solids build-up on the agitator surface.

The heat-transfer medium circulates, typically countercurrent, through the jacketed shell and hollow agitator assembly. The transfer of heat raises the temperature and evaporates water from the solid surface. The evaporated water is transported from the surface of the solids and out of the dryer by low -- volume sweep gases or exhaust vapors. A weir at the discharge end of the dryer ensures complete submergence of the heat-transfer surface in the material being dried.

### *Operational Controls for Paddle, Hollow-Flight or Disc Dryers*

Operational controls for paddle, hollow-flight, or disc dryers include:

- Moisture content – The moisture content of the feed is typically decreased to 40 to 50 percent by blending dried biosolids with wet feed to reduce agglomeration and fouling of the dryer surfaces (Niessen, 1988). Some manufacturers claim to be capable of drying without backmixing dried product. This approach must provide enough power to turn the agitator shaft to break up the clumps against internal breaker bars and also must provide a strong enough agitator shaft to avoid damage.
- Agitation – Agitation improves the rate of drying. As more individual particles are exposed to the heat-transfer surfaces, bed temperatures within the dryer become more uniform.
- Gas velocity – The paddle, hollow-flight, or disc dryer typically uses little or no sweep gas. When used, the sweep gas velocity typically is controlled at approximately 0.5 ft/sec.

#### **4.7.2 Dryer Selection**

The type of dryer selected is dependent on a number of variables. These include:

- Scale
- Dryer capacity
- Product use

Indirect dryers typically are popular for smaller operations and in “scalping” operations prior to incineration. Because indirect dryers generate limited quantities of noncondensable gas, the volume of gas requiring treatment is significantly less than direct dryer systems. Likewise, dust problems are reduced because of the small volume of sweep air used in indirect drying. Indirect dryers allow operation under a vacuum or closely controlled atmosphere. Therefore, fire and explosion hazards are reduced.

The dried biosolids product from indirect drying tends to be dustier than the direct rotary dried product. In some facilities dust has been greatly reduced by adding a waste vegetable oil to the product. The oil is added using a chemical metering pump to an outfeed screw conveyor.

If the goal is to achieve a final product solids content of 65 to 85 percent, then indirect dryers offer a relatively high thermal efficiency. However, to achieve a solids content of 92 percent with indirect dryers for safe product storage, a high temperature must be used, drying time must be increased, or dried biosolids must be recycled and mixed with the feed. These steps will reduce the thermal efficiency advantage of indirect dryers.

#### **4.7.3 Critical Control Points / Operational Controls**

Controls that should be considered for dryers include:

- Backmixing Equipment - Paddle mixers, pug mills, and hammer mills are used to mix recycle and feed. Heavy-duty equipment is needed to reduce imbalance and bearing problems that result from fouling.



- Feeder Selection - Wet cake requires uniform feeding to maintain effective drying. A self-cleaning, intermeshed twin-screw feeder will effectively control solids build-up on the screw conveyors.
- Construction Materials - The composition of the feed significantly affects the construction materials selection for a dryer and ancillary equipment. Although mild steel typically may be appropriate for components that contact dry solids, the abrasiveness of the feed calls for consideration of stainless steel and hard surfacing of areas prone to wear to avoid frequent equipment replacement. Dryer and ancillary equipment need to be airtight and well insulated to reduce heat losses and consequent loss of efficiency.
- Storage - Storage prior to and following the drying process is a very important system element. Sufficient storage is required upstream of the drying system to accommodate drying-system shutdowns and to attenuate variations in solids production. Post drying storage should be sufficient to handle fluctuations in demand. Typically, between 30 and 90 days of product storage is a reasonable allowance for drying and marketing operations.

### *Fire Hazard/Explosion Reduction*

Dried product is often stored in silos, sealed from the outside environment. This fire hazard can be reduced by the addition of nitrogen gas to the storage silo to create an oxygen free environment. Pelletization prior to storage will reduce the fire hazard by reducing the dust associated with the product. The best method of preventing spontaneous combustion is achieving a product with 92 percent or higher solids concentration. Explosion hatches to release pressure should be provided in the storage bins. Dried biosolids produce a fine organic dust, which can reach explosive concentrations. The hazard is reduced by keeping the dryer temperature less than approximately 540°C (1,000°F).

The dryer and dried biosolids conveying system from the process air streams may be designed to control dust by maintaining a negative pressure in dust prone areas. Also, high-efficiency cyclones, Venturi scrubbers, bag houses, or a combination of these can be provided to remove dust and fine particles from the process air streams. Well-trained operators, controls with interlocks, and monitoring equipment are important considerations for reducing the fire hazard. A centralized fire extinguisher system that will inject carbon dioxide into the dryer or a water dousing system are other design considerations for controlling fires. A nitrogen gas blanket and product precooling can reduce the hazard of fire in the storage system.

- Emissions and Odor Control - Dryer equipment and material handling and storage should be enclosed and vented to dust collection and odor particulate removal control equipment. Chemical scrubbing and thermal oxidizers are typically used to treat odors. Cyclone separators, wet scrubbers, bag houses, or a combination are used to remove particulates.
- Sidestreams - Liquid sidestreams produced by condensation of water vapors from dryers contain both organic oils and ammonia. Wet scrubbers and other ancillary equipment will create other sidestreams. The effects of all sidestreams on the

wastewater treatment facility should be considered.

- Safety - The design considerations for a thermal drying system include an emphasis on system safety. In addition to reducing fire hazards, continuous monitoring of temperature, feed rates, air rates, and drying time are recommended. Instrumentation is best positioned where operators can easily observe and respond to process indicators or alarms. An automatic shutoff, as a backup to the alarm system, is also recommended.
- Heat Recovery - Heat recovery and reuse is recommended wherever feasible. Recovered heat from dryer or furnace exhaust may be reused to preheat combustion air, preheat feed, or supplement facility heating requirements.
- Pilot Testing - Many manufacturers have a laboratory for demonstrating their drying equipment with a customer's feed material. In addition, some manufacturers have pilot scale equipment. Pilot testing is recommended to obtain actual operating data prior to design.

## References

Benfield, L.D., and Randall, C.W., (1980), *Biological Process Design for Wastewater Treatment*, Prentice-Hall, Englewood Cliffs, N.J.

Gould, M.S., and Drnevich, R.F., (1978), “*Automated Thermophilic Aerobic Digestion*”, *J. Environ. Eng.*, 104, 259.

Hartman, R.B., et al., (1979), “*Sludge stabilization through aerobic digestion*”, *J. Water Pollut. Control Fed.*, 51, 2353

Haug, R.T., (1980), *Compost Engineering, Principles and Practice*, Ann-Arbor Science, Ann Arbor, Michigan.

Hoitink, H.A.J. and Kerner, H.M., (1993), *Science and Engineering of Composting: Design, Environmental, Microbiological and Utilization Aspects*, The Ohio State University, Wooster, Ohio.

Matsch, L.C. and Drnevich, R.F., (1977), “*Autothermal aerobic digestion*”, *J. Water Pollut. Control Fed.*, 49, 296.

Mavinic, D.S. and Koers, D.A., (1979), “*Performance and kinetics of low temperature, aerobic sludge digestion*”, *J. Water Pollut. Control Fed.*, 51, 2088.

Maxwell, M.J., et al., (1992), “*Impact of New Sludge Regulations on Aerobic Digester Sizing and Cost Effectiveness*”, Paper presented at 65th annual Conf. Water Environ. Fed., New Orleans, La.

Metcalf and Eddy, Inc., (1991), *Wastewater Engineering, Treatment, Disposal and Reuse*, Third Edition McGraw-Hill, Inc., New York, N.Y.

Niessen, W.R., (1988), “*Thermal Processing of Wastewater Treatment Plant Sludges*”, Proceedings from National Conference of Municipal Sewage Treatment Plant and Sludge

Perry, R.H., and Green, D.W. (Eds.), (1984), *Perry’s Chemical Engineers’ Handbook*, McGraw-Hill, Inc., New York N.Y.

Reynolds, T.D., (1973), “*Anaerobic Digestion of Thickened Waste Activated Sludge*”, Proceedings from 28th Ind. Waste Conf., Purdue Univ., West Lafayette, Ind.

Schafer, P., and Mathis, A., (1987), “*Making Dried Sludge Marketable*”, Paper presented at Water Pollut. Control Fed. Spec. Conf., Los Angeles, Ca.

United States Environmental Protection Agency, (1974), “*Process Design Manual for Upgrading Existing Wastewater Treatment Plants*,” (USEPA-625/1/71-004a)

United States Environmental Protection Agency, (February, 1993), "*Standards for the Use or Disposal of Sewage Sludge*," Fed. Regist., 58,32,40 CFR Part 503 Rule

United States Environmental Protection Agency, (1994), "*A Plain English Guide to the USEPA Part 503 Biosolids Rule*", (USEPA/832/R-93/003)

United States Environmental Protection Agency, (September, 1979), "*Process Design Manual for Sludge Treatment and Disposal*", (USEPA 625/1-79-011)

Water Environment Federation, (1990), "*Operation of Municipal Wastewater Treatment Manual of Practice No.11*, Alexandria, Va.

Water Environment Federation, (1992), "*Design of Municipal Wastewater Treatment Plants*", Manual of Practice No.8, Alexandria, Va.; Am. Soc. Civ. Eng., Manual and Report on Engineering Practice No.76, New York, N.Y.

Williams-Gardner, A., (1982), *Industrial Drying*, Gulf Publishing Company, Houston, Tx.

## Chapter 5 – Solids Thickening and Dewatering Systems

---

Thickening and dewatering are important components of biosolids management programs. The proper solids concentration is critical in stabilization processes from aerobic digestion to advanced alkaline stabilization. The recent advances in solids thickening and dewatering have increased performance and capture rates while often reducing chemical and polymer consumption, electrical usage, space requirements and odor potential. In addition, automation has reduced the degree of operator attention required, further reducing the cost of operation.

When evaluating thickening and dewatering equipment, it is important to "start with the end in mind". Consider downstream processes and alternatives when establishing design criteria. For example, thickening waste activated solids prior to anaerobic digestion will increase the detention time in the process. However, the volumetric loading to the digester also should be considered. Maximizing thickening efficiency may not maximize digester performance.

Consider the impact thickening or dewatering will have on the sidestreams returning to the liquid stream treatment process. Increased dewatering efficiency will reduce cake transportation cost or potentially eliminate the need for supplemental fuel in an incineration process. However, it also will create a sidestream flow returning to the liquid stream process of the wastewater treatment facility. This sidestream could impact the capacity of the facility and ultimately its performance.

Also consider the impact solids conditioning will have on biosolids quality and characteristics. The use of lime as a conditioning agent as part of recessed chamber press dewatering operation adds solids and raises the pH of the biosolids. These additional solids may impact downstream processes. The increased pH may be a benefit in meeting pathogen reduction requirements. The increased pH also will result in the release of ammonia. This release may create an odor concern for some processes.

Changing polymers or changing from another conditioning agent to a polymer may impact the characteristic of biosolids. In a number of instances, changing polymers is believed to be the cause of odors. More data is required before any definitive conclusions can be made. However, noting the odor associated with a biosolids cake or product prior to and after any change in conditioning agents is recommended. The importance of bench scale testing for performance and product characteristics cannot be overemphasized.

### 5.1 Solids Thickening

Solids thickening reduces the volume entering subsequent solids processing steps. Thickening technologies include gravity, centrifugal thickening, gravity belt thickeners, and rotary drum thickeners. These thickening methods differ significantly. The following sections describe the processes and present design information and operational controls.

#### *General Controls*

A number of controls should be considered in the design and operation of any solids thickening

technology. They include:

- Dry weight of solids to thicken
- Downstream solids handling processes
- Period of thickening operation
- Relationship of desired period of operation to downstream process operation
- Pre and post thickening storage requirements and capacity
- Solids conditioning requirements

Each control should be addressed in the planning or optimization of a solids thickening system.

### 5.1.1 Gravity Thickeners

In gravity thickening, solids are concentrated by the gravity-induced settling and compaction. Gravity thickening of solids provides a two-fold benefit: concentration and flow equalization/storage. Gravity thickeners typically are used for thickening of primary solids. They also are used to thicken combinations of primary and waste-activated solids (WAS) and, in some cases WAS only. Primary solids gravity thicken easily as they typically settle quickly and achieve a high solids concentration, 4 to 6 percent, without chemical conditioning. The presence of (WAS) complicates gravity thickening and typically results in sporadic performance. WAS settle slowly and resist compaction, resulting in reduced loading rates. WAS also have a tendency to stratify because of the flotation effect of gas produced from continuing biological activity.

Gravity thickeners typically consist of a circular tank with a side water depth of 10 to 13 feet. Gravity thickener tank diameters range significantly. Floor slopes of 2:12 to a 3:12 are typical. (WEF MOP 8, 1992)

#### *Operational Controls*

A number of items should be considered in the design and operation of a gravity thickening system. They include:

- Solids Loading Rate
- Hydraulic Overflow Rate
- Odor Potential

#### *Solids Loading*

A critical consideration for gravity thickening is the solids loading expressed as total solids per unit area per unit time. Typical solids loading rates for various types of solids are presented in Table 5.1. If site-specific solids settling or pilot scale data can be obtained, they should be used for design. Table 5.1 also provides the typical concentrations that will be achieved by gravity thickening.

#### *Overflow Rate*

Another important consideration is the overflow rate. Overflow rates between 380 and 760 gpd/sq ft are typically used for primary solids. Overflow rates in the 100 to 200 gpd/sq ft range are used for thickening secondary solids. A high overflow rate can result in excessive solids carry -- over. A low overflow rate (corresponding to high thickener detention times) can result in septic conditions causing floating solids and odors. A

dilution water supply is often used to maintain minimum overflow rates and minimize septicity problems. Chlorine, potassium permanganate, or hydrogen peroxide addition to the thickener, usually through the dilution supply, can also be used to reduce odor.

*Odor Potential*

Gravity thickeners are often a significant odor source in a treatment facility. They are typically covered to control odors for treatment.

**Table 5.1 Typical gravity thickening performance and loading rates for various types of solids**

Type of Solids	Feed Solids Concentration, %	Expected Underflow Solids Concentration, %	Solids Mass Loading lb/d/sq ft
<b>Separate Solids</b>			
Primary	2.0-7.0	5.0-10.0	20-30
Trickling Filter	1.0-4.0	3.0-6.0	8-10
Rotating Biological Contactor (RBC)	1.0-3.5	2.0-5.0	7-10
<b>Waste-activated Solids (WAS)</b>			
Primary+WAS	0.5-1.5	4.0-6.0	5-14
	2.5-4.0	4.0-7.0	8-16
Primary +Trickling Filter	2.0-6.0	5.0-9.0	12-20
Primary+RBC	2.0-6.0	5.0-8.0	10-17
<b>Tertiary Solids</b>			
High Lime	3.0-4.5	12.0-15.0	25-60
Low Lime	3.0-4.5	10.0-12.0	10-30
Iron	0.5-1.5	3.0-4.0	2-10
Alum	0.5-1.5	2.0-4.0	2-10

Source: WEF MOP 8, 1992

**5.1.2 Gravity Belt Thickeners**

Gravity belt thickeners (GBT) have become a popular method of thickening WAS. They have low energy requirements, are relatively easy to operate and require limited attention following start-up. In gravity belt thickening, solids are concentrated as free water drains by gravity through a porous horizontal belt. Successful gravity belt thickening requires chemical conditioning, typically using a polymer. GBTs are particularly suitable for the thickening of WAS before further processing and for thickening digested sludges as a volume reduction measure before transport.

*Equipment and operating variables that influence GBT performance for a particular solid include polymer dose, feed rate, polymer and solids mixing, belt speed, ramp use and angle, belt type, and plow configuration.*

Solids capture for WAS or digested solids thickening using a GBT typically will range from 90 to 98 percent with a polymer addition of 3 to 10 lbs/dry ton. Thickened WAS

concentrations of 4 to 8 percent are readily achievable; digested biosolids can be thickened to 10 percent.

Equipment and operating variables that influence GBT performance for a particular solid include polymer dose, feed rate, polymer and solids mixing, belt speed, ramp use and angle, belt type, and plow configuration.

### *Operational Controls*

A key operational control consideration for a GBT is the feed rate. Loading rates to gravity belts vary significantly. A loading rate at or below 150 gpm/meter of belt width should provide good performance.

Other operational control considerations for GBT installations include:

- The need for adjustable rate solids feed and polymer feed
- Pressure drop requirements for the solids/polymer mixing device
- Provision of adequate flow and pressure for the belt washwater supply
- Building ventilation and odor control

### **5.1.3 Dissolved Air Flotation Thickeners**

Dissolved air flotation (DAF) thickening concentrates solids as a result of the attachment of microscopic air bubbles to suspended solids, reducing their specific gravity to less than that of water. The attached particles then float to the surface of the thickener tank for removal by a skimming mechanism. DAF thickening has been commonly used for WAS. It generally is not used for primary solids or attached growth solids because gravity settling for these types of solids is more economical.

The feed solids to a DAF thickener are normally mixed with a pressurized recycle flow before entering the tank. The recycle flow rate typically varies up to 100 percent of the feed rate; the recycle flow is pressurized up to 75 psig. The recycle flow is normally DAF tank effluent, although providing water from another source as a backup is recommended. The recycle flow is pumped to an air saturation tank where compressed air enters and dissolves into the recycle. As the pressurized recycle containing dissolved air is admitted back into the DAF tank, the pressure release from the recycle forms the air bubbles for flotation. A typical bubble-size distribution would contain bubble diameters ranging from 10 to 100  $\mu\text{m}$ . Solids and air particles float and form a sludge blanket on the DAF tank surface while the clarified effluent flows under the tank baffle and over the effluent weir. Capture of suspended solids is typically greater than 90 percent.

Polymer is frequently used to enhance DAF performance. Polymer addition allows an increase in solids loading rates and solids capture, but less effectively increases float solids concentrations. Polymer should be introduced at the point where the recycle flow and the solids feed are mixed to get the best results. Good mixing to ensure chemical dispersion while minimizing shearing forces will provide the best solids-air bubble aggregates.

### *Operational Controls*

The solids loading rate of a DAF thickener is generally 0.4 to 1.0 lb/hr/sqft to produce a thickened WAS of 3 to 5 percent TS. Adding polymer increases the solids loading rate to



as much as 2.0 lb/hr/sq ft without negatively impacting performance. Polymer additions of 4 to 10 lbs per dry ton are common. WAS sludge volume index (SVI) is a solids characteristic that correlates well with DAF performance. An SVI of 125 or less is required for optimum performance.

DAF thickeners are designed hydraulically to operate in the range of 0.5 to 2 gpm/sq ft, with a suggested maximum hydraulic loading of 0.8 gpm/sqft.

The quantity of air provided in DAF thickening is defined in terms of an air: solids dimensionless weight ratio. Adequate flotation is achieved in most municipal wastewater thickening applications at ratios of 0.02 to 0.06.

### 5.1.4 Rotary Drum Thickeners

A rotary drum or rotary screen thickener functions like a gravity belt thickener allowing free water to drain through a porous media while solids are retained on the media. Rotary drum thickeners are often used as a prethickening step with belt filter press dewatering. They are well suited for the thickening of high-fiber sludges such as those in the pulp and paper industry and also for thickening either raw or digested biosolids that contain a significant primary solids fraction. Their success with municipal WAS is variable and dependent on solids characteristics. Polymer requirements are a concern because of floc sensitivity and shear potential in the rotating drum. The thickener uses a rotating drum with wedge wires, perforations, stainless steel fabric, polyester fabric or a combination of stainless steel and polyester fabric as the porous media.

The drum either is equipped with a center shaft mounted on a steel frame or is mounted on four trunnion wheels supporting its outer perimeter. A variable speed drive unit rotates the drum at approximately 5 to 20 rpm. Conditioned solids enter the drum and filtrate drains through the screen openings. Solids are conveyed along the drum by a continuous internal screw or diverted angle flights and exits through a discharge chute. Washwater is used to flush the inside and outside of the drum cleaning the screen openings of solids.

#### *Operational Controls*

The performance of a rotary drum thickener is similar to GBTs. Rotary drum thickeners typically require less space than other thickening methods and have a relatively low capital cost. The need for polymer conditioning and necessary operator attention are O&M cost related considerations. Rotary drum thickeners offer the flexibility of varying process performance with sludge feed and polymer feed rate control and drum speed adjustment. Equipment sizes and configurations vary among manufacturers. Design considerations include control of solids and polymer feed rate, drainage, and screen washwater supply.

*Solid bowl conveyor centrifuge technology has proven to be widely successful in solids thickening.*

### 5.1.5 Centrifuge Thickeners

Centrifuge thickeners use centrifugal force to separate solids. Centrifuges are commonly used for thickening WAS and other biological solids. They also have been used to thicken stabilized biosolids to reduce transportation costs. The most common centrifuge technology is the solid bowl conveyor, which has proven to be widely successful in solids thickening. The two basic configurations of solid bowl conveyor centrifuges are countercurrent and cocurrent. The primary differences between thickening and dewatering centrifuges are the configuration of the conveyor toward the liquids discharge end of the machine and the location and configuration of the solids discharge ports.

#### *Operational Controls*

Features differ substantially among centrifuge manufacturers. Table 5.2 lists the major design and operating variables that influence the operation of a horizontal solid bowl centrifuge. In general, performance of a centrifuge, as measured by thickened solids and solids capture, can be adjusted to desired values by modifying feed flow rate, bowl and conveyor differential speed, polymer addition, and pool depth. For a particular solid, polymer addition allows increasing the hydraulic loading while maintaining solids capture and thickening solids performance. Polymer use also improves achievable solids capture efficiencies typically to over 90 percent.

**Table 5.2 Factors affecting centrifugal thickening.**

<b>Basic Machine Design Parameters</b>	<b>Adjustable Machine and Operational Features</b>	<b>Sludge Characteristics</b>
Flow Geometry	Bowl Speed	Particle and Floc Size
Countercurrent	Bowl and Conveyor	Particle Density
Co-Current	Differential Speed	Consistency
Internal Baffling	Pool Depth and Volume	Viscosity
Bowl/Conveyor Geometry	Feed Rate	Temperature
Diameter	Hydraulic Loading	SVI
Length	Solids Loading	Volatile Solids
Conical Length	Flocculent Use	Sludge Age
Pitch and Lead		Sludge Septicity
Maximum Pool Depth		Floc Deterioration
Sludge and Flocculent Feed Points		
Maximum Operating Speed		

WEF MOP-8, 1992

Design considerations for centrifuge thickening include:

- Provide effective wastewater degritting and screening or grinding. Where wastewater screening or grinding is inadequate, grinders should be provided on the solids feed to the centrifuge to avoid plugging problems.
- Use adjustable rate feed pumping with positive flow rate control from a feed source that is relatively uniform in consistency. A mixed storage or blend tank is recommended.
- Consider centrate-handling delivery to either primary or secondary treatment

- processes, venting, and foam suppression.
- Provide water for centrifuge flushing when equipment shutdown occurs.
  - Consider the need for heated water supply to periodically flush grease buildup.
  - Ensure proper ventilation and consider odor control.
  - Consider struvite formation potential when thickening anaerobically digested sludge.
  - Provide flexibility within the polymer feed system.

### 5.2 Solids Dewatering

Dewatering is an important step in a number of solids and biosolids management programs. Dewatering removes a significant amount of water from the solids entering the process and greatly reduces the volume. Dewatering solids from 2 percent to 20 percent reduces the volume of the material an order of magnitude. At 2 percent, one dry ton will require 60 cubic yards of storage volume. Dewatering to 20 percent solids reduces the volume to 6 cubic yards. There are a number of dewatering technologies available. The following sections describe the processes and present design and operational information.

#### *General Operational Controls*

A number of operational controls should be considered in the design and operation of any dewatering system. They include:

- Dry weight of solids to dewater
- Type of solids being dewatered
- Downstream solids handling process
- Period of dewatering operation
- Relationship of desired period of operation to downstream process operation
- Pre- and post-dewatering requirements and capacity
- Dewatered solids transport
- Solids conditioning requirements

Each operational control should be addressed in the planning or optimization of a dewatering system.

*Solids are dewatered using three operational stages: chemical conditioning, gravity drainage, and compaction in a pressure and shear zone.*

#### 5.2.1 Belt Filter Press Dewatering

Belt filter presses have one or more moving belts to dewater solids using a combination of gravity drainage and compression. Solids are dewatered using three operational stages: chemical conditioning, gravity drainage, and compaction in a pressure and shear zone.

A number of variables affect the performance of the belt filter press:

- Solids characteristics
- Type of chemical conditioning

- Belt pressures developed

Press configuration, type of gravity drainage, belt speed. Although performance data indicate significant variations in the dewatering capability of different types of solids, a belt filter press is generally capable of producing a dewatered cake between 18 and 25 percent total solids. Solids capture rates ranges from 80 to 95 percent.

The operation of the belt filter press begins when the polymer-flocculated solids enters the gravity drainage zone. Filtrate from the gravity zone is collected and piped into a drain system. The thickened solids leave the gravity zone and enter the compression zone. Dewatering occurs as the solids are squeezed between two porous belts. The pressure increase begins in the “wedge” zone where the two belts are brought back together following the gravity zone. Pressures continue to increase as the solids pass through the wedge zone and enter the high -- pressure or drum pressure stage of the belt filter press. The belts travel around several drums or rollers of varying diameters to maximize shearing action. The shear forces in the high -- pressure section are great enough to release some of the bound water and possibly some intercellular water.

The major components of the belt filter press include its frame, belts, rollers and bearings, belt tracking and tension system, belt wash system, cake discharge blades, drive system, control panel, and flocculation system. Support systems for the belt filter press include polymer conditioning, feed pumps, belt washer supply, and dewatered cake conveyance. Information regarding the components and the support systems can be found in WEF Manual 8 1992. The information is summarized in this section.

### *Frame*

The structural mainframe of the belt filter press is normally constructed of steel. All components of the belt filter press system are supported and attached to this frame. Corrosion is an important consideration because of the variety of environments and material to be handled. Coatings that provide corrosion resistance and longevity include epoxy paint systems, hot dipped galvanizing, and fiberglass encapsulation. Because polymer can attack the zinc in galvanized steel, frequent washdown of the frame is necessary.

### *Belts*

Most belt filter presses have two sets of operating belts made of woven synthetic fibers. Seamed and seamless belts are available. Seamed belts have either stainless steel clipper-type seams or zipper seams; they tend to wear quickly at the seam. This, in turn, wears the rollers and the doctor blade. Zipper-type seams provide less discontinuity than clipper seams and have a longer life. Seamless belts are continuously woven endless belts that have a longer service life than any other type belt. Belts should be evaluated relative to the expected solids characteristics, solids capture required, and durability.

### *Rollers*

Rollers support the belts and provide tension, shear, and compression through the pressure stages of the belt filter press. Rollers can be made of a variety of materials

including stainless steel. Corrosion and structural considerations are important. Rubber coatings are generally preferred, at least on the drive rollers. Roller deflection at the rated belt tension of at least 40 lb/in should be limited to 0.05 in. at roller midspan. Perforated stainless steel rollers are used in initial pressure stages by some manufacturers to enhance drainage.

### *Bearings*

Bearings are an extremely important part of the belt filter press. Many manufacturers mount the bearings directly on the mainframe, making them accessible for maintenance and service on the exterior of the units. These bearings are normally of the pillow-block-type construction and should be rated for a life of 300,000 hours. Bearings should be double- or triple-sealed to reduce contamination and wear. They also should be self-aligning. Split-house type bearings are necessary when ready access is unavailable outside of the mainframe. A centralized lubrication system is recommended to enhance maintenance.

### *Belt Tracking*

A belt-tracking system keeps the belts centered on the rollers. The belt-tracking system requires sensing arms connected to a limit switch to sense movement in belt position. A continuously adjustable roller senses a shift in belt position and automatically adjusts the belt position; this roller is connected to the response system that is pneumatic, hydraulic, or electrically operated. An automatic, continuous modulating control must be an integral part of the system.

### *Belt Tension*

Belt tension during operation is both maintained and controlled pneumatically, hydraulically, or mechanically. Increasing belt tension increases belt-dewatering pressure. Several manufacturers offer separate control systems for both the upper and lower belts so that each can be adjusted independently. An automatic adjustment system, similar to that described for tracking, is necessary. Belt life decreases as belt tension increases.

### *Belt Washing*

A high-pressure belt wash system cleans each belt after dewatered cake discharge. A belt wash station is normally provided for each belt. The belt wash system provides a high-pressure water spray to remove any residual solids, grease, polymer, or other material that binds the belt. Self-cleaning nozzles are suggested, however, most manufacturers provide a manual cleaning feature that includes a hand-wheel operated brush device mounted internally in the nozzle header pipe.

### *Drainage*

Drainage must be provided to collect and transport filtrate and washdown water. Collection-housing units and drainage piping, connected to the belt filter press, should discharge to a sump or floor drain system directly below the unit. When sizing the drainage system, the filtrate plus washwater flows must be included. A 2.0 meter belt press can discharge from 175 to 200 gpm of filtrate and washwater. The sidestream flow

from the dewatering system should be discharged.

### *Discharge Blades*

The discharge or doctor blade is normally a knife-edge constructed of ultrahigh molecular weight plastic. The doctor blade, typically located at the outlet end of the high-pressure section, scrapes the solids from the belt onto a collection system. The blade's adjustment should be inspected frequently as poor blade adjustment reduces belt life. Doctor blades can be reground or sharpened by a machine shop to extend useful life. Double-edged blades should be considered to reduce frequency of replacement or resurfacing.

### *Operational Controls*

A number of items should be considered in the design and operation of a belt filter press. Control include:

- Hydraulic and Solids Loading Rates
- Solids Conditioning
- Flocculation System
- Systems Control

### *Loading Rates*

The capacity of a belt filter press is based on hydraulic and solids loading rates. The solids loading rate is typically the more limiting of the two. Hydraulic loading rates to a belt filter press range between 45 and 60 gallons per minute per meter of belt filter press width, (gpm/m). Solids loading rates range between 480 and 600 dry pounds per hour per meter of belt filter press width, (dlb/hr/m). Table 5.3 presents hydraulic and solids rates for belt filter presses dewatering a variety of solids. The table presents ranges of loading rates applied and the results experienced.

### *Solids Conditioning*

Polymer conditioning systems typically include chemical metering pumps, polymer storage and mixing equipment, polymer and solids mixer, and controls. Some installations operate directly from the drums of delivered polymer, eliminating the need for mixing and conditioning tanks and feed pumps.

### *Flocculation System*

Belt filter presses typically have a system to flocculate and agglomerate the solids after polymer addition. This system normally has a flocculating tank unit, a static mixer, or an inline Venturi-type mixer. Each unit is design to mix the solids with the conditioning chemicals. Flocculation tanks provide a longer detention time and allow slower mixing of the solids and the polymer. This often results in improved performance.

### *System Controls Panel*

Controls panel is designed for each application to operate the belt filter presses and the auxiliary systems. Critical alarms should be annunciated and a system emergency power shutdown should be provided. The controls should be located in a dry area within sight of the belt press but away from potentially corrosive atmosphere or spray from equipment washdown.

**Table 5.3 Typical Belt Filter Press Performance Data**

Type of Solids	Feed Solids %	Loading per meter belt width		Dry polymer lb/dry ton dry solid	Cake solids %	
		gpm	dlb/hr		Typical	Range
Raw primary (P)	3-7	30-51	800-1200	2-8	28	26-32
Waste activated solids (WAS)	1-4	10-40	100-400	6-20	15	12-20
P+WAS (50:50)	3-6	21-51	400-700	4-16	23	20-28
P+WAS (60:40)	3-6	21-51	400-700	4-20	20	18-25
P+Trickling Filter (TF)	3-6	21-51	400-700	4-16	25	23-30
Anaerobically digested:						
P	3-7	30-51	800-1200	4-10	28	24-30
WAS	3-4	10-40	100-300	8-20	15	12-20
P+WAS	3-6	21-51	400-700	6-16	22	20-25
Aerobically digested:						
P+WAS, unthickened	1-3	10-51	300-500	4-16	16	12-20
P+WAS (50:50), thickened	4-8	10-51	300-500	4-16	18	12-25
Oxygen activated WAS	1-3	10-40	200-400	8-20	18	15-23

(WEF MOP – 8, 1992)

Polymer type, injection points, aging time, and mixing energy are all variables that directly relate to cost-effective dewatering.

Metering pumps are generally the positive displacement diaphragm, rotary lobe, or progressive cavity. Variable frequency drives should provide for variable polymer feed. Polymer storage system should be sized to take advantage of bulk delivery.

The type of mixing equipment required will vary, depending on the selected polymer, viscosity, and solids characteristics. Before injection, polymers are mixed into a dilute solution between 0.25 and 0.50 percent by weight. In addition, a metered, potable water supply connected to the mix tank discharge is recommended to further dilute the polymer solution and thoroughly disperse the polymer into the solids.

Polymer system controls are extremely variable. System range from simple, mechanical systems with mixing provided by water supply pressure, to more complex systems, including microprocessor-based control of batching sequence, especially where both dry and liquid polymer systems are used.

### 5.2.2 Centrifuge Dewatering

Centrifuge dewatering uses centrifugal force to separate solids from liquid. Advantages of centrifuge dewatering systems include enclosed operation, which reduces odor potential, good dewatering performance, reduced operator attention and safety. Dewatered solids concentrations of 30 to 35 percent have been reported using a centrifuge. Mixtures of primary and waste activated solids routinely dewater to solids concentrations above 22 percent. Solid bowl centrifuges, which operate with a continuous feed and discharge, are used almost exclusively for solids dewatering.

*Advantages of centrifuge dewatering systems include enclosed operation, which reduces odor potential, good dewatering performance, reduced operator attention and safety.*

Two types of solid bowl centrifuges have proven successful -- the countercurrent flow and the co-current flow designs. Major differences in the designs relate to the location of the feed ports, the removal of centrate, and the internal flow patterns of the liquid and solid phases.

In the co-current flow configuration, the solids travel the full length of the bowl while the liquids travel in a parallel pattern with the solids phase. Conduits remove the liquid, which then flows over the discharge weirs.

In the countercurrent design, feed enters the centrifuge at the junction of the cylindrical conical sections. Solids travel to the conical end of the centrifuge while the liquid travels in the opposite direction. The liquid overflows weir plates located at the large diameter end of the centrifuge.

Polymer is generally added either into the feed compartment or through an injection port within the machine. At a number of facilities, polymer is added at points upstream from the centrifuge. Multiple polymer injection points provide flexibility in system operation.

Typical dewatering performance for a solid bowl centrifuge is presented on Table 5.4.



**Table 5.4 Dewatering performance for solid bowl centrifuges**

Type of Solids	Solid Bowl		
	Cake Solids, %	Solids Capture, %	
		Without Polymer	With Polymer
Raw			
Primary	25-35	75-90	90+
Primary and trickling filter	20-25	60-80	90+
Primary and waste activated	12-30	55-65	90+
Primary and rotating biological contactor			
Secondary Solids			
Trickling filter	10-20	60-80	90+
Waste activated	5-15	60-80	90+
Pure oxygen waste activated	10-20	60-80	90+
Anaerobically digested			
Primary	25-35	65-80	85+
Primary and trickling filter	18-25	60-75	85+
Primary and waste activated	15-20	50-65	85+
Aerobically digested			
Waste activated	8-10	60-75	90+

Metcalf and Eddy, Inc., 1991

*Operational Controls*

A number of items should be considered in the design and operation of centrifuge dewatering systems. They include:

- Hydraulic and Solids Loading Rates
- Polymer Addition
- Cake Discharge
- Centrate Handling
- Control Systems

*Hydraulic Feed and Solids Loading Rates*

The hydraulic feed rate and the solids loading rate are important control variables in the operation of a centrifuge. The hydraulic feed rate to the centrifuge impacts the solids capture rate. The solids loading rate impacts the cake solids performance. Increasing the hydraulic load will decrease the solids capture and may increase polymer consumption. When solids loading rate changes occur, a corresponding change in the differential speed is required. The best performance is achieved at minimum differential speed and at a feed rate that matches the reduced volumetric conveying capacity (USEPA, 1987). The selected hydraulic feed rate should minimize floc shear and turbulence.

*Polymer Addition*

As discussed, the location of the polymer injection points requires careful consideration. The design, generally, will allow polymer feed directly into the solid bowl centrifuge and upstream of the centrifuge, either before or after the feed pump. Maximum flexibility is needed to allow future modifications of the system. Design considerations also include

the space requirements of the polymer feed system and pilot testing a range of polymer concentration.

### *Cake Discharge*

Direct gravity discharge, belt conveyors, screw conveyors, or pumps are used to convey the cake from the centrifuge. Conveyors require a great deal of cleaning and maintenance for reduced odor and consistent operation. Pump systems are a popular way of conveying the cake. They allow the maintenance of a “closed system”.

### *Centrate Handling*

The centrate generated during dewatering usually is discharge downstream from preliminary treatment. Centrate piping must be properly sized and sloped to prevent centrate backups; long radius bends are recommended. If struvite build up is a concern, the ability to add ferric chloride should be considered. Ferric chloride binds with the phosphate ion preventing struvite buildup.

Because polymers can often produce foam or froth, a froth spray is required. A sampling line from the centrate discharge line to the sample sink should be provided. This will allow a simple check of performance.

### *Controls*

Electrical control provisions and interlocks are an important part of centrifuge dewatering system. The centrifuge drive motor should run at full speed before the feed control can function. The control circuitry shuts down the centrifuge and shuts off the feed to the centrifuge if any centrifuge malfunction occurs.

A water flush system should be interlocked with the centrifuge on-off controls. After each shutdown, the centrifuge should be water flushed. Plant water can be used for centrifuge flushing. (USEPA, Process Design Manual, 1979).

*Recessed chamber presses, operated as a batch process, use a pressure differential to dewater a liquid/solids slurry.*

### **5.2.3 Recessed Chamber Press Dewatering**

Recessed chamber presses, operated as a batch process, use a pressure differential to dewater a liquid/solids slurry. The main advantage of a recessed filter press system is that it generally produces cakes drier than those produced by other dewatering alternatives. Recessed chamber presses also have adaptable operation to a wide range of solids characteristics, acceptable mechanical reliability, and high filtrate quality that lowers recycle stream treatment requirements. The main disadvantages of recessed chamber presses are substantial quantities of conditioning chemicals or precoat materials, periodic adherence of cake to the filter medium, which requires manual removal, and relatively high Operation and Maintenance costs.

Solids conditioning, generally required to produce a low-moisture cake, involves adding lime and ferric chloride, polymer, or polymer combined with either inorganic compound to the solids before it is filtered. Several installations use only polymer for conditioning.

Their experience has shown that a small decrease in performance is offset by savings of chemical costs, reduced ammonia odors, and reduced overall volume of cake produced. (WEF MOP-8)

### *Operational Controls*

A number of items should be considered in the design and operation of recessed chamber dewatering systems. They include:

- Standby capability
- Access
- Corrosion protection
- Conditioning system
- Precoat system
- Feed system
- Washing system, and
- Cake handling

### *Standby Capacity*

Capacity must be provided for periods when the equipment can not be operated.

### *Access*

Adequate access must be provided to maintain the dewatering system. A minimum of 4 to 6 feet is recommended at the ends of the filter presses. A clearance of 6 to 8 feet is recommended between filter presses. Height clearance must be sufficient for removal of plates.

### *Corrosion Protection*

Because filter presses require frequent washdown, the area around the press should be constructed of corrosion resistant materials. The floor around the equipment and the support structure are also subject to the corrosive nature of the cleaning agents. The chemical-handling facilities for bulk storage and preparation of conditioning chemicals must also be corrosion resistant.

### *Conditioning System*

Most recessed chamber systems use lime or ferric chloride for conditioning. The lime and ferric chloride are typically added in the conditioning tank on a batch basis. Some facilities have converted to polymer for conditioning. Polymer is easier to work with and can be added “in-line” rather than on a batch basis.

### *Precoating*

The precoat system aids cake release from the filter media and protects the media from blinding. Solids with a high biological content, that are difficult to dewater, have a tendency to stick to the filtration media. The two types of precoat systems that have been used are dry material feeding and wet material feeding. The dry material system is used for larger installations and for those that operate on a continuous basis.

### *Feed System*

The recessed chamber press feed system must deliver the feed solids to the presses under varying flow pressure conditions. The feed system should complete the initial fill cycle by achieving an initial pressure of 10 to 20 psig within 15 minutes to minimize uneven cake formation.

### *Washing System*

Filter media washing, either by water spray or acid wash, is an essential component of good press operation. Washing removes residual cake and grease impregnated in the filter media. It also reduces buildup behind the filter media on the filter drainage surface. Water spray wash method is a portable spray-wash unit. The acid wash method uses cleaning in place of filter media. A dilute solution of hydrochloric acid is pumped into an empty filter press in the closed position. The acid is circulated through the plate chamber and discharged.

### *Cake Handling*

Cake handling requirements depend on the management practice. When trucks are used to transport the cake, the simplest procedure is to allow the cake to discharge directly into the truck. Recessed chamber presses can also discharge onto a conveyor system.

The cake conveying system can pose a major housekeeping problem. Each point of cake transfer onto a conveyor provides an opportunity for cake material to fall or cling in the immediate area. The return runs of a conveyor continually release cake material that was not removed at the discharge point.

The number of cake transfer points and the drop distance at any cake transfer point should be minimized. Discharge chutes of flexible material at each cake transfer point can be provided to reduce loss. Skirt boards can be installed on belt conveyors to assist in containing the cake on the conveyor. Drip troughs should be provided to collect any spillage. The troughs should be rounded and sloped to drain for washdown.

### *Ventilation*

Ventilation of the filter press building is essential for operator comfort, odor reduction, and fume protection. Solids conditioning is the greatest source of odor. In particular, when solids are conditioned with lime or ferric chloride, significant amounts of ammonia are released as pH rises. The fumes are most noticeable when the press is opened for cake discharge.

Recessed chamber presses are either fixed volume or variable volume. Both types can be reliable when proper attention is given to the maintenance and operation. The major operational difficulty encountered in pressure filter installations is inconsistent clean separation of the cake from the filter media. This problem may indicate the need for filter media wash or increased chemical conditioner dosages.

### *Fixed-Volume Press*

The fixed-volume press has a number of plates held rigidly in a frame to ensure

alignment. These plates are pressed together either hydraulically or electromechanically between a fixed and moving end. A filter cloth covers the drainage surface of each plate and provides a filter medium. Solids are pumped into the press and collect in the chamber until a feed pressure is reached. The feed pump is then stopped, and the individual plates are shifted, allowing the cakes to be discharged.

### *Variable-Volume Press*

The variable-volume press incorporates a flexible membrane across the filter plate face. This compresses the filter cake within the plate chamber, increasing the dewatering rate and decreasing cycle time.

### **5.2.4 Vacuum Filtration**

Prior to the 1970s vacuum filtration was the most common form of mechanical dewatering in the United States (USEPA/625/1-87/014 Design Manual, Dewatering Municipal Wastewater Sludges, September 1987) from the mid 1920s until the late 1950s. The drum rotary vacuum filter was the most common. The belt type filter using stainless steel coils was introduced in 1951. The belt type filter with stainless steel coils mesh or a synthetic fabric was the popular until the mid 1970's.

The operating vacuum filter has three zones:

- Pickup zone
- Drying zone
- Discharge zone

In the pick up zone, the drum is submerged to between 20 and 35 percent of its depth in the reservoir of conditioned solids. While submerged, a vacuum is applied. This vacuum causes the solids to stick to the media while the filtrate passes through.

As the drum rotates, the solids attached to the media enter the cake drying zone. The drying zone represents 40 to 60 percent of the drum circumference.

When the solids reach the discharge zone the vacuum is removed. The cake is released from the media prior to the media re-entering the pick up zone.

Typical performance data for rotary vacuum filters is presented on Table 5.4. The table provides a summary of performance for filters incorporating coil and cloth media.

The major components of the rotary vacuum filter press include its frame, coils or filter media, vacuum pump, cake discharge blades, drive system, control panel, and flocculation system. Support systems for the press include conditioning system, feed pumps, and dewatered cake conveyance. Information regarding the components and the support systems can be found in the USEPA design Manual for Dewatering Municipal Wastewater Solids.

### *Operational Controls*

A number of items should be considered in the operation of a vacuum filter. Operational controls include:

- Solids Loading Rate
- Vacuum Level
- Drum Speed and Solids Conditioning

*Loading Rates*

The capacity of a rotary vacuum filter is based on hydraulic and solids loading rates. The solids loading rate is typically the more limiting of the two. Solids loading rates range between 3 to 6 dry pounds per square foot per hour for blended primary and secondary solid per hour per meter of filter press width, (dlb/hr/m). Table 5.3 presents hydraulic and solids rates for belt filter presses dewatering a variety of solids. The table presents ranges of loading rates applied and the results experienced.

**Table 5.5 Typical Dewatering Performance Data for Rotary Vacuum Filters – Coil and Cloth Media**

Sludge Type	Feed Solids Conc. %	Chemical Dosage <sup>1</sup> lb/dry ton		Loading Rate <sup>2</sup> dry lb/ft <sup>2</sup> /hr	Cake Solids %
		FeCl <sub>3</sub>	CaO		
Raw P	4.5-9.0	40-80	160-240	4-8	27-35
WAS	2.5-4.5	120-200	240-720	1-3	13-20
P + WAS	3-7	20-80	180-240	3-4	18-25
P + TF	4-8	40-80	180-240	2-6	23-30
<u>Anaerobically Digested</u>					
P	4-8	60-100	200-260	4-7	25-32
P + TF	3-7	80-120	300-400	4-7	18-25
P + WAS	5-10	80-120	200-350	4-8	20-27

<sup>1</sup> All values shown are for pure FeCl<sub>3</sub> and CaO. Dosage must be adjusted for anything else.

<sup>2</sup> Solids loading rates are impacted by feed solids concentration. Increasing the solids concentrations normally gives a higher yield.

Source: USEPA Dewatering Design Manual 1987.

*Vacuum Level*

The vacuum level associated with filter operation ranges from 1.4 to 2.0 cubic feet per min. per square foot (cfm/ft<sup>2</sup>) at 5 pounds per square inch (psi). If the solids loading to the filter is greater than 5 to 10 lb/ft<sup>2</sup>/hr the vacuum air flow should be increased to between 4.0 and 6.0 cfm/ft<sup>2</sup>.

*Drum Speed and Solids Conditioning*

The optimum drum speed, vacuum level and solids conditions are best determined by bench scale testing. Performance will be impacted by feed solids content. Feeds solids below three percent will be difficult to dewater. Solids capture on well operated filters range from 85 percent for course media to 98 percent for close weave media.

**5.2.5 Drying Beds**

Sand drying beds provide a low-tech means of solids dewatering. They are popular at wastewater treatment facilities with capacities below 5 million gallons per day (USEPA 1979). Performance is impacted by weather conditions, and is better in arid regions of the

country.

Drying beds fall into four categories:

- Conventional drying beds
- Paved drying beds
- “Wedge-wire” drying beds
- Vacuum assisted drying beds

### *Conventional Beds*

The elements of a conventional sand drying bed include a sand and gravel layer constructed over an underdrain system. Sand drying beds also include sidewalls, partitions, distribution systems, and, in some installations, wheel runways and/or enclosures.

A gravel layer (8 to 16 inches in depth) is usually constructed over the underdrain system. Gravel size ranges from 0.1 to 1.0 inches in diameter.

The sand depth on beds range between 9 and 18 inches. A minimum depth of 12 inches is recommended to reduce the frequency of sand replacement caused by losses from cleaning operations. Good quality sand with a uniformity coefficient that is under 3.5 is recommended. Effective size of sand grains between 0.01 and 0.03 inches is also recommended.

Sand drying beds can be covered with glass or translucent fiberglass panels to enhance drying. Completely covered drying beds minimize the impact of precipitation and insulate the operation during cold periods. Covered beds usually require less area than do open beds. Open beds located in arid climates evaporate cake moisture faster than covered beds.

### *Operational Controls*

The operation of a conventional sand drying bed is impacted by the following:

- Solids concentration of the feed
- Depth of solids applied
- Sand/underdrain system performance
- Solids conditioning digestion provided
- Pan evaporation rate
- Type of removal method used, and
- Ultimate disposal method used.

### *Solids Loading*

Solids loading criteria for sand drying beds are 10 to 25 lb/yr/sqft for open beds and 12 to 40 lb/yr/sqft for enclosed beds (USEPA, 1979).

### *Chemical Conditions*

In some cases, drying bed installations include chemical conditioning. Conditioning helps improve the drying capacities of the beds.

### *Polymer Addition*

If a drying bed system includes polymer addition, a minimum of three polymer addition points are recommended for optimum effectiveness. One near the suction side of the pump, another at the pump discharge, and the third near the discharge point to each bed.

### *Total Drying Time*

The total drying time required depends on the desired final moisture content, and also relates to the means of removal and subsequent use. Ultimate bed sizing is a function of evaporation, solids application depth, and applied solids concentration.

The time required to achieve a liftable cake depends more on the initial solids content and percentage of total water that is drained than on the initial drainage rate. This is particularly significant from a dewatering standpoint since the time required for evaporation of moisture is longer than that required for drainage. Therefore, the total time the solids must remain on the bed is controlled by the amount of water that must be removed by evaporation.

The depth of applied solids affects the drainage rate. (Quon and Johnson 1966) The recommended initial depth of solids on a drying bed ranges from 8 to 16 inches. The applied depth should result in a solids loading rate between 2 and 3 lb/sqft.

### *Paved Drying Beds*

There are a limited number of paved drying beds. The advantages of paved drying beds include equipment access and reduced maintenance. Most beds are rectangular in shape, 20 to 50 ft wide by 70 to 150 ft long. Concrete, asphalt, or soil cement is used for drying bed liners.

### *Wedge-wire Drying Beds*

In a wedge-wire drying bed, solids spread onto a horizontal, relatively open drainage media. The bed has a shallow, rectangular, watertight basin fitted with a false floor of wedge-wire panels with slotted openings of 0.01 inches. An outlet valve to control the rate of drainage is located below the false floor.

The procedure used for dewatering solids begins with the movement of water or plant effluent into the unit until a depth of approximately 1-inch over the wedge-wire is reached. Water reduces the uneven buildup of solids on the wedge-wire screen. The drainage water is allowed to percolate at a controlled rate, through the outlet valve in the underdrain system. After the free water has been drained, the solids further concentrate by drainage and evaporation until it is removed.

Wedge-wire beds normally can dewater between 0.5 and 1.0 lb/sqft per application. The loading rate depends on the initial solids concentration of the solids applied. Most solids can be dewatered to a solids concentration of 8 to 12 percent solids within 24 hours. Solids loading rates of 180 to 365 lb/yr/sqft are typical with product total solids ranging between 8 and 12 percent.



*Vacuum-Assisted Drying Beds*

Vacuum-assisted drying beds incorporate the use of a vacuum pump with a sand drying bed. Solids are applied to a depth of 12 to 30 inches. Polymer, used to enhance performance, is injected to the sludge in the inlet line. Filtrate drains through the multimedia filter into a sump. After the solids drain by gravity, a vacuum system is started. A vacuum of 10 to 25 in. Hg is created.

When the cake cracks and vacuum is lost, the vacuum is shut off and solids removed. Vacuum systems are capable of dewatering a dilute solid to 14 percent total in approximately 24 hours. Solids recovery can approach 95 percent.

## References

Metcalf and Eddy, Inc., (1991), *Wastewater Engineering, Treatment, Disposal and Reuse*, Third Edition McGraw-Hill, Inc., New York, N.Y.

United States Environmental Protection Agency, Office of Research and Development, (1979), *“Process Design Manual for Sludge Treatment and Disposal”*, 625/79-011 Cincinnati, Ohio,

Water Environment Federation and American Society for Civil Engineers, (1992), *“Design of Municipal Wastewater Treatment Plants”*, (MOP No. 8)

Water Environment Federation, (1992), *“Design of Municipal Wastewater Treatment Plants”*, Manual of Practice No.8, Alexandria, Va.; Am. Soc. Civ. Eng., Manual and Report on Engineering Practice No.76, New York, N.Y.

## Chapter 6 – Odor Control

---

Odors are often the initial concern cited with a biosolids management program. Once odors are associated with a facility or a program, other concerns often are raised. Odor is frequently noted as the reason a facility or program is abandoned.

There are a number of sources for odors within wastewater treatment and solids management facilities. Significant potential sources at treatment facilities include:

- Headworks area
- Primary clarifiers
- Solids holding and thickening tanks
- Aerobic digesters
- Dewatering systems
- Solids loading areas

Solids processing facilities such as composting and thermal drying facilities also can generate odor. The minimization of odor generation and release should be a primary consideration during all process and facility design.

There is no single process to eliminate odor. Odors are always a potential with a biosolids management program. However, careful planning of a biosolids management program can greatly reduce the potential for offensive odors.

This chapter addresses odor control at wastewater treatment and solids management facilities. It discusses containment, collection, treatment, and dispersion of odors generated “inside the fence”. This chapter does not address reducing odor through process optimization. Methods to optimize unit processes and biosolids management programs are described throughout the manual.

### 6.1 Odor Controls

A number of controls are associated with the containment, collection and treatment of odors. They include:

- Ventilation rates
- Negative pressure
- Airstream characteristics
- Type of odor requiring treatment

These controls should be addressed in the planning and implementation of odor control systems.

### 6.2 Ventilation Rates

Ventilation of enclosed spaces is required to prevent the buildup of combustible vapors, minimize the escape of odors, reduce the potential for corrosion, and provide a safe working environment for employees. Required ventilation rates will vary widely depending on the

characteristics of the odorous air, the degree of conservatism in minimizing the escape of odors, and the use and accessibility of the enclosed space. (NFPA 1990)

Criteria for establishing ventilation rates for covered processes include:

- Maintenance of a minimum negative pressure. A minimum negative pressure of 0.1 inch water column is recommended to prevent release of odors.
- Maintaining a safe working environment. If the enclosure will be entered routinely, the hydrogen sulfide (H<sub>2</sub>S) concentration must remain below 10ppm.
- Minimize the potential for buildup of combustible gases such as methane.
- Control hydrogen sulfide (H<sub>2</sub>S) levels to reduce corrosion.

Ventilation rates for enclosed areas are usually expressed by the number of air changes per hour (AC/hr), which can be calculated as follows:

$$\text{AC/hr} = \frac{\text{Exhaust air flow (cfm)} \times 60}{\text{Enclosed Volume (cu ft)}}$$

Table 6.1 provides recommended ventilation rates for various covered processes. Facilities should have an air exchange rate of at least 12 air changes per hour for continuously ventilated and occupied areas having exposed biosolids. This ventilation rate suggested in National Fire Protection Association's (NFPA) *Fire Protection in Wastewater Treatment and Collection Facilities* publication number 820, is necessary to reduce the possibility of accumulation of combustible vapors. (NFPA 1990)

### *Negative Pressure*

For covered channels, grit chambers, and effluent launders that are not routinely entered, the most important criterion is minimizing the escape of odors. NFPA recommends a minimum negative pressure of 0.1 inch water column under all operating conditions. Consider the opening of hatches and inspection of ports as part of routine operating and maintenance practices.

Ventilation fans should be sized to provide a slightly than required rate of ventilation higher approximately 10 percent. Cover seals may deteriorate over time and hatches may be left open by operations staff. The application of the negative pressure criteria may or may not be necessary depending on the strength of the odor and how much escape is acceptable. Maintaining a negative pressure under all operating conditions may result in high air flow rates and large treatment systems that are expensive to construct and operate.

### *Materials of Construction*

Enclosing or covering of odorous processes without ventilation is not recommended. If the area to be enclosed is a source of odors, it is likely to contain H<sub>2</sub>S, which is corrosive at low concentrations and toxic at high concentrations. The decomposition of organic matter can generate methane gas, which is explosive. Hydrogen sulfide will attack concrete and carbon steel. Significant damage will occur in spaces that do not have adequate ventilation. Even processes or channels that normally treat or convey aerobic

*If the area to be enclosed is a source of odors, it is likely to contain H<sub>2</sub>S, which is corrosive at low concentrations and toxic at high concentrations.*

wastewater can accumulate gases when taken out of service and the wastewater is allowed to become septic.

**Table 6.1 Typical Ventilation Rates**

<b>TYPICAL VENTILATION RATES</b>	
<b>Process</b>	<b>Air Exchange Rate (air changes per hour)</b>
Lift Station	15 to 25
Headworks	12 to 20
Covered Primary Clarifiers	12 to 15
Covered Secondary Clarifiers	12 to 15
Gravity Thickeners	12 to 20
Mechanical Thickeners	12 to 15
Mechanical Dewatering	12 to 15
Anaerobic Digestion Control Room	12 to 20
Enclosed Composting Facility	12 to 15

## **6.2 Odor Treatment Technologies Methods**

### *Airstream Characteristics*

Enclosing an odorous process, ventilation of the enclosed space, and treatment of the air are very effective means of controlling odors and emissions. The selection of an odor control technology depends largely on the characteristics of the air stream to be treated, site considerations, and the degree of odor reduction required.

Determining the characteristics of the air to be treated is extremely important in selecting a control technology. Air stream characterization can include GC/MS or other analytic techniques to identify specific constituents. Analytic techniques are particularly important for odor control applications where the odors are complex and consist of compounds other than hydrogen sulfide and reduced sulfur. Odor panel analysis also can be used as an analytic tool. Such tests provide useful data on odor strength or detectability, which is defined as the number of dilutions required before half the odor panel can no longer detect the odor. Air flow is also an important design parameter that may affect the cost-effectiveness of a particular technology. Ventilation rates of enclosed spaces also should be evaluated for fire prevention.

Technology selection and design are affected by the specification of performance requirements. If high odor removal efficiencies are required, multiple stages or a combination of technologies may be necessary.

A summary of air treatment technologies is presented in Table 6.2.

**Table 6.2 Summary of Odorous Air Treatment Alternatives**

<b>SUMMARY OF ODOROUS AIR TREATMENT ALTERNATIVES</b>				
<b>Technique</b>	<b>Frequency of Use</b>	<b>Cost Factors</b>	<b>Advantages</b>	<b>Disadvantages</b>
Packed-tower wet scrubbers	High	Moderate capital and O&M cost	Effective and reliable; long track record	Spent chemical must be disposed; high chemical consumption; not effective for VOCs
Fine-mist wet scrubbers	Medium	Higher capital cost than packed towers	Lower chemical consumption; can be designed for VOC removal	Water softening required for scrubber water; larger scrubber vessel
Activated carbon adsorbers	High	Cost-effectiveness depends on frequency of carbon replacement/regeneration	Simple; few moving parts; effective	Only applicable for relatively dilute air streams in order to ensure long carbon life
Biofilters	Medium	Low capital and O&M costs	Simple; minimal O&M; effective for some VOCs	Effective with a range of odors; requires monitoring for bed moisture; requires periodic media replacement
Thermal oxidizers	Low	Very high capital and O&M (energy) costs	Highly effective for VOCs and odors	Only economical for high-strength, difficult-to-treat air streams
Diffusion into activated sludge basins	Low	Economical if existing blowers/diffusers are used	Simple; low O&M; effective	Concern for blower corrosion; may not be appropriate for very strong odors
Odor masking agents	High	Cost dependent on chemical usage	Low capital cost; easy to obtain; good for sporadic odor incidents	Only mask odors; no VOC control

Source: Water Environment Federation, MOP-22, 1995

There are a number of odor treatment methods available. This section provides a summary of the treatment systems commonly implemented.

### *Packed-Tower Wet Scrubbers*

The packed-tower wet scrubber consists of a vessel with an air inlet, packing bed, packing irrigation system, and air outlet. A scrubbing liquor sump may be integrated with the scrubber or may be located remotely. Sumps are often located indoors in cold climates to reduce freezing potential. The basis for wet scrubbing is the induction of intimate contact between the contaminant-laden air and a scrubbing solution, causing a mass transfer between the two media in which the contaminant molecules are absorbed into the liquid. The packing bed is the region where this mass transfer occurs. The scrubbing solution is usually recirculated through the system while its pH and/or oxidation reduction potential (ORP) are continually monitored and adjusted.

### *Fine-Mist Wet Scrubbers*

Fine-mist or fog scrubbers treat odor by bringing the air in contact with 10 micron-sized droplets of scrubber solution. Special atomizers, usually using compressed air, create the fine droplets of controlled dilute chemical solution. The atomization is a continuous process and the air and droplets flow concurrently with no recirculation of liquid effluent. Chemical feed rate is continuously controlled by sensing exhaust, liquid effluent, or inlet parameters. A mist scrubber functions on two principles: diffusion and reaction of water-soluble contaminants, and adsorption of non-water-soluble compounds.

### *Activated Carbon Absorbers*

Activated carbon adsorption is effective for removing low levels of odorous compounds such as hydrogen sulfide, reduced sulfur compounds, and VOCs from air emissions at municipal wastewater treatment facilities. Granular activated carbon (GAC) is an extremely effective adsorbent because it possesses a high surface area per unit weight, an intricate pore structure, and a primarily hydrophobic surface. Bituminous coal and coconut shell are the most widely used sources for manufacturing GAC because they create an activated carbon with good physical properties and excellent porosity. Activated carbon made from coconut shell is preferred for use in VOC removal because of the greater retentivity of the coconut shell carbons for small VOC molecules. Alkali-impregnated bituminous coal carbons are commonly used to remove H<sub>2</sub>S and other reduced sulfur compounds. The alkali impregnant (e.g., NaOH or KOH) increases the low adsorption capacity of H<sub>2</sub>S and methyl mercaptans on virgin GAC from about 3 to 5 percent by weight for virgin carbon and from approximately 25 to 27 percent by weight for impregnated carbon. Mixed beds of media, a layer of impregnated GAC, and a layer of coconut shell-based GAC have been used for applications requiring simultaneous a H<sub>2</sub>S and VOC removal.

### *Biofiltration*

Biofilters use a porous media to absorb and adsorb compounds from an airstream similar to dry media scrubbers. However, biofilters rely on microbial degradation of the absorbed/adsorbed compounds to renew the sorptive capacity rather than frequent media replacement. Biofilters are typically constructed with an in-ground air distribution system that discharges through media beds, which can be open to the environment, covered, or totally enclosed for a stack discharge. Packaged, proprietary biofilter systems are also available. Biofilters are effective in removing

both odors and VOCs and are considered most appropriate for airstreams with hydrocarbon levels up to 1,000 ppm, such as, methane. Table 6.3 provides design criteria.

**Table 6.3 Biofilter Design Criteria Summary**

<b>BIOFILTER DESIGN CRITERIA SUMMARY</b>		
<b>Item</b>	<b>Range</b>	<b>Typical</b>
Detention Time (secs)	30 to 60	60
Bed Depth (ft)	2 to 3	3
Surface Loading Rate (cfm/sq ft)	Up to 7.5	3
Moisture Content (%)	45 to 65	50
Media pH	6 to 9	7
Media Temperature (°C)	5 to 45	15 to 37
Influent Gas Humidity (%)	>95	>98

*Thermal Oxidation Systems*

Thermal oxidation is a very effective means of destroying odors and VOCs that are primarily organic, because organic compounds are completely oxidized to carbon dioxide and water vapor. In general, thermal oxidation is not recommended for inorganic odors composed primarily of sulfur and nitrogen such as H<sub>2</sub>S, ammonia NH<sub>3</sub>, sulfides, etc. The reason for this is twofold. First, combustion of sulfur- and nitrogen-based compounds will form sulfur dioxide (SO<sub>2</sub>) and nitrogen oxides, which are odorous. Second, SO<sub>2</sub> can form sulfuric acid, particularly in the final stages of heat recovery systems where the flue gas temperature is lowered, and condensation of acid gases may occur and cause severe corrosion. Low levels of sulfur- and nitrogen-based compounds can be incinerated provided that the concentrations of SO<sub>2</sub> and nitrogen oxides in the flue gases are low and adequately dispersed in the atmosphere so that ground-level concentrations of these compounds are below detection limits. In addition, the combustion and heat recovery system should be designed so that the chance for condensation of acid gases is minimal. The flaring of landfill gas is one example where oxidation of significant levels of H<sub>2</sub>S is commonly performed.

The four types of thermal oxidation systems are:

- Direct flame or flare
- Recuperative
- Catalytic
- Regenerative

All four types have been used extensively in industrial applications. For wastewater treatment and biosolids management facilities applications, regenerative thermal oxidizers (RTOs) have several advantages over the other types of oxidizers and are more commonly used.



### *Direct Flame*

Direct flame or flare units are the simplest to operate and have the lowest capital costs, but are the most costly to operate because no heat recovery is provided. Therefore, direct flame oxidizers are usually used on fume streams, which are sufficiently concentrated to sustain autogenous combustion. For dilute air streams, direct flame units are usually considered for only low-flow cases of less than 2,000 cfm.

### *Recuperative*

Recuperative thermal oxidizers use heat exchange tubes to transfer thermal energy from the hot combustion flue gases to the inlet airstream. Recuperative oxidizers with extensive heat recovery can achieve thermal efficiency of 70 to 73 percent. However, even with this relatively high thermal efficiency, the fuel cost to operate the system is high. The most important limiting factor with recuperative oxidizers is that their metallic heat recovery tubes are susceptible to corrosion from condensation of acid gases. At wastewater treatment facilities, most odorous airstreams contain H<sub>2</sub>S or other reduced sulfur compounds which would render the heat recovery sections of recuperative oxidizers susceptible to corrosion.

### *Catalytic*

In catalytic oxidizers, the presence of a catalyst allows oxidation of an organic vapor or solvent to take place at a lower temperature (typically 800°F to 1,100°F) and without a flame. Catalytic oxidizers are capable of high VOC destruction efficiencies of approximately 95 percent or more. The catalytic element is usually a ceramic fixed grid or honeycomb structure coated with platinum, palladium, or other rare earth metals. The use of catalytic units is generally limited to pure organic vapors and solvents with low residual ash content, which will not clog or coat the catalytic surface. Because of the presence of sulfur in most odorous airstreams at wastewater treatment plants, catalytic oxidizers generally are not recommended.

### *Regenerative*

An RTO essentially consists of a combustion chamber filled with gas-fired burners and three or more heat recovery chambers filled with inert ceramic packing media or saddles. The RTO is equipped with inlet and exhaust manifolds with flow diverter valves that alternate the flow of cool inlet air and hot flue gas through the heat recovery chambers. Each chamber alternately absorbs heat from the flue gas and then releases this heat to the air inlet stream, preheating the inlet air. By switching the flow of flue gas and inlet air from chamber to chamber, a high degree of heat recovery can be attained. Overall thermal efficiencies of greater than 90 percent are possible, which results in low fuel use. An RTO can achieve very high VOC destruction efficiencies of 95 to 98 percent. RTOs are used on odorous airstreams with low levels of H<sub>2</sub>S and NH<sub>3</sub> because the ceramic saddles and refractory lining in the heat recovery and combustion chambers are resistant to these compounds and their acids.

RTOs are available in a variety of configurations with features such as different types of packing media (loose, structured, or gravel), purge air systems, and proprietary valve and manifold systems.

### *Activated Sludge Diffusion*

Odorous air can be treated effectively by diffusion of the air into the mixed liquor of activated

sludge aeration basins. Odors are removed through a combination of absorption, adsorption, and biological oxidation. Most facilities with this odor treatment process use the existing blowers and diffusers associated with the activated sludge process. Unfortunately, few design criteria are available for new facilities. For a diffusion system designed exclusively for odor control, energy costs can be high. Diffusion of odorous air into anything other than an aeration basin is not recommended. The aeration basin has the high active biomass necessary for effective removal of odors.

### *Dispersion*

The adage “dilution is the solution to pollution” applies to odor. Dilution may be accomplished by applying a mechanical fan, using an exhaust stack to improve atmospheric dispersion, or implementing a combination of the two. In general, dilution and dispersion should be considered for exhausts from odor control systems, but rarely should be the principal means of odor control.

There are aerodynamic recirculation zones around a building and other nearby structures. Emissions should not be discharged into or trapped in these recirculation zones, which will minimize the dispersion and dilution effect. A stack is preferred over a roof exhaust fan. A horizontal-discharging wall exhaust fan is least desirable. Sufficient emission exit velocity and temperature, which improves the upward movement of the plume, also are desired. A rain cap or gooseneck design at the top of the stack merely deflects the exhaust downward and should be avoided.

## References

National Fire Protection Agencies, *“Fire Protection in Wastewater Treatment and Collections* Publication 820

Water Environment Federation, (1995), *“American Society of Civil Engineers, Odor Control in Wastewater Treatment Plants”*, WEF Manual of Practice No. 22, ASCE Manuals and Reports on Engineering Practice No. 82

National Fire Protection Association, (1990), *Crouse-Hinds ECM Code Digest*, Publication 70

## Chapter 7 – Transportation

---

The successful transportation of biosolids is an essential component of a reliable program. In addition to complying with local, state and federal regulations, the transportation portion of a program must be acceptable to the public.

Transportation is often the largest cost associated with a biosolids management program. However, “cutting corners” on transportation may not always result in lowering the overall program cost, and can even lead to program failure due to the public and political ramifications.

### 7.1 Critical Control Points / Operational Controls

Controls that should be considered in the implementation of a biosolids transportation program include:

- Quantity of material to transport
- Solids concentration of material being transported
- Distance to transport
- Number and capacity of vehicles
- Vehicle maintenance
- Vehicle appearance
- Accident and spill control programs

*Determining the size, type and number of vehicles needed for transporting biosolids to use/disposal sites is critical to maintaining the desired flow of material.*

Transport methods include truck, railroad, barges, pipeline, or a combination thereof. Methods selected and accompanying costs depend on such factors as biosolids characteristics, amounts to be transported, distance to travel, availability and flexibility.

#### *Size, Type and Number of Trucks*

Determining the size, type and number of trucks needed for transporting biosolids to use/disposal sites is critical to maintaining the desired flow of material. (USEPA 2000) Such decisions depend on:

- quantities to be used/disposed
- distances
- road conditions
- vehicle maintenance schedules
- seasonal needs and
- percentage of time in use

#### *Peak Use/Disposal Periods*

The transport system should have the capacity to handle the maximum levels of biosolids production during peak use/disposal periods, taking into account any storage capacity that is part of the overall biosolids management plan.

#### *Keeping Trucks Clean*

Develop and implement procedures for keeping trucks clean during transport. Each vehicle should be equipped with a scraper, shovel, broom and absorbents so drivers can clean vehicles

before they enter public roads and clean up any biosolids drips or small spills. Transport vehicles that frequently are taken off paved surfaces to unload in fields should also be equipped with splashguards to keep any mud adhering to tires from splattering other vehicles when they return to the road.

*Equipment must be selected based on size needed, types of biosolids to transport and hauling distances.*

### *Community Relations*

Regulations regarding vehicle weight limits and other road safety limitations must be known and observed for all operations. It is advisable to inform potentially affected communities about traffic resulting from operations, and make every effort to avoid significant or prolonged impact on these communities. Flexibility in haul routes, timing of operations and careful adherence to traffic management are essential to address community concerns. These considerations, regardless of whether they are regulatory requirements, should be operational requirements for biosolids programs to succeed.

## **7.2 Transport Method**

### *Liquid Transport*

Sealed tanks are used for transporting liquid biosolids, which typically (although not always) contain less than 10 percent solids. Systems range from tank wagons attached to farm tractors for short distances and small quantities, to 6,000-gallon tankers for over-the road transport. For land application, if tankers are not used for field application, they function as "nurse trucks" to supply field application vehicles or an irrigation system. (USEPA 1995)

Tankers should be equipped with internal baffles to minimize the movement of liquids inside the tanks. Biosolids are loaded into tankers with pumps and hoses. Standard pumps capable of handling solids can transfer the biosolids, or tankers may contain built-in vacuum-pressure pumps. The vacuum systems are a benefit when transferring liquids containing higher percent solids.

### *Dewatered Biosolids Transport*

Dewatered biosolids generally have a solids content above 15 percent. Dried materials like compost or heat-dried pellets usually have much higher percent solids -- 50 and 90 percent respectively. Dewatered biosolids can be transported in rail cars, specialized highway trucks (dump trucks), tractor-trailers and roll-off containers. Trailers are usually loaded at treatment facilities using conveyor belts or storage hoppers, or with front-end loaders for stockpiled material. Truck capacities vary from 10 to 25 tons (8 to 30 cubic yards). To reduce odors and spills, truck covers (hard top or tarped) should be provided. Other necessary features include leak-proof tailgates with seals and wide anti-splash shields.

Transporting dewatered biosolids reduces hauling and storage costs, but entails increased costs associated with dewatering. Cake material also can be land applied at higher rates with a single pass of the spreading equipment, improving operational efficiency. (USEPA 1979) Cake biosolids are land applied with spreading vehicles that resemble those used in agriculture for

applying animal manure, although larger projects usually require more heavy-duty, commercially available specialized equipment designed for biosolids operations. Although cake operations typically can be conducted for longer periods of the year, seasonal restrictions still apply in most cases, and must be addressed in the transport component of overall project planning.

### 7.3 Other Transport Methods

While less commonly used, transport by pipeline, rail and barge also may be employed for biosolids projects. Pipelines, generally feasible only for liquid biosolids, have limited application due to their high capital cost and limited flexibility in terms of land application site accessibility. Rail and barge transports are economical for high volumes and long hauling distances. Rail transport has become more common in recent years. When contemplating use of these transport methods, biosolids managers will need to consider appropriate loading and unloading facilities, not neglecting the local community's regulations and sensibilities regarding the activities involved in operating such facilities.

### 7.4 Spill Prevention

Spills are a reality in any biosolids program involving transportation. Consider the following scenario:

A medium size municipality contracted with a transporter to take biosolids to a landfill. The transport vehicle was a tractor with a 20 cubic yard roll off container. All of the transportation requirements were met and the container was covered. On the way to the landfill, the truck overturned in a ditch. The entire load of biosolids ended up in a ditch. It was a Friday afternoon, raining, and traffic was a mess. The local newspaper reporter arrived to find that the entire accident scene was in total confusion. When the municipal manager showed up, a plan was quickly prepared. However, the newspaper headline and front-page pictures were not positive. The reporter's concern...there was no plan to deal with the spill. Even the smallest incident can turn out badly if no thought has been given to how to respond.

The following should be considered before beginning to transport biosolids:

- If feasible, alert truck drivers to the need for making sure that biosolids are not unusually odorous, with directions about procedures to follow if they are.
- Make sure vehicles are clean before they leave the facility and before they leave the use/disposal site.
- Check for good haul routes that don't have road and bridge weight restrictions or low overpasses that cannot accommodate delivery vehicles.
- Ensure that safe truck entrance and exit locations are used at the site.
- Use truck entrance warning signs and/or flag operators to prevent accidents.
- Cover and seal containers and truck boxes or trailers to reduce the potential for odors and spills.
- Maintain vehicles so breakdowns on the road are rare.
- Follow applicable state and local transportation rules and regulations.

### *Spill Control*

A “spill control plan” is an essential part of transporting biosolids. The plan should be posted, explained to all personnel (including in-house and contract truckers) and a copy kept in each transport vehicle. It also is advisable that each transport vehicle has a Material Safety Data Sheet (MSDS) or equivalent to establish that the biosolids are not a hazardous or dangerous material. Drivers should be familiarized with basic facts relating to biosolids' properties (especially the fact that they are non-hazardous), in order to be able to respond to questions should a spill occur where no other project staff are present. Accessibility to radio/telephone communication among those involved in transporting and managing biosolids will enhance spill control measures. Project personnel should be familiar with procedures to follow if vehicles are involved in an accident, with particular emphasis on first making sure that individuals involved in the accident and any bystanders are safe and receive medical attention if needed.

### *Spill Prevention and Control Plan*

A general spill prevention and control plan is presented below. The plan can be modified to meet a particular agency's needs.

*Spill Prevention and Control Plan*

**Spill Prevention**

Project operations staff will implement the following to prevent spills from occurring:

- Insure truck drivers receive instruction in the importance of observing weight limits, highway speed limits, and conservative driving practices.
- Insure that trailer hatches are closed and latched during transport.
- Inspect trailer seals daily and replace as needed.
- Insure unloading operations are conducted to avoid potential runoff or tracking of biosolids.

**Management of Cleanup**

The site project manager will take immediate charge to initiate and oversee cleanup efforts. Additional labor will be secured as needed to clean up the spill as expeditiously as possible. The project manager will communicate with adjacent neighbors and the public at the scene to answer questions and inform them of the progress of the cleanup. Immediate actions taken will be as follows:

- *Halt the source:*  
Immediately cease using any leaking or damaged unit that is causing the spill. The unit will remain out of service until repaired.
- *Containment*  
If large amounts of biosolids are spilled, straw bales will be used to form a barrier and/or absorb spilled biosolids.
- *Cleanup*  
Use appropriate equipment to remove the biosolids from the spill area. Such equipment may include front-end loaders, the vacuum equipment of liquid biosolids applicators and water trucks. A sufficient supply of shovels and brooms will also be provided to crewmembers cleaning up the spill. Biosolids removed from the spill area will be either spread on an approved application site or taken to a permitted disposal site.
- *Final Cleanup*  
Roadways will be swept or flushed with water as needed to clean the area. If the spill is on a non-paved and tillable area, the final residue will be incorporated into the soil. If it is on private property, final cleanup will be completed to the satisfaction of the property owner.
- *Reporting*  
All spills will be reported immediately to: *(List contact names and telephone numbers of law enforcement and other appropriate state/local agencies, internal management, the designated media contact person, any others identified as needed)*  
Within 24 hours, the site manager will send a written report detailing how the spill occurred, quantities and remedial action taken to:  
*(List contact names as above and/or others as appropriate)*



## References

United States Environmental Protection Agency, (July, 2000), "*Guide to Field Storage of Biosolids*", (4204) (USEPA/832-B-00-007)

United States Environmental Protection Agency, (September, 1979), "*Process Design Manual for Sludge Treatment and Disposal*", (USEPA 625/1-79-011)

United States Environmental Protection Agency, (September, 1995), "*Process Design Manual for Land Application of Sewage Sludge and Domestic Septage*", (USEPA/625/R-95/001)

## Chapter 8 – Agricultural Land Application

---

Land application of biosolids provides valuable nutrients for crops and adds organic matter to the soil. Land application can turn barren land into fertile soil and improve farmland productivity. Agricultural land application programs have developed so as to provide benefits to both farmers and biosolids producers.

The biosolids producer (generator) is responsible for insuring that the land application program meets all regulatory requirements. Equally important to success is operating a program that goes beyond minimum regulatory requirements and addresses both farmer and community needs. An agricultural land application program must be based on good management practices and the promotion of public acceptance. This chapter provides information to develop and operate a successful biosolids program. Included are guidance to help estimate land base needs, select and permit sites for land application, and develop and manage biosolids land application programs in ways that improve crop yields, soil productivity and water quality.

Primary components of an agricultural land application program are listed below. Each component has its own set of operational controls.

- Biosolids characteristics
- Land area requirements
- Site selection
- Permitting sites
- Field operations
- Managing operations
- Monitoring
- Record keeping and reporting

### 8.1 Biosolids Characteristics

An important internal control that should be established before initiating a land application program is establishing biosolids characteristics. Biosolids characteristics include the following:

- Nutrient content (nitrogen, liming potential if applicable, phosphorus)
- Pollutant, pathogen and vector attraction reduction (VAR) requirements
- Potential for odors
- Product consistency

If biosolids quality data have been consistent over a number of years, documentation should be fairly straightforward. For a first-time agricultural land application program, biosolids data must be collected for at least several months, and longer if the data show much variability.

*For a first-time agricultural land application program, biosolids data must be collected for at least several months, and longer if the data show much variability.*

Following federal, state and local regulatory requirements and the biosolids program recommendations contained in this manual can help develop a level of confidence in biosolids characteristics. Having such confidence in the quality of the biosolids

goes a long way in establishing that the land application of biosolids is a safe and valuable practice and that the farmer's needs are balanced with those of the biosolids producer.

### 8.2 Land Area Requirements

Operating an agricultural land application program is an ongoing process that requires a flexible land base. Expanding the available land area provides backup due to poor weather and site conditions, land lost to development, sites withdrawn from the program, and changes in agricultural operations. Successful land application operations should begin with estimating acreage needed to provide a land base suitable for regulatory approval.

#### *Estimating Acreage Needed*

Agricultural land application operations can occur only when weather and field conditions are suitable and cropping practices allow. Therefore, reliability can be achieved by having a variety of farms, fields, and crops to go to. A simple method to estimate how many acres should be available for a reliable biosolids land application program is:

1. Establish the amount of biosolids (in dry tons) handled annually. Use an average from the past three years. Be sure biosolids stored for later application are included.
2. Establish an application rate for the basic crops in the program, using average nutrient-based application rates.
3. Divide the amount of biosolids produced annually (dry tons per year) by the average application rate (dry tons per year) to estimate the minimum number of acres needed to support the per acre program.

*Only one-third to one-half of the acreage may be available each year for biosolids application. Estimate three times the number of acres required, based on the annual biosolids production, to satisfy the biosolids program land base needs.*

To account for the availability and accessibility of the land over the course of a year, multiply the number of acres by a “factor”. This number will vary based on location, local agricultural practices and amounts of biosolids to be land applied. For small to medium size programs, a factor of three may be reasonable. It is often desirable to apply biosolids to a farm intermittently over several years rather than annually, to accommodate farmer’s crop rotations and nutrient management needs. Therefore, tripling the acreage required provides flexibility to meet contingencies and management objectives.

For example, a medium facility serving 100,000 people may produce about 1,500 dry tons of biosolids per year. At an application rate of 3.5 dry tons per acre, 430 acres of land would be required to handle the annual biosolids production. Using a factor of 3 to provide operational flexibility, the producer would develop a land base of approximately 1,290 acres to support the biosolids land application program.

The acreage estimation should be modified whenever allowed application rates for typical crops in the program, amounts or nutrient content of biosolids, or other factors that affect the capacity of the land base change significantly.

## 8.3 Site Selection

The criteria for suitable agricultural land application sites (farms) can vary considerably from state to state. However, there are a number of factors to consider when evaluating a farm for inclusion in a land application program. The success of the biosolids program depends on selecting farms that fit with the producer's biosolids program goals and meet all federal and state regulatory requirements.

The factors to consider are:

- Preliminary evaluation
- Soil properties
- Buffer zones
- Conservation planning
- Nutrient assessment
- Access to the farm

### 8.3.1 Preliminary Evaluation

Selection of suitable sites is essential to a successful land application program. Land applicators need a roster of suitable sites to accommodate production and application schedules. To conduct an initial screening of available agricultural sites in an area, ask some general questions. If the answer is “no” to any of these questions, consider eliminating the site from further consideration.

#### *Initial Site Screening*

- Is the landowner/farmer interested in participating in the program?
- Is the landowner willing to agree in writing to having biosolids applied to the land and to comply with all applicable regulatory requirements?
- Is the farm operator willing to agree to comply with all applicable regulatory requirements?
- Is the site within an economical hauling distance of the biosolids source?
- Does the site have enough acreage in sufficiently large blocks to meet biosolids production needs?
- Are there any local ordinances or zoning requirements to consider?

If the landowner/farmer is willing or unable to accept and follow the regulatory requirements of a biosolids land application program, their site should not be considered

### *Attitude of Landowner and Farmer*

The attitude of the landowner and farmer is an important component in determining agricultural site suitability. They must be confident about the benefits of biosolids and be willing to accept and comply with all of the Part 503 Rule and state regulatory requirements, as well as meet the biosolids program needs. Discuss with the landowner and farmer the level of public acceptance of biosolids in the neighborhood and community. Ask if they feel that there will be a negative neighborhood reaction to biosolids. A number of states require that landowners adjacent to an application site be notified before the first biosolids application. The landowner/farmer should be aware of this requirement prior to neighbor notification. Specific requirements for landowners and site operators are contained in the federal regulation, 40 CFR Part 503 (see Federal and State Regulations, Chapter 2 of this Manual). Discuss these responsibilities with the landowner/farmer and make sure they agree to follow the site restrictions in regard to waiting periods before the harvesting of certain food crops and the 30-day limitations on public access and livestock grazing

### *Nutrients Application Rate*

- Buffer zones to ensure biosolids are only applied in approved areas
- Commit to injection or incorporation in a timely fashion, if the farmer is responsible for this activity
- Coordinate applications of manure or chemical fertilizers to avoid excessive nutrient application
- As applicable, implement and maintain practices specified in the farm conservation plan or erosion and sediment control plan according to the prescribed schedule

### *Maximum Acceptable Handling Distances*

There are a number of factors to consider when determining the maximum acceptable distance for transporting biosolids. Ask these questions when establishing a maximum hauling distance:

- What equipment is available? Larger vehicles allow travel over greater distances while still being able to handle daily production from a facility.
- Are the biosolids liquid or dewatered? Liquid biosolids require more trips to transport a given dry weight of biosolids from a facility.
- What is the travel time per trip? The number of round trips each vehicle must make in one workday limits how many miles can be traveled. Having multiple vehicles reduces the total number of round trips per vehicle, thereby allowing longer hauling
- Are the roads congested? Delays due to traffic decreases the number of trips that can be made to a site in a day.
- Are there any zoning ordinances that regulate or restrict the types of vehicles or the transporting of biosolids through a jurisdiction? Such local controls may eliminate potential sites within the potential land application area.

### *Management and Economic Factors*

Consider the size and type of fields from both a management and economic perspective.

Potential agricultural sites should have sufficient acreage and/or specific characteristics with respect to operational considerations (e.g., usability during wet conditions) to justify hauling biosolids to the site. There is no established minimum for field size, and each manager should weigh the factors important to his/her program when deciding whether to include specific fields or sites. If a site passes initial screening, a more detailed evaluation will determine if the site is in fact suitable for agricultural land application. The Part 503 regulations do not contain specific criteria for selecting agricultural sites. However, most state regulations do have certain standards and guidelines for site suitability. These should be consulted when evaluating site suitability. Generally, examining a few physical features and farming practices can help determine if a site is suitable. Suggested physical features and farming practices to consider include:

- Soil properties
- Buffer zones
- Conservation plan
- Nutrient assessment
- Access to the site
- Distance to neighbors

*Conduct a "quick" agricultural site evaluation to determine if adequate land area is available at a*

These are discussed in the following sections.

### 8.3.2 Soil Properties

Soil properties affect the suitability of an agricultural site for the application of biosolids. To properly evaluate a site, start by looking at soil related features. A good source of information on soil features can be found in the County Soil Survey available through the local office of the Natural Resources Conservation Service (NRCS). The Soil Survey contains maps (drawn on aerial photographs) that show soil types, slopes, and physical features of the landscape. Other reports and tables that provide basic information on soil productivity and cropping potential needed for managing the site are also included in the Soil Survey.

*Use the soil survey to determine soil characteristics.*

#### *Using the Soil Survey*

To use the Soil Survey manual to evaluate a site, follow the steps listed below:

- Locate the site on the index map page to get the number of the detailed soil map sheet (soil map)
- Find and outline the field(s) on the detailed soil map sheet
- For each field, write down the symbols denoting the various soil types
- Review the soils descriptions, located in the body of the manual, for the soil types in each field
- Decide whether the soils at the site meet general agricultural recommendations or the state requirements related to soils

The soil descriptions and other tables in the Soil Survey provide basic information about important soil features, such as soil texture, erodibility, drainage, and slope. Review this information carefully before making a decision about the suitability of the site. A brief

summary about these soil features -- and how they relate to suitability of a site for land application -- is below. More detailed discussion of soil properties is contained in Appendix C of this Manual (Soil Characteristics).

### *Soil Texture*

Soil texture refers to the size distribution of the soil mineral particles, specifically, the proportions of sand, silt and clay. Textural differences result in differences in ability to absorb and hold water, as well as the surface area available for retention of nutrients and other biosolids constituents, and susceptibility to erosion. While most soil textural classes are acceptable for the application of nutrients to groundwater. Sandy soils are more apt to allow transport of nutrients to the water table.

### *Erodibility*

The extent of soil erosion, or erodibility, should be considered in determining the suitability of a site for biosolids recycling. The potential for erosion is primarily influenced by slope, soil type, and vegetation. The Soil Survey provides information about erosion potential relative to soil type. Each soil type is classified in one of three classes based on potential for erosion. Soils rated as slightly erodible are generally suitable for biosolids application with minimal conservation measures. Soils that are moderately erodible are acceptable for biosolids recycling with implemented conservation plans. Soils that are severely erodible frequently occur on steep slopes and require significant erosion control practices which may limit the usefulness of these soils for biosolids.

### *Drainage*

Soil drainage refers both to how easily water can move through soil (due to soil texture) and to the soil's propensity to be dry or saturated due to landscape position. Part 503 Rule does not address soil drainage or limit the application of biosolids due to poor soil drainage. However, most state regulations do limit biosolids applications on poorly drained soils. Drainage classes are discussed more thoroughly in Appendix C: Soil Characteristics.

In general, soils suitable for the land application of biosolids should allow water to drain through the soil readily, but not rapidly. The soils that fall into the following NRCS drainage classes can be considered suitable: somewhat poorly drained, moderately well drained, well drained, and somewhat excessively drained. Soils that fall outside of these classifications may not be suitable or may require additional management practices. Very poorly drained (hydric) soils can be associated with wetlands and generally are not suitable for land application. Each NRCS office has a list of hydric soils found in every county that can be a helpful tool in assessing site suitability.

Liquid biosolids must be applied in a manner that does not overwhelm the soil's ability to absorb liquids and cause ponding or runoff. The soil survey can be used to identify soils with limited infiltration capacity due to high clay content, restrictive layers (hardpans) or other features. If necessary, applicators can then adjust the total amount of liquids they apply at one time to give the soils adequate time to absorb them.

## *Slope*

A number of states do not allow application of biosolids to agricultural fields with slopes greater than 15 to 25 percent. Slopes steeper than these increase the possibility of surface runoff and erosion and therefore require more intensive conservation measures that may restrict biosolids application options. In addition, safe operation of equipment becomes more difficult as slopes increase. The slope that is acceptable on any one site varies and depends on farming practices, soil infiltration rates and erosion potential.

The soil survey provides an estimate of the slopes at a site. A formal on-site verification of slopes should be conducted if a visual inspection indicates potential discrepancies between existing site conditions and those shown in the soil survey.

### **8.3.3 Buffer Zones**

Sites selected for biosolids applications must be consistent with federal and state regulations regarding buffer zones -- physical separations between the biosolids application area and certain other areas, including streams, wetlands, dwellings, or wells. The Part 503 Rule does not allow the application of biosolids within 10 meters (33 feet) of a surface water source, such as a stream, pond, or wetland. Other federal requirements regarding management practices are contained in Chapter 2 of this Manual (Federal and State Regulations).

#### *Typical Setbacks*

Many states have buffer requirements. These typically include setbacks from:

- Property lines
- Homes/wells
- Water bodies
- Dry runs, grass waterways, etc.
- Rock outcroppings
- Public roads

*Record all state and local buffers on a map to decide if the remaining acreage is realistic for your program.*

#### *Factoring In Buffers*

During site evaluation, all buffer zones should be noted and marked on a site map. The removal of application areas to accommodate buffer zones may result in less acreage at the site than is acceptable. Buffer zone requirements may cause removal of a field or even an entire farm from further consideration for land application of biosolids.

### **8.3.4 Conservation Planning**

Farm conservation plans -- tools for farm operators to protect water quality and prevent soil erosion -- are a part of good farming practices. The Part 503 Rule does not require

*Having a fully implemented conservation plan at an agricultural site is a sound farming practice and should be an important consideration in deciding on the suitability of that*

that a farm conservation plan be in place for biosolids applications; however, many states do require some measure of erosion control. In the initial phases of site selection, find out if a plan has been prepared for the farm and the status of its implementation. If a farm does



have a plan, review specific conservation practices for the fields considered for land application of biosolids. Certain conservation practices (e. g., use of no-till or residue management) may affect land application options. In such cases, determine whether surface application without incorporation is possible. A detailed discussion of conservation control is contained in Biosolids Recycling and Soil Conservation, Appendix E of this Manual.

### **8.3.5 Nutrient Assessment**

The application of nutrients to crops is necessary to achieve good yields. Farmers apply nutrients in the form of animal manures, chemical fertilizers, biosolids, and other residuals. To protect surface and ground water resources from excess nutrients, those supplied must balance with the needs of the crops to be grown. Nitrogen is the focus of most regulations, due to its more available (soluble) forms in soils. However, increasing attention is being given to phosphorus in managing farm nutrients. Nutrient management is discussed further in Biosolids Nutrient Management, Chapter 13 of this Manual.

#### *Nitrogen Balance Check*

For initial screening of potential sites, perform a nitrogen balance check (see Nitrogen Balance Check, Appendix D of this Manual) to compare the amount of nitrogen available at the site (animal manure estimate) to the nitrogen need of the crop (average crop nitrogen need). With this information, decisions about the need for additional nutrients at the site can be made.

### **8.3.6 Access to the Farm**

When conducting a site evaluation, accessibility is an important consideration. Communicate with local officials to determine acceptable routes. Once at the site, determine how to gain access to the application area. The best fields in the world are of no value if vehicles and equipment can't get to them.

#### *Off-Site Road Restrictions*

Road restrictions can result in problems, especially if they aren't considered during the site evaluation. Ask the following questions about roads leading to the site before deciding that a site is suitable:

- Are there any road limitations, such as road or bridge weight restrictions or bridge height restrictions that can keep vehicles from getting to a site?
- Are there any local limits on heavy vehicle traffic in certain residential or business districts that may limit options for getting to a site?
- Have local officials been consulted to determine acceptable routes?
- Does the farm have a safe and accessible entrance? Are turning angles adequate for vehicles?
- Are there blind turns or hidden entrances that may create a safety hazard to vehicle drivers and other motorists? Will warning signs or flagmen be necessary?

#### *On-Site Road Restriction*

As the following questions about roads on the site:

- Are there adequate areas to unload if necessary? For instance, a level area to

offload dewatered biosolids may be needed so they can be loaded into spreaders; or a staging area may be needed for transferring liquid biosolids.

- Do the roads become inaccessible during and after wet weather conditions? Heavy vehicles can get bogged down or create unacceptable ruts, or worse yet, become stuck.
- Are there ways to cross streams or conservation areas such as grassed waterways to get to remote fields?

Most issues associated with transportation routes and site access can be resolved. Discussing the route with local officials is strongly recommended as they may ask

that certain roads be avoided. The farmer may express concerns about access to remote fields at the farm. Field access should be discussed with the farm operator during the site evaluation. This is probably the single most important issue to the farmer. Getting an application vehicle stuck in a muddy farm lane or unloading biosolids in an inappropriate area can ruin a relationship with the farmer. In some cases, it may be advisable to work with the farmer to improve farm roads to accommodate your equipment.

*Consider transportation and site access issues during the initial farm evaluation and resolve them, or eliminate the farm from further consideration.*

### 8.3.7 Distance to Neighbors

The importance of proximity to neighbors depends on such factors as the type of biosolids application, type of biosolids processing, whether neighbors are also farmers, existing natural barriers (e. g., trees), degree of overall community acceptance for the program and other subjective judgments. Good communication with participating farmers often can help determine which factors are important, and common sense is the best way to determine desirable distances from neighbors for specific sites. Many states have requirements for buffer distances from abutting property lines and houses, but these alone may not be sufficient to address neighbors' concerns. Try to be as flexible as possible in dealing with this issue -- it may be possible to find mutually agreeable ways to satisfy neighbors and still be able to operate on a site. At the very least, it is important to acknowledge the validity of their interest, and make reasonable efforts to accommodate their wishes, particularly with respect to such factors as timing of operations.

## 8.4 Permitting Sites

While the Part 503 Rule does not require site-specific land application permits, many state regulations may contain specific criteria for selecting suitable land application sites and require that specific documentation be developed for site approval. Make certain that the state requirements are fully understood and that those requirements are factored into the initial site evaluation.

*Make certain that the state requirements are fully understood and that those requirements are factored into the initial site evaluation.*

While the Part 503 Rule does not require site-specific land application permits, many state regulations may contain specific criteria for selecting suitable

land application sites and require that specific documentation be developed for site approval. Make certain that the state requirements are fully understood and that those requirements are factored into the initial site evaluation. This section outlines general procedures commonly needed to “qualify” (for regulatory approval) a site for a land application program. The specific information needed for site approval is available through individual state regulatory agencies (see state and regional Contacts, Appendix B of this Manual).

### *Obtain Landowner Permission*

Some state regulations require the landowner to sign a consent form to participate in a biosolids program. It is a good idea to share this form with the landowner during the first visit. In most cases, the form is a legal document and time should be taken to explain the form fully. In cases where there is more than one landowner, it may be necessary to obtain signed consent from each owner. In situations where the landowner and the person operating the farm are not the same individual, make sure that they are both in agreement about participating in the program.

### *Establish Baseline Soil Fertility and Chemistry*

Most state regulations require that soil samples be collected and analyzed for nutrients (fertility) prior to the first application of biosolids to the farm. Some states also may require analysis of regulated metals, soil pH, and, in some cases, phosphorus. There may be good reason (e. g., public acceptance) for testing for such parameters even if not required. A good strategy in these cases would be to collect both background and post application samples for analysis. As a minimum, know the state and local regulations and follow them.

Soil fertility information can be useful to farmers, and they may appreciate receiving it. Consider supplying soil fertility information to participating farmers on a regular basis. Knowing soil nutrient recommendations from the soil fertility report can be useful in planning biosolids applications.

*Collect and analyze required soil and water characteristics prior to any biosolids application. This allows the program to document any conditions existing prior to land application.*

*Collecting Soil Samples* There may be a concern that soil metals at a farm are greater than natural background soils. Past farming practices may have contributed to higher than background metal levels in the soils. As a result, collecting soil samples and having them analyzed for regulated metals may be a reasonable thing to do. In some areas of the United States, background soil metal levels may be elevated due to natural minerals in the soils. Again, collecting soil samples for metal analyses prior to the initial application is a good idea.

### *Consistency with Conservation Planning*

If a farm has a conservation plan, biosolids application should be done in a manner consistent in place and maintained for permitting requirements. In particular, look at structural Best Management Practices (BMPs) such as grass waterways and diversions, which are used to manage the movement of water on a site. These practices, if not in place or if poorly maintained, may require significant time and money to install or repair and may delay the opportunity for land application of biosolids. Look for evidence of uncontrolled water movement such as rills or gullies or accumulations of sediment indicating a need for conservation measures. Conservation plans also address cover crops, conservation cropping (crop rotation), and tillage systems.

### *Mapping Tools*

Maps are essential tools in permitting and managing agricultural sites. Nearly all states require some type of map before biosolids applications are permitted. Typical requirements for maps include:

- Property and field boundaries
- Location of surface waters and buffer zones
- Location of dwellings and wells and buffer zones
- Biosolids application areas
- Soils information
- Slopes
- Conservation structures, such as waterways

Maps can be produced in a variety of formats from topographic quadrangle maps prepared by the U. S. Geological Survey (USGS) to aerial photographs of sites used by the Farm Services Administration for farm conservation planning and agricultural cost-sharing purposes. Cooperative Extension Offices, state land grant universities and local governmental planning units may have base maps that can be used to meet state mapping requirements.

Maps are most useful when the farm location and application areas are clearly shown. Problems with farmers and neighbors can occur if good mapping isn't available for the applicler. A clear map provides truck drivers with the means of locating correct fields for land application on each farm.

*Select the source of map for use at the site. Generate a "base map" to mark property boundaries, field boundaries, buffer zones, and other areas to be excluded from the application.*

Other farm information also should be included on a map including staging or storage areas, and farm and field access points. It may even be a good idea to use the site map to show daily application areas for record keeping purposes. Geographic Information System (GIS) can sometimes be used to record information and develop a database for an application program.

Farmers may have fields where drainage is poor and soil compaction from application equipment may be a concern, and it may be wise to exclude those fields from consideration. As a minimum, know the state and local regulations and follow them, using the base map to identify areas to exclude from the application area. Individual states may have additional criteria that should be identified on the base map as well for exclusion from the application area.

Farmers prefer to have biosolids applied to an entire field. Additional applications of other sources of nutrients are not necessary (on portions of the field) if the entire field is acceptable for biosolids. If there are substantial areas in a particular field where biosolids cannot be applied due to federal or state requirements, the farmer may not want to have biosolids applied to that field.

### *Application Restrictions and Buffer Zones*

In qualifying a site for biosolids applications, certain sensitive areas must be eliminated from the application area. As discussed buffer zones are required to minimize the potential for surface runoff or leaching to impact surface or ground water resources.

The Part 503 refers to restrictions to protect surface and ground water as management practices that must be addressed during site selection. Refer to Federal and State Regulations, Chapter 2 of this Manual and

references (USEPA 1993 and USEPA 1994) and (4) for more detailed discussion of management practices. For Class B biosolids, the Part 503 Rules Management Practices require restricting the application of biosolids:

- Where biosolids applications will likely adversely affect a threatened or endangered species (any place where a threatened or endangered species lives and grows during any stage in its life cycle);
- On flooded land (land is considered flooded when the soil at the surface is saturated with water, regardless of whether water is visible on the ground);
- Within 10 meters of surface water bodies (buffer zone so that biosolids do not enter surface waters or wetlands).

*Use common sense in eliminating poorly drained and steep areas from the biosolids application area. Try to accommodate the farmer by keeping as much of a field in the application area as possible.*

Make certain to identify areas on the site that meet the above descriptions and eliminate them from the application area. Most states also have additional restrictions (e. g., shallow depth to groundwater or shallow seasonal water tables). Consult state regulations and include such restrictions in the information provided for regulatory site approval.

## 8.5 Field Operations

The following functional groups are associated with basic levels of responsibility for biosolids management in a land application program:

- Preparer (Generator): The person who prepares biosolids during the treatment of wastewater.
- Transporter: The person who transports biosolids from the point of production (treatment plant) to the point of use at the agricultural site.
- Applier: The person who applies biosolids at the farm to condition the soil and fertilize crops.
- Farmer: The person who grows and harvests the crops fertilized with biosolids.

In many programs, typically the smaller and medium sized, the generator is responsible for the activities of the entire program. Other programs may contract with other entities to transport and/or apply biosolids. Each of the entities above has a responsibility as defined by regulation and possibly by contract. However, the generator also has the responsibility to make certain biosolids are transported and applied in compliance with the regulations. It is also wise for the generator to provide guidance and oversee the activities of the transporter and applier. If the transporter or applier does not follow good management practices, the generator may lose the trust of the farmer and the community. A manual developed by the California's Water

Environment Association of this chapter contains a summary of the responsibilities of the various functional groups. (California Water Environment Association 1998)

### 8.5.1 Scheduling

Before scheduling, check to make sure ownership of the land has not changed since the landowner consent forms were signed. Also confirm that required state and local approvals have been obtained and are current. Note any fields that were deleted since the site was selected. Make sure all required maps, soil testing and other analytical monitoring requirements are up to date.

The application of biosolids to agricultural sites requires working closely with the farmer. Meeting the schedule of the farmer is very important. For the most part, farmers have tight schedules and when it is time to apply biosolids, it needs to happen quickly. Scheduling land application activities must account for the operational controls described below.

#### *Biosolids Production Schedules and Storage Capacity*

Each treatment facility produces solids on a daily basis. Some facilities do not have storage capacity and require daily end-use options. Other facilities generate biosolids periodically when lagoons or digesters are cleaned, or have storage for biosolids. These application sites in the spring is great as managers meet fertilizer requirements before crops are planted. Storage over the summer months is often critical, as access to planted fields is limited.

#### *Cropping Patterns and Land Availability*

Most biosolids are applied to cropland. The most active seasons for land application are in the spring before row crops are planted, and in the fall after crops are harvested, when fields are generally accessible over a longer period of time. Crops have different growing seasons in different parts of the country. Biosolids managers should become familiar with the different windows of opportunity for biosolids application, and incorporate them in overall biosolids management program planning.

Plan to meet with each farmer at the beginning of every year to talk about cropping schedules and potential biosolids application periods. Based on the cropping information supplied by the farmers, prepare an annual application plan for the biosolids. The plan should address the following:

- What is the quantity of biosolids available for land application in the coming year?
- Which fields will and will not be available for biosolids applications in the upcoming season?
- When will the selected fields be available for biosolids applications?

Provide a copy of a completed annual application plan to farmers. They are more likely to call when fields become available if they know the schedule for potential biosolids applications.

*Seasons, Weather, and Soil Conditions*

The seasons, prevailing weather conditions, and soil conditions greatly influence the schedule of biosolids application operations. Winter can be a difficult period, since biosolids may not be applied to flooded, frozen, or snow-covered ground. Wet periods in the spring may restrict application on low-lying fields since heavy traffic can cause compaction. Storage and/or disposal alternatives are needed when poor weather conditions prevent land application operations.

*Know the farmer's planting schedules and potential biosolids application periods. Be ready to quickly move biosolids during those times.*

*Sensitivity to Neighbors*

In scheduling sites for biosolids operations, be sensitive to the farm neighbors by considering timing and weather conditions. For example, in many parts of the country where neighbors are relatively close to application sites, it's not a good idea to schedule biosolids applications on a hot, humid Friday of Labor Day weekend. Common sense and consideration can determine whether or not biosolids land application is accepted in the community.

Identify sensitive sites and give them special consideration when scheduling biosolids applications. Make sure the land base has some less sensitive/isolated sites that can be used for unusually odorous materials, when hot weather conditions increase the potential for off-site odors, and during times when neighbors likely will be outdoors, such as holidays and weekends.

To minimize the odor associated with a land application program, consider injection of liquid biosolids or immediate incorporation of dewatered biosolids. Besides odor, consider the potential impacts of traffic and noise from trucks delivering biosolids and equipment loading and spreading biosolids. More detailed discussions of odor and other aesthetic considerations are contained in Public Acceptance, Odor Control, and Odor Control in Land Application Chapters (1, 7 and 11) respectively, of this Manual.

**8.5.2 Determining Application Rates**

The Part 503 Rule requires that biosolids be land applied at “an agronomic rate” that meets the crop's nutrient requirement for optimum growth. This rate must be calculated for specific crops grown on various soils in different parts of the country. For most biosolids land applied under the requirements of the Part 503 Rule, nitrogen will be the limiting constituent on an annual basis. Therefore, the application rate must be calculated giving careful consideration to the kinds and amounts of nitrogen in the biosolids. Typical ranges for these forms of N in anaerobically digested biosolids are shown in Table 8.1.

**Table 8.1: Composition of Representative Digested Biosolids**

Component	Range
Organic nitrogen	1% - 5%
Ammonium nitrogen	1% - 3%
Total phosphorus	1.5% - 5%
Total potassium	0.2% - 0.8%

*Plant Available Nitrogen Calculation*

Organic nitrogen is estimated as total nitrogen (TKN) minus NO<sub>3</sub>-N and NH<sub>4</sub>-N. Both of these latter forms of N are inorganic and therefore more readily available for plant uptake or movement through the soil. Organic nitrogen must be mineralized to these inorganic forms through a microbial decomposition process in the soil in order to become more available to plants. Nitrogen transformation processes occur in various combinations depending upon environmental conditions. For example, nitrification converts NH<sub>4</sub>-N to NO<sub>3</sub>-N by means of an aerobic process. Conversely, the anaerobic denitrification process converts NO<sub>3</sub>-N to gaseous N forms (N<sub>2</sub> or N<sub>2</sub>O that can be lost from soils), which occurs to a significant degree in water-saturated soils. Immobilization occurs when soil microorganisms use inorganic N in such a way that it is no longer available for plant uptake. Nitrogen may also be lost through volatilization of NH<sub>3</sub>, especially when biosolids remain on the ground surface. The calculations used to determine plant available nitrogen (PAN) are detailed in Biosolids Nutrient Management-Calculating Agronomic Rates of Application, Chapter 14 of this Manual. A series of sample worksheets are included that help calculate an agronomic application rate.

*Agronomic Rate Calculations*

Once the plant available nitrogen is calculated, the amount of biosolids needed to meet crop needs - the agronomic rate - can be determined. The agronomic rate is the amount of biosolids required to meet the nitrogen recommendation for the crop grown as shown on a soil test report, factoring in applicable nitrogen credits (e. g., from manure application or legume plow down). Balancing the amount of nitrogen applied to the crop to meet the need of the crop minimizes leaching of nitrogen below the root zone and to groundwater. Agronomic application rates are expressed in dry tons per acre. This unit application rate needs to be converted to “as-delivered” units. For example, for dewatered biosolids, the amount of wet tons per acre or cubic yards per acre that can be applied must be calculated.

*Use the application plan information to correctly calculate the agronomic application rate. Plan to apply biosolids as close to the agronomic rate as conditions allow.*

*Variations from the Rate*

Although it is best to apply biosolids at this agronomic rate, there are situations when that isn’t possible. Poor weather conditions, wet fields, farmer’s schedule, and equipment problems, are a few examples of times when not enough biosolids can be applied to meet the calculated application rate. Liquid biosolids may not be applied to the full agronomic rate if soils do not have the ability to transmit the liquid (water) portions fast enough to prevent ponding. It also can take longer to transport liquid biosolids



because the majority of what is being moved is water.

### 8.5.3 Field Operation Checklist

When a site is scheduled for biosolids application, use the following checklist as operational controls.

#### *Regulatory Compliance*

- Take the following steps to prepare the site and ensure compliance with federal, state, and local regulations
- Verify site documentation from the management plan
- Check the annual application plan and consult with the farmer about timing, fields, tillage, incorporation responsibilities
- Mark buffer zones and setbacks
- Calculate agronomic application rate if not already specified
- Consider any other specific regulatory requirements

#### *Operation “Inventory”*

Before operations on a land application site begin, brief all personnel, especially truck drivers and equipment operators who apply the biosolids. The following information is needed:

- Correct haul route as shown on a map with written directions to the site
- A map showing the fields and identification numbers where applications will take place
- Location of the flagged areas and buffer zones and any fields restricted from biosolids application
- Locations of loading/stockpiling areas
- Application rate to be used on each field and the total field capacity
- Method of application (surface or injection) and, for surface application, any time limits for soil incorporation (If the vector attraction reduction requirement will be met by soil incorporation within six hours after application, emphasize the need to observe this time limit.)
- Weather/field conditions that require operations to be shut down or delayed
- Any special requirements imposed by regulatory agencies, instructions from the farmer, and any good neighbor practices regarding odors, operating hours, or other aesthetic considerations

## 8.6 Managing Operations

Once all of the program requirements have been met, operations can begin. The following discussions include operational controls to consider during operations at the farm.

### **8.6.1 Biosolids Management Plan**

Land application activities should be conducted according to a written management plan, in which everyone's role is clearly defined. The farmer, producer, transporter, and program. Facilities should consider developing a plan. If a plan is beneficial to their program it should be provided to each person with a significant role in the program. The plan should be reviewed and updated as needed.

#### *Farm Specific Information*

The plan should contain relevant general information about relevant farming operations, cropping practices and biosolids application practices. In addition, specific information about each farm should be developed that includes the following:

- Map(s) that identify application sites. All buffer zones (buildings, surface waters, wetlands) required by the state regulations should be included on the map(s). Staging and storage areas should be clearly marked to assist transporters.
- Description of crops to be grown, crop planting and harvesting schedules, commercial fertilizer use, conservation measures needed, and information about any use of animal manure.
- Application practices related to the method of spreading, methods of incorporation, agronomic application rates, nutrient management measures (when required), and other agricultural management practices.

### **8.6.2 Plan to be a Good Neighbor**

The key to successful land application programs is being a good neighbor. This means conducting operations in compliance with all regulations and working to accommodate and be courteous to neighbors.

#### *Brief Field Crews*

Brief field crews on appropriate responses to inquiries from citizens or local government representatives. They should listen respectfully to concerns and make every effort to resolve issues. Timely and quick responses can resolve issues before they escalate. Be sure field staff knows the program's contact names and phone numbers for their own use, and to provide to neighbors as appropriate.

#### *Complaint Response*

If complaints are received, document them. Record the complainant's name, the date and time, and a summary of the complaint. Investigate every complaint. The results of the investigation and any planned corrective action, if needed, should be promptly shared with whomever filed the complaint and others involved in the situation (such as local government representatives). Ongoing communication with these individuals or groups should be maintained until the situation is resolved. Further discussion of communication efforts is contained in the Chapter Public Acceptance.

### 8.6.3 Coordinate Operations with the Farmer

Consult the farmer regarding preferences and concerns about hours and days of operations, truck access routes to the fields, soil moisture condition as they relate to equipment traffic and potential for soil compaction. Discuss tillage practices and Best Management Practices (BMPs) used on the farm. Fields where a Conservation Plan specifies no-till or residue management practices may be limited to surface application, or biosolids applications may be scheduled only when tillage is allowed in the crop rotation.

#### *Verify Pervious Data*

Since several months can elapse between regulatory approval of a site and biosolids application, verify the previously collected data and note any changes with the farmer. Verify which fields the farmer wants to receive biosolids and make sure they are still eligible. In addition, verify the crop to be planted on each field.

#### *Review Fertilizer Needs*

Discuss crop yield goals and fertilizer needs. Find out if any fields have been, or will be, fertilized with manures, residuals (such as food wastes), or chemical fertilizers. This may change the projected biosolids application rates or make the field ineligible for biosolids application.

*It is recommended that biosolids application sites that can allow injection or incorporation be selected*

#### *Biosolids Nutrient Information*

Provide the farmer with a description of the type of biosolids and expected nutrient additions. The farmer will be particularly interested in the amounts of nitrogen (N), phosphorus (P), and potassium (K) that will be applied so that any supplemental chemical fertilizer necessary to meet crop fertility requirements can be applied at planting. When lime treated biosolids will be applied, provide the farmer with equivalent lime information.

#### *Application Timing, Method*

If biosolids are surface applied to hay, pasture or rangeland it is important that they be well stabilized. Liquid application of well-digested anaerobic biosolids may be more acceptable to neighbors than surface application of lime-treated dewatered biosolids.

If biosolids are to be applied to hay or pasture, plan application so as to apply biosolids right after fields have been cut or grazed to a recommended height of four to six inches. Verify that the farmer can and will restricting grazing for 30 days after biosolids application. If the farmer cannot rotate livestock pastures to comply with required waiting periods, biosolids should not be applied to the field.

Finally, the applier should periodically contact the farmer and conduct site visits to monitor crop growth and site conditions. The applier also should be available to troubleshoot potential problems.

### 8.6.4 Identify Buffer Zones and Restricted Areas

Before beginning biosolids application operations, positively identify all buffer zones and areas where applications are restricted in the field. Develop a method to notify the applier of these areas.

#### *Flagging Fields*

On small sites, or in areas with close neighbors, flags are used to delineate buffer areas. Placing flags in the field will show equipment operators what areas of the field should receive biosolids. When flagging fields, the following practices are recommended:

- Determine the exact location of off-site features (e.g. private wells) that must be buffered.
- Do not guess.
- Verify unclear property line boundaries. If the boundary between contiguous fields is a property line and there is no distinct natural or manmade boundary, the boundary should be established using the current deed, tax map, or property survey.

### 8.6.5 Managing Areas for Staging, Storage or Stockpiling

Discuss the vehicle route to be followed with the farmer. Many farmers will not permit narrow-tired delivery trucks to cross fields because of soil compaction. Decide with the farmer where loading and stockpile areas will be located.

#### *Minimizing Field Impact*

Heavy vehicle traffic in loading areas causes soil compaction. With dewatered biosolids operations, loading areas also tend to have high levels of biosolids mixed into the soil or left as a surface residue. These factors may prevent good crop growth in loading areas and may leave bare spots in fields. To minimize impacts on a field, scrape off-loading areas to remove excess amounts of biosolids. These areas also can be evened out through back-dragging, chain drags, or discing. If soil compaction is a major concern, these areas should be chisel-plowed or v-ripped. Discuss options with the farmer and make sure measures taken comply with the Farm Conservation plan.

#### *Selecting Loading, Stockpiling Areas*

These steps should be followed when selecting areas for loading and stockpiling biosolids:

- Ensure the area is designated for biosolids application
- Avoid low spots
- Choose areas with little or no slope
- Minimize the distance application vehicles must travel to spread material
- Ensure easy truck access
- Maintain required buffer or setback distances

Normally, biosolids are applied starting at one field border and proceeding to the other. The off-loading site must be selected so that the unloading vehicles do not have to drive through areas where biosolids have been applied. Conservation practices on a site, such as contour plowing and strip cropping, can make biosolids application challenging due to

difficulties in maneuvering equipment. Such practices may eliminate a field from consideration. Also note the location of conservation structures such as earthen diversions and grass waterways. Be careful that trucks and other heavy equipment do not damage these structures.

### **8.6.6 Site Application Equipment**

Land application equipment should be designed and maintained to ensure that biosolids are applied evenly across the field at the proper application rate. Application equipment (box spreaders or liquid applicators) should be calibrated regularly. It is important to apply biosolids at the proper rate, as exceeding applications limits can become a serious compliance issue.

#### *Liquid Application Options*

Liquid soil injection units have a series of hoses running from a tank to a tool bar equipped with a series of injectors. The injectors are vertical knife-like blades, resembling a chisel plow, which slice through the soil and inject a band of liquid up to 10 inches below the soil surface. On cropland, chisel plows or disc harrows pulled behind a tractor also are used to incorporate the biosolids into the soil and to provide a more uniform application. Injecting liquid biosolids reduces ammonia volatilization and decreases odor potential by minimizing biosolids exposure to the atmosphere. Liquid handling equipment may operate by gravity or pumps. Gravity fed systems not requiring mechanical pumps are less expensive, and are suitable for biosolids with low solids contents. Gravity systems work best for surface applications that exhibit less resistance to flow of materials. Using pressurized or vacuum pumps to apply thickened liquid biosolids reduces application time and provides a uniform application.

#### *Spray Irrigation*

Spray irrigation on land application sites may be used for biosolids with a very low solids content. Standard irrigation equipment may be used with pipe sizes and pump pressure adjusted for the solids content of the biosolids. Spray guns or drop hoses may also be used; drop nozzles are less likely to produce nuisance odors since they do not disperse a fine mist into the air.

#### *Spray, Drop-Hose Applications*

Liquid biosolids also may be applied on the soil surface using spray or drop-hose pastures, fields managed using no-till or conservation tillage, or for top dressing growing crops such as small grains).

If incorporation is desired following surface application, biosolids may be worked into the soil with standard agricultural chisel plows or agricultural discs. Surface application works well on very coarse, gravelly or stony soils that might damage injection equipment or when high clay content makes the soils difficult to chisel plow. It also provides more uniform application than the banding effect from injectors. The wider application pattern from surface application also reduces the number of equipment passes required to cover a field.

### *Cake Application*

Delivery trailers offload dewatered biosolids into piles across a field or in a centrally located area. Front-end loaders are used to transfer the material to applicator vehicles. Dewatered biosolids can be applied using standard side or rear discharge manure spreaders (pulled by tractors) or self-propelled hopper-style spreaders.

After biosolids are spread, discing or chisel plowing may be used to work them into the soil. Where soil incorporation is inappropriate, such as pastures, dragging a chain harrow across the field helps break up biosolids clumps for more uniform distribution.

### **8.6.7 Equipment Calibration**

To meet regulatory requirements and the needs of farmers in a land application program, applicators must calibrate equipment properly to insure uniform application at agronomic rates. Calibration may be accomplished by spreading a known amount of biosolids at a given speed, and measuring the area covered.

#### *Calculating Application Rate*

To calculate the application rate (AR):

$$\mathbf{AR} = \mathbf{Amount\ Applied} / \{ (\mathbf{L} \times \mathbf{W}) / 43,560 \}$$

*Where:*

**AR** = amount applied (gal, wet tons, cubic yards) per acre at a given vehicle speed

**L** = length in feet

**W** = width in feet

**43,560** = square feet per acre conversion factor

By repeating this calculation at several speeds, the speed needed to apply a specific source of biosolids at the allowed application rate can be determined. Changes in solids content will change the amount of total material needed per acre to achieve the selected application rate, and may necessitate recalibration. When operating at specific gear settings and ground speeds, application rates should be determined for each gear settings.

#### *Check Field Conditions*

Just prior to biosolids application, check the condition of the fields for wetness and adequate access. Scheduled applications may have to be postponed due to weather or saturated soils. Wet soils are more subject to compaction and rutting and can bog down equipment. Make sure the farmer agrees that conditions are acceptable for land application.

#### *Liquid Application*

Liquid application should not exceed the soil's ability to absorb the liquid (hydraulic loading rate), which could result in surface runoff or ponding of the material. Depending on the rate at which the soils on a site are able to absorb liquids and the slope, operators may opt to limit the volume of liquid biosolids applied in a given period of time. This practice need not affect the total amount of biosolids (dry tons) that can be applied per acre, but it may affect how many application passes must be made before the full rate is

applied.

### 8.6.8 Recording Field Applications

Once application of biosolids is completed, the applicator is responsible for gathering and summarizing the application information. It is important to carefully record application information during operations. Make certain that the applicator has a system in place to record the application information accurately. The applicator should have a site or field map and a form to record each load.

#### *Data to Record*

Biosolids application information may be recorded on a daily basis or a field basis. Most state biosolids programs have preferred methods for recording this information. Follow the suggested method for your state. It is important to record:

- Number of loads hauled
- Number of gallons or wet tons per load
- Average percent solids
- Number of acres in the application area
- Field and weather conditions

#### *Report to Farmer*

When biosolids applications are completed on a field, give the farmer a report that shows the total amount of biosolids, nutrients, and trace metals applied to each field. This report is designed to give farmers a record of what was done to each field and help them determine supplemental fertilizer needs.

A follow-up meeting with the farmer is advisable to review all crop and grazing restrictions and make sure that the farmer knows his obligations. This is also an ideal opportunity to inquire about any further follow-up work needed at the farm, and determine satisfaction with the biosolids application operation.

### 8.6.9 Scheduling Applications

Land application operations require that the available land be managed to account for seasonal variations in amounts of biosolids removed from a given facility. Daily production amounts may be only partly related to the equipment required for managing those quantities of biosolids. Weather and soil conditions in the field, stored biosolids that must be removed and applied at certain periods of the year, and availability of fields based on cropping practices will all play a role in determining equipment needs.

*Scheduling land application operations requires that the available land be managed to account for seasonal variations in amounts of biosolids hauled from a given facility, weather patterns, amounts of stored biosolids, and crop production practices.*

#### *Variable Quantities*

An example of the variability in quantities for a liquid land application program is contained in Table 8.2, which shows the monthly distribution for the Madison, Wisconsin

Program.

**Table 8.2: Monthly Biosolids Distribution for Agricultural Program, Madison, Wisconsin**

Month	% of Annual	Gallons/day
January	0	0
February	0	0
March	0	0
April	10.2	147,600
May	19.7	285,000
June	5.2	75,000
July	5.9	85,000
August	14.1	205,000
September	17.2	250,000
October	18.6	270,000
November	9.1	132,000
December	0	0

Table 8.2 illustrates the seasonality (in most parts of the country) of land application operations. In the case shown, winter weather conditions and agricultural planting schedules limit or prohibit field operations during several months of the year. These considerations are critical to providing adequate equipment capability. Liquid operations that employ subsurface injection (as is done exclusively for the Madison project) are even more field-limited than surface application of liquid or dewatered cake biosolids.

*Managing the Land Base*

A flexible approach to managing the permitted land base can maximize the land application days each year. The following suggestions may be useful in managing the land base:

- *Use fields on a rotating basis:* Maximize biosolids applications to the field by waiting one to three years between applications. Annual biosolids applications reduce agronomic application rates when residual nitrogen from the previous year’s applications is accounted for.
- *Avoid buildup of excess soil phosphorus:* Phosphorus (and, in some cases, lime) can build up in the soil from repeated biosolids applications. Concerns regarding excess phosphorus application may be reduced if the land base is managed appropriately.
- *Apply biosolids at agronomic (crop nitrogen need) application rate:* Lower biosolids application will increase the recycling costs, and lower the economic benefit for farmers. The net effect is fewer nutrients and organic matter are provided with low application rates.
- *Include a variety of types of farms in the land base:* Farms with different crops, soils, locations, transportation routes, or local government units add flexibility to



the program. For example, soil types at farms in one area may allow applications in wet weather, and in another area the farmers may grow crops that allow summer access. Having both types included in the land base provides needed flexibility.

### **8.6.10 Housekeeping - Good Neighbor Policies**

Control of potential for nuisance conditions should be an integral part of all phases of biosolids management practices. For example, greater processing (e.g., digestion, lime addition) to reduce vector attraction during treatment also can serve to prevent odors from developing during handling, transport and application of the biosolids in the field. This subject is discussed in greater detail in the Odor Control in Land Application Programs Chapters.

*Control of potential for nuisance conditions should be an integral part of all phases of biosolids management practices.*

Applying common sense procedures to prevent nuisance conditions during transport and handling of biosolids is one of the most important aspects of successful projects. It is in this area of biosolids management, perhaps more than any other, that the "good neighbor policy" is essential to success.

#### *Review Housekeeping Issues*

Field operational practices to address housekeeping issues include:

- Spill prevention and cleanup
- Daily (or more frequent, if needed) equipment cleaning
- Prompt incorporation of biosolids into the soil where appropriate
- Avoiding application near dwellings during weather conditions when odors are more likely to occur
- Avoiding field conditions that might lead to biosolids' ponding
- Avoiding tracking of mud/biosolids onto roadways
- Selecting off-loading areas that are as inconspicuous as possible
- Limiting field stockpiling whenever possible

Good housekeeping at the farm maintains a positive impression with the farmer and the surrounding community. The operator should properly cover trucks, repair leaks (e. g., tailgate seals), and clean tires and mudflaps. Recognize that even if subcontractors are used to transport biosolids, the generator's program is at risk if housekeeping is ignored. During operations and equipment transport to new fields/sites, keep roadways clean of biosolids and mud. Truck drivers should not drive through biosolids. Clean vehicles before leaving the field to prevent dragging or spilling biosolids on the roadways.

#### *Procedures at Application Site*

At the end of each day and after completing application to a field, some or all of the following may be necessary:

- Remove any signs at the entrance
- Pick up trash
- Back-drag and/or till off-loading areas

- Till compacted areas (truck routes, staging areas)
- Secure fence openings/gates
- Repair any damaged property as agreed upon with the farmer (e.g., fences, gates, mailboxes, cattle guards, culverts, farm roads, rutted areas)
- Clean up any materials tracked onto roadways during field operations and during equipment moves with absorbents, brooms and shovels or broom tractors
- Chain drag/harrow pasture and hay fields where necessary

### 8.6.11 Site Restrictions and Public Access

Part 503.32 (b) (5) contains specific site restrictions that apply to the application of Class B biosolids. The site restrictions are summarized below:

- Food crops with harvested parts above ground but touching the biosolids/soil mixture shall not be harvested for 14 months after application.
- Food crops with harvested parts below the surface shall not be harvested for 20 months after application when the biosolids remains on the surface for 4 months or longer prior to incorporation into the soil.
- Food crops with harvested parts below the surface shall not be harvested for 38 months after application when the biosolids remains on the surface for less than 4 months prior to incorporation into the soil.
- Food/feed/fiber crops shall not be harvested for 30 days after application.
- Domestic animals shall not be grazed on land for 30 days after application.
- Public access to land with a high potential for public exposure shall be restricted for one year after application of biosolids.
- Public access to land with a low potential for public exposure shall be restricted for 30 days of biosolids.
- Turf grown where biosolids are applied may not be harvested for 1 year after application when the harvested turf is placed on land with a high potential for public exposure or a lawn, unless otherwise specified by the permitting authority.

These restrictions were designed to ensure sufficient reduction in the number of viable helminth ova, one of the hardiest of pathogens. The soil environment serves as the medium for further reduction of pathogens, beyond normal treatment processes. Refer to (Environmental Considerations) Chapter 14 of this Manual, for an explanation of the fate of pathogens in the soil once the biosolids have been land applied.

According to the site restrictions in the Part 503 Rule, public access must be restricted for sites with both low and high potential for public exposure following the application of Class B biosolids, as set forth above. The manner in which access is restricted will vary based on the size of the site and location relative to neighbors. Large rangeland parcels may require no signage. Small farm sites with nearby neighbors may require posting to restrict public access.

#### *Applier Responsibilities*

The Part 503 Rule defines the applier as the individual or party who land applies biosolids. This may include farmers, municipalities, and private enterprises that land apply or their contractors. The applier of Class B biosolids is responsible for making

certain that land application activities are in full compliance with the site restrictions. In fact, the Part 503 Rule requires the applier to describe how each site meets the site restrictions, and certify that they are being met. This requirement is part of the Part 503 reporting requirements.

It is very important that appliers of biosolids discuss the site requirements with the farmers. If a participating farm has animals, the farmer will be required to meet the 30day grazing restriction. Appliers should verify that all farmers in the program understand and are willing to adhere to required site restrictions.

### **8.7 Monitoring**

Monitoring, record keeping, and reporting are essential components of a successful biosolids management program. Biosolids preparers and appliers are responsible for compliance with state and federal regulations. Demonstrating that the biosolids meet the processing and quality standards and that the land application program is being managed properly can be shown through adequate monitoring, record keeping and reporting efforts.

A sound approach to sampling and monitoring is essential when demonstrating to regulatory agencies and the public a good compliance record. Preparers must show compliance with biosolids quality standards. Appliers must show compliance with certain management practices at the land application site.

#### **8.7.1 Monitoring Frequency**

The minimum frequency of monitoring biosolids quality can be found in Part 503.16(a). Monitoring frequencies range from once per month to once per year, based on the amount of biosolids used or disposed.

#### *Additional Monitoring Condition - Non-Compliance*

Some states have additional monitoring requirements for biosolids preparers. In certain situations, additional monitoring may be warranted. Examples are:

- Biosolids quality that changes and is not consistent over time
- One or more biosolids pollutants that are close to the Part 503 Rule Ceiling Limit
- Variable quality of the treatment plant influent
- Significant wastewater contribution from industries

Any biosolids that do not meet quality standards are not in compliance with the regulations and may not be applied to a site. Non-compliance could result in enforcement action. Most states have site specific monitoring requirements for soil fertility and chemistry. Because these monitoring requirements vary by state, it is important to institute monitoring programs that conform to federal, state and local regulatory requirements. Be sure to check these agencies for specific information regarding monitoring requirements and frequency of monitoring.

#### **8.7.2 Measuring Biosolids Characteristics**

Preparers must be able to show that biosolids meet the quality requirements of the federal

and state regulations. Sampling biosolids for nutrient content is also necessary so that the applicator and farmer know how to apply the biosolids to best meet their needs. Minimum biosolids monitoring should include the following parameters.

- Pollutants
- Microbiological testing
- Vector Attraction Reduction
- Nutrients
- Solids content
- pH

Monitoring biosolids for other parameters, such as PCBs, may be required by the state. Contact the state regulatory agency for specific information on monitoring for other parameters.

### 8.7.3 Sample Collection

The aim of collecting biosolids and soil samples is to obtain a representative sample and to preserve the sample in a way that insures its quality and integrity. Selecting a qualified analytical laboratory is just as important as collecting a representative sample. The laboratory selected should be experienced in conducting routine analyses of biosolids products and soils. Reference (6), Chapter 9 - Sampling Procedures and Analytical Methods, provides suggestions relative to selecting a laboratory.

#### *Biosolids Sampling Plan*

The validity of analytical results reflects the care given to the various components of sampling and monitoring. A sampling plan is a useful tool in assuring the quality and consistency of the results. At a minimum, a sampling plan should provide the following information.

- Where to collect representative samples
- Appropriate sample types (grab or composite) and sample volumes
- Appropriate containers and equipment to use
- Sample preservation during transit to the laboratory
- Chain of custody procedures
- Validation of laboratory analyses with QA/QC
- Analytical methods
- Procedure to review the data promptly
- Procedures followed when results are outside regulatory requirements

*To assure a quality and consistent biosolids product, a written sampling plan should be prepared and followed.*

A sampling plan should be a written document that all employees can access when conducting monitoring. Creating standard forms and procedures can enhance the usefulness of the plan. The sampling plan should be unique to a facility, and be prepared in accordance with the size, treatment processes, and type of biosolids produced at the facility.

Representative sampling is a critical component of sampling and monitoring. Instances of

questionable data in sampling and monitoring programs are often the result of sampling errors. Establishing biosolids product quality is the end result of a good sampling and monitoring program.

### *Sample Types*

There are two types of samples: grab and composite. A grab sample represents biosolids quality at a specific time and location within a monitoring event. A sampling event is the timeframe in which a series of samples are collected to meet the Part 503 Rule monitoring requirements. A composite sample consists of individual sub-samples that are mixed together to form one sample. Analytical results from a composite sample represent the quality of biosolids over time.

Grab samples are preferred for microbiological testing and measuring parameters relating to vector attraction reduction. For these types of samples, strict constraints are placed on the time between sample collection and its arrival at the laboratory. Composite samples are appropriate for the analysis of pollutant concentrations. Design a program for taking subsamples for pollutants that represents a particular period of production. For smaller facilities, samples could be collected over a one-day period. For larger facilities with monthly sampling requirements, collect and store sub-samples over the period of a month before combining into one sample for analysis.

### *Sample Location, Handling, and Documentation*

The sampling location selected should reflect the following objectives:

- Most samples should be collected from processed biosolids that are ready for use,
- The sample should represent the entire unit of material, and
- The sample should be taken when the material is in motion.

Each time samples are collected for any one parameter, they should be taken from the same location, based on the above objectives. For example, a sample collected from a stockpile for pollutant analysis should be a composite of subsamples. The stockpile should be divided into a grid with cores (subsamples) taken at varying depths in each grid. With each monitoring event, the samples should be collected in the same manner.

Once samples are collected, they must be prepared for transit to the laboratory. Be sure to check ahead of time with the laboratory that will be conducting the analysis to find out what size sample is needed, and the type of container required for various analyses. Regardless of whether the sample is going to the facility laboratory or an outside laboratory, sample handling is the same. Handling requirements include proper:

- Preservation
- Packaging
- Sealing and labeling
- Shipping
- Holding times

A chain-of-custody form must accompany every sample to establish possession from the time the sample is collected until it arrives at the laboratory. The information needed for a

chain-of-custody record is summarized in Chapter 9 of Reference (USEPA 1999). It is recommended to “record sufficient information so that the sampling situation can be reconstructed without reliance on the collector’s memory”.

Additional information about sample collection, preservation and analytical procedures may be found in Standard Methods Publication of the American Public Health Association. (APHA/WEF 1998)

### *Soil Sampling and Analysis*

Soil sampling and monitoring for fertility is part of normal farming practices. Soil pH and fertility information is important for farmers to know, to obtain optimum growth of their crops. These are good reasons to sample soils periodically and provide the results to the farmer. The Part 503 Rule does not require soil sampling prior to or during land application. However, many states do require collecting and analyzing soil samples (particularly to establish agronomic application rates) prior to the first application to a site, and/or at some time after biosolids applications. Because soil sampling and monitoring may be required, knowing how to collect and prepare soil samples for analysis is important, and this information is generally available from the state Land Grant University.

*Representative sampling, proper sampling handling and preservation, and documentation of the sampling event are essential in demonstrating the quality of the biosolids.*

Good soil sampling techniques provide reasonable soil test information. Follow the general guidelines below when collecting soil samples:

- Collect a minimum of one composite sample per 20 acres
- Stay away from old fence lines, terraces, dead furrows, and roadways
- Break up clods in soil for proper mixing
- Do not sample near manure piles, animal dropping, or biosolids
- Avoid heavily eroded areas or depressions
- Try to collect the sample before the application of manure or biosolids
- Obtain a core sample the depth of the plow layer and avoid getting the soil surface only
- Use sampling equipment that will not contaminate the soil sample

Most state Land Grant Universities perform soils analyses for a fee. Follow the instructions provided by the testing laboratory to make sure you are preparing the soil samples correctly for shipment. Soils can be analyzed for fertility (phosphorus, potassium, calcium, magnesium, and other micronutrients), and chemistry (regulated metals, pH, PCBs). Check state requirements for specific soil sampling and analysis requirements.

More complete information on agricultural soil analysis, including metals, micronutrients and quality assurance plans can be found in the Soil Analysis Handbook of Reference Methods (Soil and Plant Analysis Council 1999).

### 8.8 Record Keeping and Reporting

Keeping records establishes compliance with biosolids regulations. Data on biosolids quality is necessary to show that the biosolids meet pollutant limits and pathogen and vector attraction reduction requirements. In addition, keeping records on land application activities shows that the land application sites are being managed in accordance with the regulations. A simple computerized system may help with record keeping and reporting, and is recommended even for relatively small land application programs.

#### *Part 503 Rule Record Keeping Requirements*

Federal record keeping requirements can be found in EPA Part 503.27 and are based on the biosolids pollutant, pathogen, and vector attraction reduction levels achieved. Certification statements are specified in the Part 503 Rule, as are retention requirements for records. Land application records must also be kept in accordance with the Part 503 Rule requirements. Most states have additional record keeping requirements such as tracking cumulative pollutant loading rates, and/or keeping daily biosolids application information. Site maps and collecting periodic soils information may also be required by some states.

#### *Part 503 Rule Reporting Requirements*

Reporting requirements for land application of biosolids can be found in 503.18. Facilities that have a design flow rate greater than 1 million gallons per day or that serve at least 10,000 people, must submit an annual report (Discharge Monitoring Report - DMR) to EPA. The preparer is responsible for completing and submitting the EPA annual report. Many states also require separate reports to be prepared and submitted annually.

## References

California Water Environmental Association, (1998), *“Manual of Good Practice”*, Oakland, Ca.

Pennsylvania Water Environment Association, Pennsylvania Department of Environmental Protection, (Pending), *Biosolids Recycling in Pennsylvania*, Harrisburg, PA.

Soil and Plant Analysis Council, (1999), *Soil Analysis Handbook of Reference Methods*, CRC Press, Boca Raton, FL..

United States Environmental Protection Agency, (September, 1994), *“A Plain English Guide to the USEPA Part 503 Biosolids Rule”*, (USEPA/832/R-93/003)

United States Environmental Protection Agency, (1994), *“Land Application of Sewage Sludge: A Guide for Land Applicators on the Requirements of the Federal Standards for the Use or Disposal of Sewage Sludge”*, 40 CFR Part 503. (USEPA/831-B-93-002b)

United States Environmental Protection Agency, (1999), *“Control of Pathogens and Vector Attraction in Sewage Sludge”*, (USEPA/625/R-92/013)

United States Environmental Protection Agency, (February, 1993), *“Standards for the Use or Disposal of Sewage Sludge”*, Fed. Regist., 58,32,40 CFR Part 503 Rule.

Water Environment Federation, (1998), *“American Public Health Association. Standard Methods for the Examination of Water and Wastewater”*, 20<sup>th</sup> Ed. Washington DC (available through, Alexandria, VA)



## Chapter 9 – Non-Agricultural Uses

---

This chapter contains specific information relative to non-agricultural land application of biosolids. This does not, however, negate the need for biosolids managers to familiarize themselves with the information contained in Chapter 8, Agricultural Land Application. Many of the controls in Chapter 8 apply equally to non-agricultural settings, and should be included in operational plans for both types of programs. As was the case for agricultural programs, this chapter assumes that class B biosolids will be applied to the land to improve soil properties and enhance plant growth with varying objectives for the use of plants grown on different types of sites. This chapter will discuss the most common types of areas to which biosolids have been applied for soil enrichment. These are not all-inclusive and biosolids managers are urged to base their selection of non-agricultural application sites on a good understanding of the needs, characteristics and inherent limitations of any non-agricultural sites, just as they would for specific types of agricultural cropland.

### 9.1 Critical Control Points / Operational Controls

Biosolids used in non-agricultural settings (e. g., soil reclamation) are valuable for both the slow-release nitrogen they provide and their soil enhancement properties (specifically organic matter, which is often lacking on such sites). To achieve these benefits, application rates considerably higher than those designed for agricultural crop production are common when biosolids are used for reclamation. Generally, this rate is a one-time application in order to rejuvenate barren soil and provide a basis for a stable ecosystem. Application rates for agronomic purposes typically range from 5 to 20 dry metric tons per hectare applied repetitively (every 1-5 years) while initial reclamation rates typically range from 50 to 150 dry metric tons per hectare. Silvicultural application rates usually fall somewhere between agronomic and reclamation and biosolids are applied only once or very infrequently for those slow growing and long life-cycle crops. Because reclamation, silvicultural, and other non-agricultural uses for biosolids are different from agricultural uses in several ways, they may entail different regulatory requirements and management practices, as well as specific community participation efforts to be successful.

These considerations, or controls, that should be considered in developing non-agricultural land application include:

- Effect of organic material on soil properties
- Nutrient addition
- Soil pH
- Access and application

#### 9.1.1 Effects of Organic Matter from Biosolids on Soil Properties

Applying organic matter in the form of biosolids can benefit plant establishment, especially on sites whose physical, chemical and biological properties do not favor growth of vegetation. In general, organic matter (the non-living mixture of organic components from the microbial and chemical transformations of organic debris) has long been recognized as contributing greatly to soils' productive capacity (Sopper, W.E., 1993). When incorporated into the soil, organic matter can favorably affect its structure (porosity, aggregation and bulk density) as well as improve the content and transmission

of water, air and heat and soil strength. Nutrients such as nitrogen are mineralized during decomposition of organic matter; this results in an increase in carbon, nitrogen and cation exchange capacity following biosolids additions. Since the organic matter represents new energy sources for organisms, changes in biological populations will also occur, in turn influencing synthesis and decomposition of humic substances produced by those microbial populations, nutrient availability and interactions with soil inorganic constituents.

Unlike fresh animal or plant residues incorporated into the soil, most biosolids have been subjected to a biological treatment where partial decomposition has occurred. Thus, biosolids decomposition rates in soils may be slower than most fresh organic residues, resulting in longer-lasting effects on soil organic matter levels and changes in the composition of the organic fraction of soils. Adding biosolids to soil decreases resistance to root penetration and results in improved root:shoot ratios as compared to inorganic fertilizer additions. Increased plant growth from biosolids application has been well documented in numerous research studies. However, a more interesting effect of biosolids is not the direct short-term fertilizer effect, but the longer-term effect of soil organic matter (i.e., an increase in soil productivity that cannot be explained by the mineral nutrients alone). This improved productivity relates to such factors as increased soil moisture, higher organic matter levels, and very importantly, an accelerated decay cycle with more rapid microbial action as well as the slow release of N and P from biosolids.

Using biosolids for reclamation provides the most dramatic evidence of the benefits of using biosolids to enrich soils and enhance plant growth. The organic matter content, which is valuable in agriculture, is especially important in disturbed sites where topsoil is inadequate or on sites where topsoil does not exist. While organic matter is an important factor in the improvement of soil physical properties which are achieved using biosolids, the fertilizer elements and neutralizing compounds that improve soil fertility and pH are also of great value for reclamation purposes. The increasing number of successful reclamation projects using biosolids across the U.S. is a further demonstration of the value of biosolids as a recyclable resource rather than a waste product.

The use of biosolids for reclamation purposes has been most prevalent in the Midwest, Northeast and mid-Atlantic areas of the U.S. These projects resulted in excellent growth of forage and cover crops in a variety of research, demonstration and full-scale operations. Many sites are seeded with a mixture of grasses (to provide quick vegetative cover) and legumes (which eventually predominate as permanent vegetative cover). The application of biosolids has also helped in the establishment of tree seedlings on reclaimed areas, by improving growth rates, particularly for the hardwood species when they are seeded simultaneously with the grass-legume mixtures.

Extensive research has been carried out in the United States and elsewhere on the practice of reclaiming disturbed land with biosolids. This research, along with large-scale projects, has demonstrated that biosolids provide an excellent soil amendment and chemical fertilizer substitute for reclamation purposes.

## 9.2 Reclamation Sites

*Mineland reclamation:* Land that has been disturbed by surface or underground mining is generally unsightly, unproductive, and a potential source of significant water quality problems. Surface mining in the U. S. has disturbed more than 1.5 million hectares, much of which has been caused by coal mining. Some type of surface mining area is found in all fifty states, and 20 states each contain more than 25,000 hectares of disturbed land (Sopper, W.E., 1993). The potential for disturbed/mined sites to receive biosolids is enormous, both on sites which have been abandoned and are not subject to the reclamation law requirements (“orphaned lands”) and on active mine sites, on which reclamation is required as the mining operation proceeds.

### 9.2.1 Regulatory Considerations

*In addition to Part 503 Rule requirements, non agricultural land application of biosolids may be subject to other federal and state requirements that biosolids managers must include in their project design and management.*

Many state regulations and guidelines include provisions for application rates higher than those established for agronomic crops in order to establish growth on these infertile sites. Such application may not exceed cumulative loading limits under federal (and most state) regulations and still qualify as land application. If reclamation with biosolids is conducted on a site that is designated as a “Superfund” site, the regulations governing such sites may also be applicable.

When using biosolids to reclaim sites, it is important to consider federal and state mining regulations concerning revegetation. These include 30 CFR Parts 816 and 817 and the federal Surface Mining Control and Reclamation Act (Public Law 95-87, Section 515, (U.S. Department of Interior, 1979; Federal Register 1982) and its amendments (54 FR 230. Regulations established under this Act require the establishment of a diverse, effective and permanent vegetative cover of the same type of plants native to the affected area. The requirements of the Act are often difficult to meet using conventional reclamation techniques and the use of biosolids represents a very effective option for meeting the regulatory requirements.

Prior to mining operations, the reclamation methods and post-mining land use must be submitted to the appropriate agency, and must adhere to the following:

- Permanent vegetative cover must at least equal the area’s natural vegetation in extent of cover, and must achieve productivity levels comparable to unmined land for post-mining use. Native and/or introduced species may be planted.
- The period of extended responsibility (after revegetation success is insured) is not less than 5 years for areas with more than 26 inches of average annual rainfall; 10 years for areas with 25 inches or less.
- Normal husbandry practices to assure plant establishment are allowed during the period of responsibility if they can reasonably be expected to continue after bond release
- Success standards are required for 2 years for pasture, grazing and cropland (specified with respect to precipitation); for ground cover, productivity, or tree

stocking, these standards are based on a 90% statistical confidence of 90% success.

Potential post-mining land use must equal or exceed the pre-mining use. Typical land uses include:

- Wilderness
- Limited agricultural or recreation use with little or no development
- Developed agricultural or recreation
- Suburban dwellings or light commercial/industry
- Urban dwelling or heavy commercial/industry

Many of the above land uses are compatible with the use of biosolids. Since reclamation sites that are managed as land application projects are subject to the same federal regulatory requirements as are agricultural sites, applying biosolids at reclamation rates will not adversely affect their potential to support agricultural production or any other land use that is appropriate to the site. The research results from such sites have paralleled the results found for agricultural crop production and have demonstrated clearly that the usability of the site has been significantly improved by the application of biosolids. Most research results have shown that trace element concentrations in biosolids-reclaimed mined areas are within the range considered normal for such metals in unpolluted and unamended soils.

### **9.2.2 Environmental Considerations**

The immediate goal of reclamation is to establish a vegetative cover to prevent soil erosion; in the longer term, a stable soil ecosystem is the goal. Since such areas lack microbial activity and organic matter, the normal soil microbial processes and N-cycling are also a measure of the degree to which these reclaimed areas resemble undisturbed soil. Application of biosolids has uniformly resulted in increased microbial populations and activity—bacteria, fungi, and actinomycetes. The use of biosolids as reclamation material has been shown to eliminate the initial lag period of several years that is characteristic of conventionally reclaimed areas during which microbial activity and plant growth are minimal. For such conventionally reclaimed areas to eventually acquire “soil” characteristics, intensive reclamation and management techniques, along with annual fertilizer additions, are usually necessary. By contrast, superior results in the form of normal soil populations and processes in the surface soil on biosolids reclamation sites can be achieved within two years.

The beneficial effects of biosolids application on the whole ecosystem of reclamation sites have been demonstrated in a variety of settings (USEPA, 1995). Except for a brief temporary elevation of nitrate-nitrogen (NO<sub>3</sub>-N) in soil percolate water resulting from a higher-than-agronomic application rate, no negative effects on water quality have been demonstrated, and in many cases significant improvement in overall groundwater quality has been observed at reclamation sites where biosolids have been used. The temporary elevation of nitrates represents a minimum ecological impact that is clearly offset by the positive environmental benefits achieved by reclaiming these sites with biosolids. It is particularly important to not remove the vegetation established on reclamation sites in

order to enhance the development of healthy, sustained vegetative growth on these sites--the primary objective of reclamation, unlike the crop production goals that determine agricultural production methods.

A number of wildlife studies conducted on reclamation sites have found no adverse effects on the health of domestic or wild animals and birds living on such sites. Research and practice have clearly shown that biosolids, if applied properly under present regulations and guidelines, can be successfully used to revegetate mined or other disturbed lands in an environmentally safe manner. Revegetation of a variety of otherwise devastated sites has been demonstrated in many studies using various types and application rates of biosolids. All of the results validate the present regulatory framework which protects the environment, as well as animal and human health, when using biosolids to reclaim drastically disturbed land.

### 9.2.3 Design and Operational Considerations

The potential for biosolids use in reclamation is significant, and combining the use of such sites with agricultural land application can allow application during periods of the year when agricultural or other cropland is not available. The following design considerations will impact overall good management of nonagricultural use of biosolids:

*Active Mine Sites:* Site evaluation should include an assessment of existing vegetation, if any; cause of site disturbance (e.g., strip mining or coal); previous attempts at reclamation, if any; need for grading; existence of approved reclamation plan, if any, for site.

*Land Application Equipment:* In some cases, the same types of equipment used for land application (see chapter 8, Vol. 1 of this Manual) are also appropriate for reclamation and other uses, especially if such equipment is relatively heavy-duty. Typically, biosolids cake application is the better choice for reclamation projects due to the amount of material that has to be applied, and the often-rough terrain of non-agricultural sites, which could damage injectors on liquid applicators. For some applications, other types of industrial equipment may be available or currently in use (e. g., forestry equipment) and can be used/adapted for biosolids use. In general, biosolids managers should think creatively when selecting application equipment and methods in non-agricultural settings.

For active mine sites, the reclamation requirements are generally part of the mining permit and must become part of the overall project design and operation. Site evaluation should include an assessment of:

1. existing vegetation, if any
2. cause of site disturbance (e.g., strip mining or coal)
3. previous attempts at reclamation, if any
4. need for grading
5. existence of approved reclamation plan, if any, for site
6. type of parent material

*Application Equipment:* In some cases, the same types of equipment used for land

application (Chapter 8) are also appropriate for reclamation and other uses, especially if such equipment is relatively heavy-duty. Typically, biosolids cake application is the better choice for reclamation projects due to the amount of material that has to be applied, and the often-rough terrain of non-agricultural sites, which could damage injectors on liquid applicators. For some applications, other types of industrial equipment may be available or currently in use (e. g., forestry equipment) and can be used/adapted for biosolids use. *Biosolids managers should think creatively when selecting application equipment and methods in non-agricultural settings.*

### 9.2.4 Factors Affecting Success

*Nutrient Status:* Depending on the treatment process, much of the nitrogen in biosolids is in the organic form, and therefore becomes available (through mineralization) over a period of several years following application. This slow-release nitrogen offers a significant advantage over the immediately soluble forms usually supplied by inorganic (chemical) fertilizers.

*To establish appropriate reclamation and other non-agricultural rates, the amount and type of nutrients in the biosolids should be taken into account, along with the requirements of the vegetation to be established.*

If the site has topsoil, annual agronomic applications may be sufficient; sites with little or no topsoil will require a much larger application rate to establish vegetation, restore soil fertility and improve soil physical properties. The phosphorus and micronutrients present in biosolids will also improve plant growth.

*Soil pH.* Non-agricultural sites may exhibit very low pH levels, and require adjustment to the optimum plant growth range of 5.5 to 7.5. Lime or other recommended pH-adjusting materials may be used, and when biosolids are processed using an alkaline material, the biosolids themselves will increase pH levels.

*Vegetation.* Many species can be successfully established, but each site should be considered individually, and careful attention paid to plant species or seed mixtures selected.

*Application methods.* Site preparation (e. g., debris removal, erosion and runoff control, and scarification) is often necessary for non-agricultural sites and mulching may also be required following planting.

*Community relations.* Relationships with nearby local communities are often especially sensitive at reclamation sites. Resentment and opposition have often accompanied the activities that led to the site needing to be reclaimed (e. g., ongoing mining operations). Neighbors are frequently concerned about quality-of-life issues. ***Biosolids managers should be especially sensitive to local community members and strive to convey the positive aspects of this final stage of the mining or other process.*** The recommendations contained in chapter 1 (Public Acceptance) of this manual should be included in the development as well as the ongoing management of non-agricultural land application

projects.

Detailed descriptions of reclamation research, methods and operations are contained in the references for this chapter.

### 9.3 Silviculture (Forestry) Application

In general, the chemical, biological and physical interactions of biosolids and soil in forest applications are similar to those in agricultural operations. Trees have been shown to respond positively to nutrient additions, particularly when forest soils are low in nitrogen and the surface litter layers have comparatively high N storage (immobilization) capacity. Some advantages of forest application include the great flexibility in scheduling because forests are perennial (which may also translate to reduced storage requirement) and the extensive acreage of forest land in many regions which provide large areas for application.

#### 9.3.1 Application to Forested Sites

The amount of biosolids applied to particular forested areas will depend to a large degree on the growth state of the forest. When the stand is developing high nutrient content tissues (early development), nutrient demand will be significantly higher than occurs in near-mature or climax forests, which maintain biomass rather than synthesizing new growth.

*Biosolids managers applying biosolids on forestland must be prepared to address any special operational challenges.*

Forestland is frequently rugged, steeply sloped and relatively inaccessible. In addition, the tree stand itself may present obstacles to biosolids distribution methods. Such factors must be taken into account in developing and managing forestland application. Forestland application can be conducted on commercial timber and fiber production lands, federal and state forests as well as privately owned forest areas. Biosolids may also be used in nurseries, green belt management and Christmas tree production as appropriate in specific situations.

The three common scenarios for forest application include:

- Recently cleared land that has not yet been planted,
- young plantations, and
- established stands.

Each of these must be considered separately when designing a forest land application program.

#### 9.3.2 Physical Features to be Evaluated

*Proximity to public access* (e.g., recreational areas, dwellings, public roads and hiking trails). The application sites should be as removed from these public access areas as practical. Many states will also impose the minimum setbacks or buffer zones that have been developed for agricultural biosolids application.

*Proximity to surface waters.* The application site should be located and managed to avoid contamination of surface waters, including setbacks (which most states require). For steep slopes and/or relatively impervious soil, greater runoff is likely to occur and increased setback distances should be considered.

*Proximity to drinking water supplies:* Where forest application is to occur in water supply sensitive areas, provisions should be made for biosolids quality control, minimization of biosolids movement and possibly monitoring of surface and/or groundwater quality in the area.

*Distance to groundwater:* Guidelines suggest that forest application sites have an average groundwater table distance of one meter (0.7 meters minimum) below the soil surface. This recommendation is to prevent seasonal surface flooding and boggy conditions, which might cause biosolids migration.

Forest soils are often infertile by agricultural standards—deficient in organic nutrients and low in available nitrogen. Added organic N from biosolids may make up this deficit without adverse impacts on groundwater. Tree species differ significantly in their uptake of available nitrogen; there is also a large difference in N uptake by seedlings, rapidly growing young trees and mature trees as noted previously. The average annual N uptake of fully established and vigorously growing forest ecosystems varies from 100 to 400 kilograms per hectare per year depending upon species, age and other factors. These estimates include the overstory and understory vegetation or gross N uptake by the forest ecosystem.

For specific projects it is recommended that state or regional forestry management or research agencies be contacted in designing forest utilization projects.

While information on forest uses of biosolids is not as extensive as that relating to agricultural production or reclamation, there has been a growing interest in such application in the last decade, particularly in the Pacific Northwest. Research conducted at the University of Washington, College of Forest Resources, coupled with a number of operating projects, has provided information and relevant experience for implementing forest application projects. Technical data are available from these efforts in a variety of silvicultural settings.

### **9.3.3 Application to Cleared Sites**

Application of biosolids to recently cleared forest sites has the advantage of providing better access for application equipment and the possible option of incorporating the biosolids into the soil if the site is sufficiently cleared. It may also be easier to control public access to a cleared forest site (which is generally less attractive than wooded areas for forest recreational activities).

There may also be an option to select species that are superior in growth and survival characteristics on biosolids amended sites.

Some disadvantages of applying biosolids to recently cleared areas include the potential



for salt or ammonia damage to new seedlings for some species (this can be overcome by allowing the biosolids to age for six months or more). Seedlings also have a low nitrogen uptake rate and biosolids application may be inappropriate if there is an underlying potable aquifer that could potentially be impacted by excess N. Extensive weed control is also necessary to prevent competition with tree seedlings for up to three or four years and browsing by deer and other pest species may also require control measures since animals may selectively feed on biosolids amended sites due to their higher food value.

### 9.3.4 Application to Young Forests

Applying biosolids to young forest plantations (over two years old) provides a greater tolerance of fresh biosolids application, less concern for weed control than with cleared sites, more rapid nitrogen uptake, reasonably good access and rapid growth response from many tree species. However, biosolids application by spraying over the canopy may be restricted to certain times of the year, some weed control will probably be necessary and plant nitrogen uptake is less than that of a well-established forest cover. Further details regarding application of biosolids to forestland are contained in reference 3 of this chapter.

## 9.4 Other Non-Agricultural Uses of Biosolids

Biosolids are used on a range of nonagricultural sites, each exhibiting specific needs and characteristics. Biosolids managers should become familiar with site characteristics and needs of their individual situations, and design projects to accommodate them. While the majority of regulatory and technical experience in land reclamation relates to such efforts on land that has been surface mined for coal or sand and gravel, the principles involved in such uses, as well as many of the agricultural considerations discussed in chapter 8 may be modified to apply to other types of marginal or disturbed sites.

Nonagricultural sites being reclaimed with biosolids include:

*Sites affected by human activity:* Roadway and other construction, deposits of dredge materials and ash, as well as forestry-related activities often result in large areas that are frequently difficult to reclaim conventionally with inorganic fertilizers and other soil amendments. Application of biosolids on the above types of sites, as well as areas disturbed by mining or other activities that disturb soil (e.g., copper mines, oil shale mine areas, zinc and lead smelters, landfills), offers an opportunity for using biosolids to stabilize and revegetate eroded, unproductive soils. The environmental benefits achieved by providing a medium for the re-creation of a soil/vegetation system are significant, and often translate into economic benefits, as well.

*Biological Deserts:* Areas that are a biological desert due to high metal contamination (e.g., zinc, lead and copper) have been successfully reclaimed using biosolids when virtually no other reclamation effort could succeed on such a site.

## References

Sopper, W. E., (1993), *Municipal Sludge Use in Land Reclamation*, Lewis Publishers

United States Environmental Protection Agency, (September, 1995), *“Process Design Manual for Land Application of Sewage Sludge and Domestic Septage”*, (USEPA/625/R-95/001)

Vogel, Willis G., (September, 1987), *“A Manual for Training Reclamation Inspectors in the Fundamentals of Soils and Revegetation”*, U. S. Department of Agriculture Northeast Forest Experiment Station. Produced for the Office of Surface Mining and Enforcement by the Soil and

Water Conservation Society 7515 Northeast Ankeny Rd. Ankeny, IA 50021-9764. Management, Palm Beach, Fla.

## Chapter 10 – Non-Restricted Distribution

---

The non-restricted distribution of biosolids products is regulated under the land application provisions of the Part 503 Rule. The regulations establish criteria designed to protect public health and the environment when these products are made available in settings where no regulatory oversight or control over their use is imposed. This approach is predicated on the understanding that such products will be used in the same way as other similar non-biosolids products (e. g., fertilizers, soil amendments). The criteria for non-restricted distribution are contained in the Part 503 Rule and discussed in Federal and State Regulations, Chapter 3 of this manual. Biosolids products for non-restricted distribution must not exceed the pollutant concentration limits of 503.13 Table 3; meet one of the Class A pathogen reduction requirements; and one of the first eight vector attraction reduction requirements. The Part 503 Rule frequency of monitoring, record keeping and reporting requirements also must be met for non-restricted distribution.

States may have additional requirements for non-restricted distribution of biosolids products. Biosolids managers should check with state regulators to ensure they are complying and have any necessary distribution permits, which are usually less complex than those required for site-by-site land application permits.

The most common non-restricted distribution products result from one of three processes: composting, heat drying/pelletization; and alkaline stabilization. Simply meeting these process requirements, however, does not guarantee a product that will find acceptance in a particular market or for a particular use. This chapter discusses the operational controls that must be addressed for successful distribution of biosolids products. It also discusses market development strategies for different types of biosolids products, as well as ways of expanding market opportunities.

### 10.1 Critical Control Points / Operational Control Points

There are a number of controls associated with non-restricted distribution. They include:

- Regulatory requirements
- Product quality
- Wastewater/ solids treatment
- Meeting customer needs
- Maintaining product outlets

### 10.2 Regulatory Requirements

A biosolids facility's responsibility for ensuring that the product meets regulatory criteria ends as soon as the product is given away or sold. It can be land applied or mixed with other (non-biosolids) materials prior to land application, but the person or facility handling the material does not have to keep records or comply further with the Part 503 Rule land application general requirements and management practices. In other words, as long as the product has met all the applicable Part 503 Rule criteria before it went out the door, the producer has met all federal regulatory criteria.

Confusion has arisen, however, with regard to product that remains on site or is blended with other materials. In 1999, USEPA's Pathogen Equivalency Committee and its contractor revised the guidance document (USEPA 1999) that addresses the biosolids processors' responsibility for continued compliance with Part 503 Rule. It states that if the preparer still retains control over the product, perhaps storing the material on site or blending it with other materials, the product still falls under the Part 503 Rule requirements -- even if prior to storage or blending it met the Part 503 Rule criteria. The biosolids manager must keep records of the material and conduct microbial analyses as shortly before distribution as possible.

If the facility changes the characteristics of the material by mixing it with another product, possibly changing its status, this constitutes a "sludge preparation" according to USEPA. This means that the mixing process must be monitored for compliance and the new material (e.g., a compost-soil blend) must comply with the Part 503 Rule. In other words, the *blend* would have to meet pathogen reduction requirements, pollutant limits, vector attraction reduction and microbial limits prior to distribution.

For product to be sold in the agricultural market, it is important to check any agricultural regulations that might apply. For example, most states require a guaranteed nutrient analysis to register a product as a fertilizer or nutrient source.

It is important to note that a biosolids product can meet the regulatory requirements for non-restricted distribution and still not be acceptable to consumers that are unfamiliar with biosolids and how they should be used. It is important to continued product acceptance that the consumer be satisfied with the product itself and with the results it achieves.

Programs that distribute biosolids products to the public should inform consumers about appropriate methods of use, by labeling or some other means. Many of the management practices discussed in other chapters of this Manual will be helpful in developing instructions for use of non-restricted biosolids products.

### 10.3 Product Quality

Ensuring that a biosolids product meets the regulatory requirements is the basic component of non-restricted distribution. Biosolids managers must be familiar with the pollutant content of the biosolids, as well as that of any amendments used in a composting process. This linkage also extends to the pretreatment component of the wastewater treatment system, in order to insure continued production of a material that meets regulatory requirements with respect to regulated pollutants.

Equally important is that the product meets customers' needs in terms of quality. This includes factors such as product appearance, odor and stability level -- and requires built-in controls throughout the process to insure that a quality product is being delivered on a consistent, reliable basis. There is no room for surprises, and having the proper controls in place minimizes the opportunity for unacceptable material leaving the facility.

### 10.3.1 General Product Quality Issues

*Housekeeping.* Overall facility appearance is important, especially if customers are coming to the facility to pick up the product. Moreover, good housekeeping is important to maximizing ability to comply with permit requirements, especially those related to pathogen control. For example, especially for smaller operations that share equipment for the whole process, equipment that has been used to handle unprocessed biosolids should not be used directly to handle finished product. Basic housekeeping steps should be spelled out in an employee manual and/or standard operating procedures (SOP's).

*Storage.* Due to seasonal demand for biosolids products, storage must be included in the overall management plan for a facility operation.

*Record keeping:* Part 503 Rule has its own set of record keeping requirements, but producers of non-restricted distribution products may want to go beyond the basic requirements, both for internal tracking purposes and for responding to customer or regulator questions.

*Product appearance, consistency and odor:* Agricultural producers, greenhouse growers, residents, golf course superintendents and anyone else using a biosolids product will be concerned about how it looks and whether it has an odor that falls out of the acceptable range for that particular application. End users also will be looking for a consistency that they can rely on. This is not just a customer “comfort” issue but also a practical one. If the biosolids product is being spread as topdressing, a certain particle size must be achieved consistently. As one example, particle size of heat dried biosolids pellets for various uses is determined by the mesh size of the screen through which the pellets pass.

When initially marketing the end product, work with the end users on their specifications, and then establish control points at the biosolids facility to ensure that those specifications are being met. Avoid sending out product that does not meet those specifications because word of a bad experience travels *very* quickly. Staff should be trained to determine when a product fails to meet specifications.

#### *Product-Specific Quality Issues*

Each type of biosolids product will have its own specific quality requirements in addition to the general ones described above. The quality issues related to the three most common types of biosolids products are described below.

### 10.3.2 Compost Product Quality

Product Maturity: The issue of maturity is critical with compost products. A product does not have to be mature to meet the Part 503 Rule pathogen or VAR requirements, as maturity relates more to the acceptability of the compost for a particular use. For that reason, biosolids managers should test products for maturity prior to distribution so that the end user knows what they are getting and whether further curing is necessary before using the product. For example, distributed compost that is not mature can actually be biologically reactivated when wetted. Further decomposition of the compost after it has been applied or mixed in a potting medium can have a detrimental effect on plant growth.

Reactivation and resultant nuisance conditions (odor) also can be an issue with product storage at a customer's site.

Amendment Consistency: Many end users rely on the total product being consistent, not just the biosolids portion. Therefore consistency in the types of bulking agent used is very important both in terms of product appearance and overall characteristics of the end product. If the facility is making changes, build in enough time for the end user to adjust to those changes, if feasible, or begin to develop different markets that can accommodate the altered compost product.

Product Screening: One sometimes overlooked aspect of compost screening is the ground surface where screening is taking place. Composting facilities that do not have all working surfaces paved should have a hard surface, versus gravel or packed clay, in the screening area to avoid mixing in items such as stones into the compost. A hard surface also is critical for all-weather access to the screening area. Some facilities also put screening operations under cover to have better control over the moisture content of the end product being screened.

Product Storage: To ensure compliance with Part 503 Rule requirements, it is important to have a systematic approach to storing compost so that sampling procedures and pile monitoring is efficient and effective.

### **10.3.3 Heat Drying/Pelletization Product Quality**

Nutrient content: Since biosolids pellets are frequently marketed for their nutrient content, a reliable sampling program must be established to determine the nutrient content to provide to users. This is especially important if the pellets are marketed as a fertilizer, for which most states require documentation of a guaranteed nutrient analysis.

Odor: Because the heat drying process enables biosolids to meet pathogen and VAR requirements without biological digestion or chemical addition to reduce potential biological activity, heat-dried products have a greater potential for odor than do biosolids that are digested or chemically treated. This problem becomes more acute if condensation from cooling occurs or pellets are otherwise rewet. The best solution is to continue to digest or add digestion to the biosolids processing train before dewatering and heat drying.

Dust: Heat dried biosolids may become excessively dusty if subject to repeated handling during product storage and/or transport. Many potential users of pellets find excessive dust to be unacceptable, or at least characteristic of an inferior product. To some degree, dustiness is a reflection of the physical properties of the biosolids themselves. Reducing or modifying product handling can compensate for inherent lack of durability.

Moisture: As noted above in the discussion of odor, moisture levels in biosolids pellets that meet regulatory standards still may be high enough to create problems in terms of aesthetics and may even result in smoldering if the pellets become moist. Provisions for

adequate cooling before pellets are stored or transported should be implemented as part of the facility processes.

### 10.3.4 Alkaline Stabilization Product Quality

Liming potential: Regular sampling and analysis must be conducted to verify liming potential, usually in terms of calcium carbonate equivalency to conform to other common sources of lime materials used by growers, of alkaline stabilized biosolids. Addition of alkaline materials at the facility should be monitored to establish both the amount needed to meet regulatory requirements, and the product's liming equivalence so that users can base application on their specific soil requirements.

Odor: Alkaline treated biosolids that rely on the heat of reaction with biosolids to kill pathogens exhibit a high residual alkalinity to prevent odors. If alkaline additions are supplemented by a heat source to meet temperature requirements for pathogen kill, lower alkalinity levels may result in odors during storage or other circumstances if pH drops to levels that allow microbial decomposition to occur. This situation requires that enough alkaline material be used to maintain a pH that prevents microbial activity during storage, usually around 10 pH units.

Ease of handling/application: Alkaline treated biosolids typically exhibit higher moisture content than other biosolids products and are therefore denser to handle and apply. Some programs producing alkaline treated biosolids provide application as a service component of their marketing effort. In this way, users are not burdened with the need for new application equipment or having to use their own equipment to apply the material when needed. This option also helps to maintain the acceptability to the public for use of the product, since otherwise there could be piles of material in fields for some period of time before application.

## 10.4 Wastewater/solids Treatment

Chapter 5, Solids Thickening and Dewatering, discusses the impact of these processes on biosolids characteristics. Non-restricted distribution of biosolids products may be affected by these processes through the impact of chemical additions on the product's use, especially with growing certain types of crops, greenhouse plants, trees, etc. Facility managers should be aware of the impacts of various chemical additions and establish a means to be informed when changes are to be made. This is another example of the linkages between wastewater/solids treatment and the ultimate use of a facility's product. By open communication and cooperation, modifications can be made that accommodate both the needs of the facility's treatment processes and the biosolids product market.

Anyone producing biosolids for non-restricted distribution must:

- 1) Know what the chemical additions are and account for them in the product's usability; and
- 2) Establish communication links between the wastewater treatment plant operations, the biosolids facility, and the product users that makes everyone aware of any changes -- before any product is distributed.

More detailed information regarding the processing and properties of the most common non-restricted distribution may be found in reference (Girovich, M. J., Ed. 1996).

### 10.5 Meeting Customer Needs

One of the essential components of a non-restricted distribution program is communicating with end users about the product and its appropriate use to meet their needs and expectations. This applies to any marketer of fertilizers and soil amendments and for good reason: misuse of the product due to a lack of knowledge has a negative impact on a marketing program. In addition, this relationship with end users is a two way street -- they will know how to best use your product, and you will know what kind of product best meets their needs. That knowledge not only helps in product marketing, but also in knowing the necessary responses to product quality issues mentioned above, for example, understanding the impact of changing chemical additions.

Methods for meeting customer needs include:

- Having product utilization information and research data (from an independent third party) available
- Insuring accessibility of biosolids facility staff to customers, including scheduled contacts with primary customers
- Keeping an updated list of customers for referrals
- Having product available (and funding if necessary) to test new applications, especially those with environmental benefits (e.g. disturbed land reclamation).

### 10.6 Maintaining Product Outlets

High quality non-restricted distribution products should be viewed as ambassadors to the public—a vehicle for reaching out to various sectors of the public about biosolids and related issues such as industrial pretreatment programs. In this way, the biosolids product can serve the function of an educational and public relations tool.

Vehicles for establishing these connections include offering facility tours; educating politicians and other public officials; and working with community beautification and gardening groups, schools and organizations such as the Scouts, 4-H, colleges and universities, and trade associations, including lawn care and landscapers, groundskeepers and golf courses. It is also helpful to have booths at trade fairs, farm shows, community festivals, science fairs and more.

To effectively implement the approach described above, biosolids product managers should:

- Build key alliances. These should be established early on in the facility's development so that the public at large and specific constituencies understand and support the use of the high quality end product.
- Include funds in the facility budget for outreach and educational initiatives.
- Train an individual(s) whose role it is to build alliances and do outreach. This person develops positive relationships with the public, and becomes someone trusted and accessible if and when problems arise.



### 10.7 Market Development

Among the hats that wastewater treatment and biosolids facility managers wear -- especially those running non-restricted distribution programs -- is that of product marketer. Many of the larger programs have a staff position for an agronomist or someone with experience selling soil amendment products. Operators of smaller facilities have learned on the job, with many creating highly effective marketing programs.

#### 10.7.1 Demonstrating Product Potential

The “proof is in the pudding” adage applies directly to developing markets for non-restricted distribution products. Demonstrating a product’s potential can be accomplished on several fronts:

*Work with universities, cooperative extension and other third parties who can conduct research and who have the trust of potential buyers, including turf growers, landscapers, nurseries.* In addition, as biosolids products are increasingly used in environmental applications, other third parties include government agencies like the Bureau of Mines, highway departments, park departments and others. Work with these entities on pilot projects and have them do analyses of the product. If their research finds some shortcomings, this is a good opportunity to correct any problems and build your own confidence in your product.

*Provide samples for trial by potential users.* After data is available, or while it is being compiled, approach potential users -- including nurseries, golf courses, schools and universities (for athletic fields and landscaping) -- about trying the biosolids product. Help them determine the parameters that should be analyzed in determining the product’s performance. While the biosolids facility can provide the product at no charge, it is important that the user at least pay for the cost of trucking so that they have invested something in the trial. Otherwise, the biosolids product may not make it further than the spot where it was unloaded.

*Research product use results.* Your facility may be able to take advantage of research done on similar products. Conduct a literature review of publications and conference proceedings. Focus on the publications from the industries being targeted as potential customers.

In addition, there is information available from other biosolids facilities with non-restricted distribution programs. Collect product analyses and examples of applications, and, if available, names of users potential customers could contact.

*Gather testimonials and make satisfied users and researchers accessible.* Ask customers for testimonials about your product. If they are willing, also ask them if their names and contact information can be made available to prospective end users. In addition, make the research findings available, and consider holding a seminar for potential end users with the researcher(s) and current customers.

Because this process can take a fair amount of time, and it is difficult to begin before the biosolids processing facility has started full-scale operations, it is critical that there is either adequate storage or that other markets and uses be tapped initially. For example, a composting facility may want use the compost for public works applications while it is developing paying markets. In addition, if a facility has the ability to run a pilot scale project while the full-scale facility is in development, that can provide a jump start to the product testing and analytical process.

Synergies may also exist between other beneficial use components of the wastewater treatment facility. Take, for example, a facility with a land application program that is installing a pellitizer. The heat dried product from the start-up operation could be applied—with concurrence of the state regulatory/permitting agency—to the sties permitted for land application, as long as the same biosolids source is being used.

### **10.7.2 Expanding and Maintaining Markets**

Every biosolids product marketing program should continuously seek new and expanded markets to insure long-term viability. Examples of such techniques include:

*Product literature, samples, demonstrations:* Marketing a non-restricted distribution product, especially if the market is geared to retail customers, is really no different than marketing any other kind of product. Some biosolids facilities, both publicly and privately owned, have fairly sophisticated marketing tools, including four-color brochures, videos and promotional items such as hats and t-shirts. Others take a simpler approach, such as planting a flower garden in a public area with a lot of traffic (e.g. the town's post office) and letting people know the soil was amended or top dressed with compost or pellets. Whether sophisticated or simple, the consistent message is: this product has value.

Other marketing tools include distribution of samples and show-and-tell days, e.g., invite managers of sports facilities to a demonstration that involves application of a biosolids product to athletic fields, then show turf health, water penetration and so forth compared to conventional treatment.

*Be ready with A's for the Q's.* Getting anyone to switch brands is a challenge, especially if prize roses, cash crops or pampered golf greens are involved. Create opportunities for open dialogue; train a staff person to be out there listening, learning, and responding. Have balanced answers -- with data -- for questions that involve concerns about biosolids; responding with "it's not a problem" or some other dismissal type answer is not adequate.

*Use all the educational tools in the book.* Speak your potential customer's language and if you can't, hire someone who can. Use the established educational system to get the word out. Develop programs for schools, encourage science and biology teachers to engage students in research using a biosolids product, and work with local agricultural high schools, colleges and professionals in your community that service your potential customers.

### 10.7.3 Exploring Market Options

Markets for non-restricted distribution products vary with the processing method. Table 10.1 contains information about the three most common biosolids products with respect to their marketing potential.

**Table 10.1 Factors affecting distribution of typical biosolids products**

Product	Compost	Pellets	Alkaline treated
Characteristics	Relatively dry & easy to handle; aesthetically acceptable; high organic matter, relatively low nutrient content	Very dry, compressed; can be applied w/ fertilizer application equipment; nutrient content nearly as high as digested biosolids	Somewhat moist, heavy to handle; good liming source; low nutrient content
Typical uses	Landscapers; nurseries; parks and other public areas; homeowners	Agriculture; parks and other public areas; homeowners	Agriculture; reclamation sites; soil blending
Distribution	Bulk (generally local) or bagged (wider distribution range)	Bulk ( as is or blended w/ other fertilizers); bagged ; wide distribution feasible	Bulk; relatively local distribution
Revenue potential*	Medium	High	Low

\*Revenue potential relative to other biosolids products--ranges may overlap depending on specifics

Requirements for product labeling vary by state and should be investigated prior to establishing a distribution system.

Some emerging applications for non-restricted distribution products include erosion control, especially on highway projects and disturbed lands; manufactured soils specified by landscape architects; remediation of contaminated soils. Biosolids products used in highway projects or for major landscaping jobs typically have to comply with specifications set by the bidders.

Biosolids facilities have been marketing biosolids products for many years. There are volumes of information on establishing and running marketing programs, therefore any newcomers to non-restricted distribution products are not starting from zero in terms of resources. Nonetheless, biosolids marketing programs must be tailored to specific situations and customers to achieve long term success.

## References

Girovich, M. J., (Ed.), (1996), *Biosolids Treatment and Management: Processes for Beneficial Use*, Marcel Dekker, Inc. New York, NY.

United States Environmental Protection Agency, (1999), "*Control of Pathogens and Vector Attraction in Sewage Sludge*," (USEPA/625/R-92/013)

## Suggested Reading

Lue-Hing, C., D. R. Zenz and R. Kuchenrither. 1992. *Municipal Sewage Sludge Management: Processing, Utilization and Disposal*, Water Qual. Mgmt. Libr (Vol. 4). Technomic Publ. Co, Inc. Lancaster, PA

## Chapter 11 – Odor Control and Aesthetics in Land Application Programs

---

Odors and aesthetics are the most common causes for opposition to land application programs. Once people are sensitized to either of these issues, real or perceived, it is difficult to regain their support for a program. Odor control, containment, collection and treatment, at a wastewater treatment facility or biosolids management facility are discussed in Odor Control, Chapter 6 of this Manual. This chapter discusses odor control as part of a land application program, which differs from dealing with facility odor issues in a number of ways. It is important to recognize those differences and address odor control at both the facilities generating or treating biosolids and at land application sites.

This chapter also discusses the impact aesthetics can have on a program. People will “smell with their eyes”. Plastic material in the product or dirty vehicles with rags hanging from them are certain to generate concern.

### *Critical Control Points / Operational Controls*

There are a number of controls that should be addressed to minimize potential for unwanted materials and odors associated with land application of biosolids. These locations and their accompanying operational controls are discussed in this chapter. Additional operational control details are provided in other chapters of this Manual. Operational controls may consist of treatment and/ or field management measures. Critical controls include:

- Liquid Stream Treatment
- Biosolids Treatment
- Transportation
- Storage
- Buffers
- Operating Practices
- Community Relations

### **11.1 Liquid Stream Treatment**

In simple terms, wastewater treatment is designed to remove suspended and dissolved solids. Suspended solids are removed using clarification. In the majority of wastewater treatment facilities, microorganisms are used to consume dissolved solids and are removed using clarification.

These systems, commonly referred to as primary and secondary treatment, will also collect and remove foreign objects such as plastic and rags. These materials will remain through the stabilization process and become part of the biosolids product.

To eliminate these materials from the final product, they must be removed prior to primary treatment. This removal takes place in the preliminary treatment processes contained in the headworks.

### 11.1.1 Influent Screening

Influent screening has been used to remove objects that can damage downstream equipment. While protecting equipment they can allow a great deal of debris to pass. Advances in technology have resulted in screens with significantly smaller openings. These “fine screens” are much more efficient and will remove the majority of the plastics and rags that enter the collection system. The removal of these materials can significantly improve the appearance of your biosolids product.

### 11.1.2 Grinding

To reduce or eliminate the need for screening disposal, a number of facilities pass their influent wastewater through a grinder or comminutor. This equipment reduces the size of the material, but does not remove it. The material that passes through the grinder will be collected along with the biosolids or removed with the scum. While grinders may not improve the aesthetics of the biosolids product as much as fine screening, it will provide protection for equipment located downstream. A number of facilities have incorporated grinders within their solids handling train to protect equipment

### 11.1.3 Grit Removal

Grit removal also improves aesthetics while enhancing biosolids product quality. Grit can result in equipment wear and the addition of fixed solids to the process. Grit removal is a significant issue in combined systems.

## 11.2 Biosolids Treatment

The vector attraction reduction (VAR) requirements of the Part 503 Rule were developed to reduce odors and other factors that attract disease vectors to biosolids, and thus are primarily related to public health implications of biosolids management as well as to the odor issue. The term "stability" which is often used to describe biosolids treatment methods is closely tied to vector attraction reduction and therefore to biosolids' odor potential. Stability is not regulated as such by the Part 503 Rule; meeting VAR requirements does not, therefore, guarantee that stability is achieved, although stable biosolids will generally meet VAR requirements. More detailed information on biosolids stability is contained in Ref. (Water Environment Research Foundation 1997). Since treatment processes generally are conducted at the wastewater treatment plant, the plant becomes the fundamental control point location for addressing potential land application odors. Treatment options may be classified as biological or chemical, and biosolids managers are urged to consult Ref. (USEPA 1999) of this Chapter for more detailed discussion of regulatory requirements and process controls.

### 11.2.1 Biological Treatment

Biological processes are those which use microbes to decompose volatile solids, thereby reducing the food available to active microorganisms in the biosolids and reducing the odor potential of the material. These processes may be aerobic (with oxygen) or anaerobic (without oxygen), and each type depends on sustaining the life cycles of the organisms that thrive under each of these two different conditions, as described in Solids Stabilization, Chapter 4 of this Manual. The effectiveness of these processes is expressed in terms of volatile solids reduction as measured before and after treatment. The "after

treatment" measurement can be immediately after leaving the processing unit or at the point of use or disposal if this occurs without any significant downstream dilution with inert (non-volatile) solids. Volatile solids reduction that occurs in such facility processes as drying beds or lagoons is included in this measurement (USEPA 1999). Biosolids that meet the federal regulatory requirement of 38% reduction in volatile solids may not achieve the desired level of "stability" to reduce odors to a level that is acceptable to the public. Additional treatment may be required to decrease odor potential (and vector attraction) of the biosolids to the point where remaining biodegradable material does not attract vectors or produce odors that people may find objectionable.

### **11.2.2 Chemical Treatment**

In contrast to the digestion processes described above, chemical treatment relies on chemical additions to retard or stop the biological processes that produce offensive odors. The most widely used chemical processes for treating biosolids are those employing alkaline materials such as lime to raise the pH of the mixture to 12 to prevent biological activity. It is important to understand that such processes are not permanent, and that if the pH drops to 10 or below over time (e. g., during biosolids storage), surviving bacteria can become active and odors may result. Adding more liming agent than is needed to achieve regulatory requirements can address this issue, just as additional digestion does for the biological treatment processes.

### **11.3 Transportation**

The transportation of biosolids should be managed to minimize odor potential and other nuisance conditions (e. g., excessive traffic, and unsightly vehicles) that can cause negative reaction to land application in the local community. Attention to these conditions cannot overcome the impact of inherently odorous biosolids, but careful attention to treatment of the material, coupled with insistence on clean vehicles throughout transport and community-sensitive transport methods will go a long way toward preventing complaints (odor and otherwise) in a biosolids land application program.

Be sure that trucks will have adequate maneuverability at application and storage sites. Trucks should not queue up on public roads and create a nuisance for other traffic and neighbors. Being considerate in all aspects of the biosolids operation helps establish community acceptance.

### **11.4 Storage**

The seasonal use of biosolids in agriculture (discussed in Agricultural Land Application, Chapter 8 of this Manual) creates the need for storage in virtually all land application programs. Well-operated stabilization processes at the treatment plant usually will result in biosolids that can be stored off-site and not create odor or other nuisance conditions. Odors can result from inadequately stabilized biosolids, whether this occurs at the time of processing or later on, as may occur with the alkaline treatment processes (see Chemical Treatment, above).

During storage, intensified management is needed, especially when stored material is being spread. Managers should monitor storage sites to determine whether unacceptable odors are occurring, and be prepared to implement mitigation measures whenever possible.

The combination of stabilization and storage should be considered prior to implementing a biosolids management program. For example, storing lime-treated biosolids can result in significant odors if the pH drops during storage, allowing microbial growth when the material is removed from storage and used. The biosolids/alkaline mixture should be carefully established to provide conditions that minimize the potential for microbial growth and associated odor.

Since alkaline materials are effective microbial inhibitors, they may also be useful as a topical treatment to suppress odors for both stored and land-applied (especially surface-applied) biosolids. It is also advisable to minimize the length of time biosolids are kept in storage (especially in hot weather) in order to prevent odor-causing conditions from developing.

In most cases, storage (especially small scale field stockpiling) does not call for sampling and analysis of odor compounds. For larger constructed facilities that operate longer-term, a specific plan for odor prevention and minimization may be needed. Odor control plans must be sensitive to community concerns, and should include methods of prompt response to complaints, along with procedures for investigation and follow-up. Plans may also include some type of monitoring for odors and methods to determine the effectiveness of mitigation measures.

The Guide to Field Storage of Biosolids contains comprehensive discussions of both constructed facility storage and field stockpiling in land application programs, along with checklists and other management tools for addressing issues that relate to storing biosolids. Biosolids managers are urged to consult this publication when developing their programs.

### **11.5 Buffers**

Physical barriers between vectors and volatile solids in the biosolids may be useful in reducing nuisance and odor potential. These barriers may be natural (e. g., distance, trees) or man-made (e. g., covering stored biosolids). Biosolids should only be stored in areas with adequate buffers (this may mean buffers that are significantly greater than those specified in regulations). All such measures should be designed to fit local situations and programs, and are discussed in the references to this Chapter.

Biosolids programs that surface-apply biosolids without incorporation will have some degree of odor associated with the program. This odor can be minimized through adequate stabilization. Proper siting and maintaining adequate buffers to neighbors can also minimize the impact of any odors. Surface application, without incorporation, of lime-treated Class B biosolids has a significant potential for malodor. If this practice cannot be avoided (for example, on permanent pastures), it is recommended that remote sites be selected whenever possible and that spreading operations be conducted with careful attention to good housekeeping practices.



### 11.6 Operating Practices

The impact of exceptional housekeeping associated with a land application program is vital to success. The public's perception regarding the overall biosolids program management is often determined by the appearance of the vehicles and equipment used in a program. This concept also applies to odors - they may be perceived as more offensive if housekeeping measures are neglected. One of the most important housekeeping aspects of land application is preventing the plastics that often accumulate in anaerobic digesters from showing up at a land application field. Farmers and neighbors alike are understandably upset if this occurs and biosolids managers should be alert to that possibility and include such measures as screening (at the treatment plant or in the field), and even diverting biosolids to a sanitary landfill if necessary, in their management program options.

Use common sense and do not schedule spreading operations when neighbors are most likely to be outdoors, such as before and after work hours and on weekends. If possible, avoid surface application of potentially odorous biosolids during meteorological conditions (hot, humid, little air movement) that can result in odor problems.

As also discussed in Agricultural Land Application, Chapter 8 of this Manual, field operations at the farm can employ several strategies to reduce the risk of odors. Methods will differ depending on the physical properties of biosolids and the agricultural practices being implemented at each site. Injection or same-day incorporation into the soil provides both a physical barrier and an active soil microbial population to greatly reduce odor potential when biosolids are land applied. For surface application, it is prudent to apply biosolids in a thin layer in order to prevent odors and vector attraction.

When biosolids are stockpiled in the field, select stockpile areas with the objective of minimizing both visibility to neighbors and potential for odors (e. g., avoid low areas where ponding of water may result in odors). Be sure designated stockpile areas are clearly marked or otherwise conveyed to truck drivers.

When applied at agronomic rates, the amount of biosolids added typically is about 1/100th or less of the mass of soil in the plow layer (approximately the top six inches of soil). With good mixing, the dilution of biosolids the surface soil is similar to that resulting from soil injection. Odor may be present and vectors attracted temporarily, as the biosolids dry on the soil surface, but diminish and are virtually eliminated when the biosolids are mixed with the soil. This mixing option applies to liquid biosolids, dewatered cake, and to dried biosolids that have not already achieved one of the vector attraction reduction requirements of the Part 503 Rule. If the biosolids are incorporated (a step that is particularly recommended when the biosolids are not well stabilized), plan to pace spreading operations to match the rate at which the biosolids can be incorporated. If biosolids must be held overnight or over a weekend, be prepared to cover them with an impermeable tarp or with a layer of pulverized lime to form an odor barrier crust.

### 11.7 Community Relations

The importance of community relations cannot be overstated, and is discussed throughout this Manual (see especially Chapter 1, Public Acceptance). As stated elsewhere, odor problems are the most likely to adversely affect biosolids programs, and this is certainly the greatest area of concern for land application programs.

Biosolids managers should be familiar with community sensitivities with respect to timing of operations, location of offloading areas, housekeeping and other management practices. If the biosolids land application program is located in a remote area with a great deal of buffer to neighbors, an occasional odor associated with the program may well go unnoticed. The location of land application sites and the proximity of neighbors will often dictate the choice of specific management practices and biosolids treatment options.

Odors during delivery and land application of biosolids are a major source of complaints in biosolids programs. Several strategies can be used to reduce the potential for creating an odor nuisance. Generally, when the quality of the product is good, odors are less likely to occur. To address odors effectively, start at the treatment facility to determine steps that may help, such as:

- Reducing the holding time of biosolids at the plant prior to land application, because biosolids can become septic when stored
- Optimizing processes for volatile solids reduction or high pH, depending on stabilization methods
- Increasing detention times for stabilization processes.
- Evaluating chemical additions (e. g., iron salts, polymers) or operational changes that may affect odor in the biosolids and modifying these as appropriate

It may be useful to develop descriptors (terms to characterize specific odors) to address odor issues with neighboring communities. Both field operators and citizens will then be better able to determine whether biosolids are, in fact, the source of an odor event, and initiate corrective measures as appropriate (USEPA 2000).

In addition to any processing or operational factors that will minimize odor concerns in a community, biosolids managers should acquire the communication skills needed to interact with community neighbors. Listening skills and acknowledgement of valid concerns and complaints must be coupled with a genuine commitment to address such concerns. This approach will help significantly to reassure communities located near land application projects that biosolids are an agricultural resource, not a threat or a nuisance. By raising the level of public trust, biosolids managers may find that community odor issues are less likely to be based on fear and hostility and thus more readily resolved.

## References

United States Environmental Protection Agency, (1999), “*Control of Pathogens and Vector Attraction in Sewage Sludge*”, (USEPA/625/R-92/013)

United States Environmental Protection Agency, Office of Wastewater Management, (July, 2000), “*Guide to Field Storage of Biosolids*”, (4204) (USEPA/832-B-00-007)

Water Environment Research Foundation, (1997), “Defining Biosolids Stability: A Basis for Public and Regulatory Acceptance”

## Chapter 12 – Storage

Storage is an extremely important element in almost every biosolids management unit process. Storage provides flexibility within and between processes. As an example, storage downstream of a gravity belt thickener allows the operators of an aerobic digester to feed the system on a schedule to optimize digestion not to meet the requirements of thickening. Storage downstream of stabilization prior to transport or dewatering has similar advantages.

Storage is also important following management at the treatment facility prior to use or disposal.

*This chapter has been developed to highlight the operational controls associated with long term, greater than three days, storage of biosolids and biosolids products.*

This chapter has been developed to highlight the operational controls associated with long term, greater than three days, storage of biosolids and biosolids products. Storage recommendations associated with other unit processes are discussed as part of those critical control point categories or locations.

### 12.1 Critical Control Points / Operational Controls

There are a number of controls that should be considered in the design and management of storage facilities for biosolids and biosolids products. They include:

- Odor potential during and as a result of storage
- Volume of biosolids to store
- Solids content of biosolids to be stored
- Stability of biosolids

The USEPA Guide to Field Storage of Biosolids. (USEPA, Office of Wastewater Management (4204) EPA/832-B-00-007, July 2000), describes these operational controls as variables related to intensity of management.

### 12.2 Odor Potential During and as a Result of Storage

The Guide to Field Storage (USEPA 2000) states that the public's greatest concern associated with biosolids storage is odor. This statement can be expanded to state that odor is the issue that ignites public concern regarding biosolids management programs. With this in mind, it is easy to understand how odor associated with the storage of biosolids can jeopardize and entire biosolids management program. What seems straightforward during the planning process, a dry level area to store biosolids when product demand is low, can turn into the issue that results in the closure of an otherwise successful program.

*What seems straightforward during the planning process, a dry level area to store biosolids when product demand is low, can turn into the issue that results in the closure of an otherwise successful program.*

There are a number of factors which contribute to odor generation. Factors highlighted in the Field Storage Guide include:

- pH changes in lime stabilized biosolids
- Deficient oxygen concentrations within the biosolids
- Rewetting of dried product
- Length of storage period
- Inadequate drainage associated with the storage facility
- Storage of not fully stabilized biosolids
- Less than adequate housekeeping

Factors that influence the impact of odor include:

- Distance to receptors
- Meteorological conditions
- Volume of material stored
- Physical features of site, valleys, water courses.

Of these factors, three should be very carefully considered; degree of stability, volume stored and distance to receptors.

Very stable product will generate little if any offensive odor. The benefit of proper stabilization can not be overemphasized. The volume stored will impact the odor potential while straight forward, the volume to be stored at a given site should be carefully considered.

*Proximity to receptors is extremely important criteria relative to storage.*

Proximity to receptors is extremely important criteria relative to storage. If you can clearly see a home or commercial facility, you are more than likely too close for biosolids storage. Very remote locations for storage is not always practicable. If storage will be close to neighboring receptors, additional stabilization and precisely controlled management of the storage site are warranted.

### 12.3 Volume of Biosolids to Store

*“A small volume of biosolids stored in a large field creates less management issues than a large volume stored in a small area”*

The volume of biosolids that require storage will be dependent upon the biosolids characteristics and the program selected. Agricultural land application programs may require storage for relatively long periods based on crop patterns and climate. Other management options may have storage requirements based on market conditions.

The characteristics of the biosolids will also impact the volume to be stored. Liquid biosolids will require a much greater volume than dewatered biosolids. Dried biosolids will have yet a higher solids concentration and require a smaller volume per unit dry weight.

A wise person once said, “A small volume of biosolids stored in a large field creates less management issues than a large volume stored in a small area”. With this in mind, it is advantageous to locate enough remote sites to provide flexibility in storage.

## **12.4 Solids Content of Biosolids to be Stored**

As discussed, the solids content of the biosolids will impact the volume to be stored. The volume difference between liquid biosolids at 2 percent solids and 4 percent solids is not 2 percent, but 100 percent.

One dry ton of biosolids at 2 percent solids will weigh 100,000 pounds with a volume of 1,600 cubic feet or 12,000 gallons. Increasing the solids content to 4 percent reduces the weight to 50,000 pounds and the volume to approximately 800 cubic feet or 6,000 gallons. If the biosolids are dewatered to produce a cake with a solids concentration of 20 percent, the weight will be further reduced to 10,000 pounds and the volume to approximately 160 cubic feet, 6 cubic yards. This is a volume one-tenth of that entering the process.

If biosolids need to be stored for long periods and then transported over relatively short time periods, the costs associated with dewatering can be easily justified. However, before implementing dewatering based on transportation or storage, consider the impact on the rest of the system. Consider the impact dewatering will have at the WWTF. Will the sidestream associated with belt filter press dewatering impact the organic or hydraulic loading to the facility? If the agency historically injected biosolids, can surface application be immediately followed by incorporation?

As the total solids concentration within the biosolids continue to increase, the concerns change from volume to dust and combustion or explosion hazard. The storage of composted and dried products presents a number of challenges. The potential for fire and explosion are very real and must be carefully considered. Heat dried products are erosive. Some compost products, depending on the amendment used, also display erosive tendencies. These must be carefully considered during the planning and design process.

## **12.5 Biosolids Stability**

The stability of the biosolids is an extremely important critical control category. As discussed in the Guide to Field Storage of Biosolids, the public’s greatest concern associated with biosolids storage is odor. Odors also generate concerns with land application programs and remote processing facilities. Proper stabilization is the best means to reduce the generation of product odor. The method by which the biosolids are stabilized is not as important as the degree of stabilization achieved. Well stabilized biosolids will generate far fewer odors than those that have not been fully stabilized. Stabilization systems and recommended operating controls are described in Chapter 4.

## 12.6 Recommended Management Practices

The recommended management practices contained in this chapter are meant to compliment those contained in the other chapters of this manual and those contained in the references cited. They are not inclusive and may not apply to all storage systems.

*Buffers.* For field storage associated with land application, if you can see the neighbors to a storage site or a frequently traveled roadway, your buffer is not large enough. Storing biosolids in remote locations, may seem like extra effort, but it may be the effort that allows a successful program.

*Water Protection.* Groundwater and surface should be protected from the concentrated nutrients associated with a stockpile. The site should be graded so that water does not pond on or around the stockpile. Water that has runoff the stockpile should be collected for evaporation or application with the biosolids. The storage pad should include an impervious base to protect groundwater quality. In certain areas, limestone should be considered for the construction of the pad. Lime can provide a good surface for vehicle traffic and storage. When solids are collected from storage, any lime that is inadvertently collected, is land applied.

*Special precautions must be made for storing dried products.*

*Liquid Biosolids Storage.* Liquid biosolids must be very well stabilized prior to storage. Mixing prior to application should be performed by mechanical mixer rather than by aeration.

*Dried Material Storage.* Special precautions must be made for storing dried products. The products range from compost product with a solids concentration of approximately 60 percent to heat dried product with solids concentration in excess of 90 percent. Care must be taken to minimize the potential for fire or explosion. Care must also be taken to insure that the products are stable, reducing the potential for odor.

## References

United States Environmental Protection Agency, Office of Wastewater Management, (July, 2000), *“Guide to Field Storage of Biosolids”*, (4204) (USEPA/832-B-00-007)



## Chapter 13 - Biosolids Nutrient Management/ Calculating Agronomic Rate of Application

---

Biosolids contain significant levels of essential plant nutrients. The availability of these nutrients to vegetation at an application site depends on biosolids composition, processing, handling and method of application, as well as a number of soil and climatic factors. Under most situations, the amount of biosolids that can be applied to the soil is based on satisfying a nutrient requirement of the vegetation. This quantity is called the “agronomic” rate of application.

The federal regulations and many state regulations require that the application of biosolids be limited to crop nitrogen (N) uptake. The goal is to apply just enough N to maximize crop growth without allowing N to degrade water quality. This Chapter provides guidance on how the agronomic rate of application is determined.

While most current regulations are based on nitrogen application, phosphorus (P)-based rates are being mandated by some agencies. Many states now regulate the application of phosphorus through biosolids, or are considering regulations that will reduce the application of biosolids based on phosphorus content. This chapter also addresses the issues associated with phosphorus application through biosolids.

Most state agencies follow USEPA's suggested N availability computation method, outlined in the *Process Design Manual* (USEPA, 1995). This chapter illustrates how nutrient management is achieved using the USEPA approach. Recognize that this approach may need to be simplified and/or tailored for local cropping practices and regulatory requirements.

### 13.1 Critical Control Points / Operational Controls

Biosolids nutrient management controls have been established for activities before, during, and after land application.

#### ***Before land application:***

- ☑ Confirm that the biosolids meet all pollutant, pathogen reduction, and vector attraction reduction requirements at the time proposed for application. Do not just rely on past history; a responsible representative must personally review the data to assure that all is in order.
- ☑ Confirm the N, P, K content of the biosolids. If the material has been stored for greater than 6 weeks, nutrient content should be reevaluated.
- ☑ Review the farm nutrient management plan for the crop(s) being planted in order to calculate the biosolids agronomic rate.
- ☑ Access information on past biosolids applications in order to consider residual N when calculating the biosolids agronomic rate.
- ☑ Calculate the “target” biosolids agronomic rate based on the nitrogen content of the biosolids, crop nitrogen need, and residual N from past biosolids applications.
- ☑ Discuss the proposed biosolids application with the farm operator to confirm that the recycling program is consistent with the farm operator's intentions. Address any last minute changes on the farm operator's part.

- ☑ Check that all regulatory approvals, notices, etc. have been completed.

### ***During land application:***

- ☑ Check the area applied versus the volume (or tonnage) of biosolids applied to confirm that the actual application rate is consistent with the target agronomic rate. This exercise should be performed daily.
- ☑ Record the location (field, portion of field) where each load of biosolids is applied, the weather conditions, responsible parties involved, visits by regulators, and any unusual observations or complaints by neighbors.

### ***After land application activities:***

- ☑ Assemble and file all records documenting the application event.
- ☑ Submit any required regulatory reports.
- ☑ Provide pertinent information to the farm operator, particularly the biosolids nutrients applied.
- ☑ Notify the farm operator (and specified regulatory officials as required) that land application activities have been completed.

## **13.2 What is Nutrient Management?**

The goal of nutrient management is to develop environmentally responsible strategies for field application of agricultural fertilizers. A sound nutrient management plan (NMP) will provide a site-specific strategy for supplying necessary nutrients for crop growth while at the same time protecting local water quality. The Part 503 Rule limits land application of biosolids N to only the amount used by growing crops.

Nutrient sources include, but are not limited to, livestock and poultry manures, compost as fertilizer, commercially manufactured chemical fertilizers, biosolids, or combinations thereof.

## **13.3 Nutrient Management Planning and Biosolids**

The Part 503 Rule specifies that biosolids may not be applied at a rate greater than the agronomic rate. The agronomic rate is defined in 40 CFR 503.11 as the:

*“whole sludge application rate (dry weight basis) designed : (1) to provide the amount of nitrogen (N) needed by the food crop, feed crop, cover crop, or vegetation grown on the land and (2) to minimize the amount of N in the sewage sludge that passes below the root zone of the crop or vegetation grown on the land to the ground water.”*

While the term “agronomic rate” is relatively new, the practice of limiting biosolids applications to supply only as much N as will be consumed by the crop and removed during harvest, is not. Most state biosolids regulations have recognized this practice for decades.

## **13.4 Biosolids and Phosphorus**

Experience has shown that repeat applications of nutrients to the same farm field may eventually result in elevated levels of soil test phosphorus (P). When elevated soil test P is found, terms

such as *high* or *excessive* are used in soil test reports to indicate that further addition of phosphate fertilizer will not increase crop yields. Such interpretations of soil fertility tests are based on agronomic/economic considerations, not on potential environmental risk posed by high soil test P levels.

Biosolids, like animal manure, are not a balanced fertilizer. The primary nutrients (nitrogen (N), phosphorus (P), and potassium (K)) required to achieve target crop yields do not match the amounts available from biosolids on a mass basis. For example, when biosolids applications are performed to meet crop-N need, P is typically over-applied. At the same time K is often underapplied. The degree to which P and K are mismatched to crop needs depends on the particular biosolids and the crop.

Current standard practice bases biosolids application on plant available nitrogen (PAN) content. The approach strives to assure that at least two of the three primary nutrients, N and P, are present in the soil in sufficient quantities to achieve the desired crop yield. While the N application is managed to avoid excessive deep percolation and associated groundwater contamination, P is over-applied. It is therefore not surprising that soil test P levels on farms utilizing N-based prescriptions for land application of biosolids may continue to climb. While excessive soil test P is not the goal, the underlying rationale behind this strategy is that high soil test P from biosolids causes no environmental harm.

Research in recent years suggests that dissolved P in runoff from fields having excessive soil test P may contribute additional P loading to adjacent streams. This finding has stirred interest, since P is the major controlling factor for nutrient-based degradation (eutrophication) of fresh water bodies. A key factor in determining impacts on eutrophication is the bioavailability of P in surface water bodies. Aquatic P levels of around 0.01 mg/L (as PO<sub>4</sub>) have been associated with the development of algae blooms in lakes and reservoirs (Deizman et al., 1989). Runoff-P levels considerably greater than this have been reported from high soil test P fields, but it has not yet been determined to what degree biosolids-applied P contribute to runoff.

It was previously believed that controlling soil loss from farm fields was an effective means of blocking P-transport to adjacent streams. The reasoning was that most P is adsorbed to soil particles. If the loss of soil particles in runoff were minimized, then P-export would be within acceptable limits. The finding that runoff-P levels from high soil test P farm fields sometimes exceeds the limit allowed for most wastewater treatment facility discharges (1.0 mg/L) has caused regulators in some states to re-examine the N-based nutrient management approach.

Definitive information relating various biosolids treatment processes and associated impacts on P-bioavailability and soil test P levels is lacking. It is believed that the treatment method and type/amount of chemicals involved in wastewater treatment and biosolids processing have an impact on P availability (Hani et al., 1980). For example, in order to meet increasingly more stringent stream discharge standards, metal salts are added to wastewater at many treatment facilities to remove effluent P. Resulting precipitated metal phosphates end up in the biosolids. Limited research suggests that the presence of elevated aluminum or iron in biosolids yield lower bioavailable-P.

Some states have established maximum soil test P levels beyond which land application of organic residuals is not permitted. This approach fails to consider factors that are known to play a role in off-site P-transport. In 1998 the state of Maryland mandated that *all nutrients* land-applied after 2004 must be managed within the context of a nutrient management plan based on both N and P. The impact of such requirements on biosolids recycling could be significant. Research to define biosolids-P availability is ongoing, and should help to provide meaningful P-based nutrient management.

### 13.5 Components of a Biosolids Nutrient Management Plan

This section provides a basic outline for addressing nutrient management issues when recycling biosolids on a farm. Biosolids application can substantially offset, or even completely eliminate the need for chemical fertilizers when careful and deliberate nutrient management is employed. There are four basic components to a *voluntary biosolids NMP*:

- Farm Identification
- Management Plan Summary
- Nutrient Allocation and Use
- Restrictions

Guidance for developing each of the four NMP components is listed below.

#### *Farm Identification Elements*

- Operator's name, address, telephone no., and signature (Include *Landowner Consent* )
- County(s) where operation is located
- Name(s) of adjacent streams
- Indication of any special protection waters (Refer to state guidance documents)
- Total acres of operation
- Total cropland acres available for nutrient application
- Total cropland acres planned for manure recycling (excluding biosolids and other Organic-N (Org-N) nutrient sources)
- Total cropland acres planned for biosolids recycling. (excluding manure and other Org-N nutrient sources)
- Total cropland acres to which biosolids and manure (both) will be applied
- Number of Animal Equivalent Units (AEU's) per acre receiving manure, if applicable
- Name and certification number of Nutrient Management Specialist, if applicable
- Location maps including:
  - SGS 7 ½ min. location map showing outline of farm site
  - NRCS soil survey map(s) containing soil types and slopes with outline of farm site
- Farm maps of sufficient scale to show:
  - Field and operation boundaries (with individual field numbers and acres)
  - Areas where biosolids application is limited or restricted

#### *Management Plan Summary*

- Manure management summary table, if applicable:

- Total manure generated on the farm site annually
- Total manure used on the farm site annually
- Total manure exported from the farm site annually
- Biosolids management summary table:
- Total biosolids generated by contributing sources
- Total amount of biosolids which could be recycled in accordance with the computed Agronomic Rate
- Nutrient application rates by field or crop group
- General summary of excess manure utilization procedures
- Implementation schedule

### *Nutrient Allocation and Use Elements*

- Amounts and various nutrient sources used on the operation
- The number of animals of each animal type, if applicable
- Acreage and expected crop yields for each crop group
- The amount of nutrients necessary to meet expected crop yields
- Residual N from legumes
- The nutrient content of the manure(s), if applicable
- The amount of PAN originating from manure(s), considering the application method and planned manure incorporation time (volatilization losses), if applicable
- The amount of PAN originating from past manure applications, if applicable
- The nutrient content of conventional fertilizers that will be used regardless of other N sources (e.g. starter fertilizer, herbicide carrier solutions, etc.)
- The amount of PAN originating from conventional fertilizers
- The nutrient content of the biosolids
- The amount of PAN originating from biosolids, considering the biosolids treatment method, biosolids-N forms, and planned application method
- The amount of PAN originating from past biosolids applications
- Planned manure application rate(s), if applicable
- Target spreading periods for manure application, if applicable
- Nitrogen balance calculation showing the biosolids Agronomic Rate for each management unit
- Winter manure spreading procedures (if applicable)

### *Restrictions*

- Frozen, snow covered, and saturated soil conditions
- Slope constraints
- Manure application isolation distances
- Biosolids application isolation distances and harvest waiting periods

## 13.6 Fundamental Terms and Concepts

To understand when and where to apply biosolids, certain common terms must be understood. The *farm field* is the basic management unit used for all farm nutrient management, as defined as

“the fundamental unit used for cropping agricultural products”. An *area of cropland* that has been *subdivided* into several strips is not a single field. Rather, each strip represents an *individual field unit*. Individual fields that are managed in the same manner, with the similar yield goals, are called a *crop group*.

The cycle of crop *planting and harvesting periods*, not the calendar year, dictates the timing of biosolids land application activities. Winter wheat and perennial forage grasses are examples of crops that may be established and harvested in different calendar years. In many regions, biosolids are commonly applied in the fall or early winter, in anticipation of a crop that will be planted the following spring. Crop nutrient management practices are linked to crop nutrient uptake (crop growth) and nutrient removal at harvest time. Biosolids land application programs must be coordinated with the cropping cycle.

The basic time management unit is often called the *crop year* or *planting season*. The *crop year* is defined as the year in which a crop receiving the biosolids treatment is harvested. For example, fall biosolids applications in 2000 intended to provide nutrients for a crop to be harvested in 2001 are earmarked for *crop year* 2001. Likewise, biosolids applied immediately prior to planting winter wheat in October 2000 should be identified as fertilizer intended for *crop year* 2001 because the wheat will be harvested in the summer of 2001. Similarly, if instead of wheat, the field is planted as corn in May 2001 that will be harvested in November 2001, biosolids applications performed in the fall of 2000 are credited to Crop Year 2001. Typically, biosolids applied January through June would be intended for a crop harvested in the same calendar year. Biosolids applied in the last six months of the calendar year usually fertilize crops harvested the next calendar year. This generalization does not always hold true. For example, biosolids may be applied in July on a grass forage crop or in preparation for a buckwheat crop that will be harvested before winter. Other common exceptions are likely in hot, humid sections of the U.S.

### 13.7 Determining Crop Nitrogen Removal

The first step in computing the agronomic rate is to establish the amount of nitrogen needed for a desired crop yield. The crop yield consists of crop removal rates and nutrient recommendations for proposed crops. This is also a good time to evaluate other primary nutrient crop removal amounts (phosphate and potash), though these elements are not normally regulated at the state or federal level.

#### *Selecting a Target Crop Yield*

Realistic yield goals can be taken from the latest edition of the *Agronomy Guide* (or equivalent) published by the *land grant university* in the appropriate State. This publication is often updated to reflect trends in common agricultural practice and recommendations resulting from current demonstrations and research. This resource is preferred for selecting crop yield goals due to its currency. Yield goals presented in an agronomy guide are normally based on “Soil Productivity Group” classifications of soils that take into account soil depth, drainage characteristics, or other important soil features. **Always use information sources appropriate for your location.** Table 13.1 is provided as an example of the type of information commonly available.

**Table 13.1 Typical Yield Capabilities of Select Soils\***

Soil Series	Crop Productivity Group	Corn grain bu/A	Corn Silage T/A	Wheat bu/A	Soybeans bu/A
Abbottstown	4	100	17	40	30
Albrights	3	125	21	50	30
Allenwood	1	150	25	60	45
Basher	2	125	21	60	40

Source: PSU, 1996

**\* Note: This table is proved as an example. Similar information is available for each state.**

Yield goals can also be based on actual field data from the site. For example, the average crop yield using the three best planting seasons out of the last five years can be used. Use of actual field data is preferred, but often not readily available when beginning a nutrient management program.

***Crop Nutrient Removal Rates***

Estimated crop removal rates for essential nutrients can be obtained from:

- State regulatory agency guidance documents
- State land grant university guidance documents (e.g. *The Agronomy Guide*)
- State agricultural extension service guidance

Some variation among sources is normal. Table 13.2 provides a number of examples of crop nutrient removal information needed to determine the agronomic rate.

**Table 13.2 Nitrogen, Phosphate, and Potash Removal from Soil by Various Crops\***  
Pounds Removed per Unit Production

Crop	Unit	N	P2O5	K2O
Corn, grain	bu	1.0	0.4	0.3
Corn, silage (65% moisture)	ton	7.0	3.0	9.0
Soybeans, grain	bu	3.8 (a)	1.0	1.5
Wheat, grain & straw	bu	1.5	0.7	1.4
Wheat, grain	bu	1.3	0.5	0.3

Footnotes:

Original source: Dr. Douglas Beegle (The Pennsylvania State University) - personal communication with R.C. Brandt in 1993. Values reflect the average of 6 sources that estimate unit production removals (unless otherwise noted).

(a) Legumes fix all of their required N except for a small amount applied as starter fertilizer. However, they also have the capability to utilize N as indicated.

Source: Brandt and Martin, 1994

**Note:** This table is provided as an example only. Similar information is available for each state.

In practice, crop nutrient removal amounts are typically less than recommended fertilization rates because the amount of fertilizer needed to stimulate an optimum crop response is greater than

harvested plant tissue levels. Hence, when possible, agronomic rate calculations should be based on N fertilizer recommendations rather than N removal rates, at least for non-legume crops. Nitrogen needs for Legume crops (e.g. alfalfa, clover, and soybeans) should be based on removal rates such as those given in table 13.2, since these crops fix atmospheric N and are not normally fertilized with N.

***Calculating Net Primary Nutrient Crop Need***

The biosolids agronomic rate is based on meeting crop needs without over application of N. The total Crop-N Fertilizer Rate (CNFR) can be calculated as:

**Equation 13.1**  $CNFR = Yield \times UNFR$

Where:

- CNFR = Crop-N Fertilizer Rate, (lbs N per Acre)
- Yield = Crop yield, (bu/ac or T/ac harvested) <sup>(1)</sup> See Table 13.1
- UNFR = Unit-N Fertilizer Rate, (lbs N per unit crop yield) See Table 13.2

<sup>(1)</sup> bu/ac = bushels per acre, T/ac = tons per acre

For example, anticipated wheat yield for a field consisting of primarily Allenwood soils is 60 bushels per acre (Table 13.1), with a UNFR of 1.3 lbs of N per bushel (Table 13.2). The resultant crop-N uptake for this field is therefore 78 lbs of N per acre (60 x 1.3 = 78). While not required by most states or current federal regulation, similar calculations can be used to estimate phosphate and potash crop removal amounts.

**13.8 Biosolids Plant Available Nitrogen**

Computing biosolids PAN should account for: (1) the type of biosolids, (2) the method of biosolids application, (3) Org-N mineralization in subsequent growing seasons, and (4) both inorganic and organic contributions to PAN.

First year, biosolids PAN may be summarized by the following equation:

**Equation 13.2**  $PAN_{0-1} = (NO_3^- - N) + K_v(NH_4^+ - N) + F_{0-1} (Org-N)$

Where:

- PAN<sub>0-1</sub> = Biosolids 1st year PAN content, (lbs of N per ton)
- NO<sub>3</sub><sup>-</sup>-N = Biosolids Nitrate-N content, (lbs of N per dry ton)
- NH<sub>4</sub><sup>+</sup>-N = Biosolids Ammonium-N content, (lbs per dry ton)
- Org-N = Biosolids Org-N content, (lbs per dry ton)
- K<sub>v</sub> = NH<sub>4</sub><sup>+</sup> volatilization factor -- based on the method of application (see Table 13.3).
- F<sub>0-1</sub> = Biosolids 1st year Org-N mineralization factor based on the method of biosolids treatment (see Table 13.4).



Example 1, located in the back of this chapter, illustrates the use of Equation of 13.2 to calculate the 1<sup>st</sup> year PAN from biosolids.

***Inorganic N Forms and Availability***

Crops directly utilize N in its inorganic forms, principally nitrate (NO<sub>3</sub><sup>-</sup>) and ammonium (NH<sub>4</sub><sup>+</sup>). Biosolids NO<sub>3</sub><sup>-</sup> concentrations are typically less than 0.05%. This translates to less than one pound per dry ton of biosolids. Hence, this fraction is usually insignificant and is not included in most agronomic rate calculations. However, it is advisable to test the biosolids NO<sub>3</sub><sup>-</sup> content before eliminating this factor.

Biosolids NH<sub>4</sub><sup>+</sup> can be significant, making up even half the biosolids PAN<sub>0</sub>. Biosolids NH<sub>4</sub><sup>+</sup>-N can vary widely depending on treatment and storage. Since NH<sub>4</sub><sup>+</sup>-N is prone to volatilization (as ammonia, NH<sub>3</sub>), the application method affects PAN. Surface applied biosolids are expected to lose half of their NH<sub>4</sub><sup>+</sup>-N. Conversely, direct subsurface injection or soil incorporation with 24 hours minimizes volatilization losses.

**Table 13.3 Biosolids Volatilization Losses of NH<sub>4</sub>-N as NH<sub>3</sub>**

Biosolids Type and Application Method	NH <sub>3</sub> Volatilization Factor, Kv
Surface Applied (liquid or dewatered)	0.5
Direct Injection into the Soil, or Incorporation into Soil with 24 Hours	1.0

Source: USEPA, 1995

***Biosolids Organic Nitrogen Mineralization Rate***

Most biosolids N exists as organic compounds, principally contained in proteins, nucleic acids, amines, and other cellular material. These complex molecules must be broken apart through biological degradation for N to become available to crops. The conversion of Org-N to inorganic-N forms is called *mineralization*.

The mineralization rate depends on many soil factors such as temperature, moisture, pH, and availability of oxygen, as well as the inherent biodegradability of organic materials. Biosolids that are digested undergo some mineralization before ever reaching the farm field. Hence, the method and degree of biosolids treatment prior to application influences the amount of N easily released for plant uptake.

Organic N in biosolids becomes available to crops (i.e., mineralized) over a period of several years. Because of the many influencing factors, we rely on estimates of mineralization. Mineralization factors shown in Table 13.4 illustrate how treatment method and length of time since field application impact the amount of biosolids PAN.

**Table 13.4 Estimated Biosolids Mineralization Rate Factors (Fyear)**

Percent Org-N Mineralized From Field Applied Biosolids (Fyear)

Time After Biosolids Application (Crop Year)	Unstabilized and Waste Activated Sludges	Lime Stabilized or Aerobically Digested Biosolids	Anaerobically Digested Biosolids	Composted Biosolids
0-1	40%	30%	20%	10%
1-2	20%	15%	10%	5%
2-3	10%	8%	5%	
3-4	5%	4%		

Source: USEPA, 1995

**Note:** Use decimal form of percentages (% divided by 100) when performing calculations. Recent WERF research (7) describes the results of laboratory and field studies in four different regions of the U.S. to determine the PAN from several different biosolids sources and under a variety of climatic conditions. Computer simulation using weather data and the data obtained in this study were used to predict annual mineralization rates both from the laboratory and field findings. The computer model provided good estimates of growing season PAN, and this method of calculating nitrogen application holds promise for more accurately determining agronomic loading rates under different climatic conditions than the factors currently in use (Tables 13.3 and 13.4 above).

**PAN from Past Biosolids Applications**

Information needed to calculate the amount of PAN from past biosolids applications includes the type of biosolids, the biosolids Org-N content, and the amount of biosolids applied (dry tons per acre).

The calculation method presented herein for determining PAN from past biosolids Org-N applications originates from the USEPA’s 1983 Process Design Manual (USEPA, 1983). This method is recommended to avoid lengthy calculations necessitated by other calculation approaches. The answers derived using this method are for all practical purposes identical to those found using the more lengthy calculation. Table 13.5 provides mineralization factors for direct calculation of PAN from previously applied biosolids Org-N.

**Table 13.5 Biosolids Mineralization Factors (K<sub>m</sub>)**

Lbs of N Mineralized per Dry Ton of Biosolids per % Org-N (K<sub>m</sub>).

Time After Biosolids Application (Crop Year)	Unstabilized and Waste Activated Sludges	Lime Stabilized or Aerobically Digested Biosolids	Anaerobically Digested Biosolids	Composted Biosolids
0-1	8.00	6.00	4.00	2.00
1-2	2.40	2.10	1.60	0.90
2-3	0.96	0.90	0.72	
3-4	0.44	0.42		

Source: USEPA, 1983

Example 2, located at the end of the chapter, illustrates the use of the carry-over PAN calculation using the K<sub>m</sub> (shortcut) mineralization factor.

### 13.9 Crop N Contributions from Conventional Fertilizers

Nitrogen contributed by use of conventional inorganic chemical fertilizers is an important component in the overall N budget available to growing crops and, this must be accounted for in the agronomic rate computation. Table 13.6 provides a summary of conventional N fertilizers in terms that are helpful in discussions with farm operators.

**Table 13.6 Conventional N Fertilizer Materials**

Fertilizer	Total N, %	Available Phosphoric Acid, %	Soluble Potash, %
Anhydrous ammonia (NH <sub>3</sub> )	82	0	0
Urea (NH <sub>2</sub> -CO-NH <sub>2</sub> )	46	0	0
Ammonium Nitrate (NH <sub>4</sub> NO <sub>3</sub> )	33-34	0	0
N solutions (UAN) (Urea + NH <sub>4</sub> NO <sub>3</sub> + Water)	28-32	0	0
Ammonium Sulfate (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	21	0	0
Diammonium phosphate (DAP) (NH <sub>4</sub> ) <sub>2</sub> HPO <sub>4</sub>	18	46	0
Monammonium phosphate (MAP) NH <sub>4</sub> H <sub>2</sub> PO <sub>4</sub>	11	52	0
Ammonium polyphosphate	10	34	0
Potassium nitrate KNO <sub>3</sub>	13	0	45

Source: PSU, 1996

Note that the nutrient content of conventional fertilizers is expressed in a three number series such as 11-52-0. This numeric series is interpreted as the percentage content of: (1) Total N, (2) Available Phosphate (P<sub>2</sub>O<sub>5</sub>), and (3) Soluble Potash (K<sub>2</sub>O). Hence, 100 lbs of 11-52-0 fertilizer contains 11 lbs of Total-N, 52 lbs of P<sub>2</sub>O<sub>5</sub>, and no K<sub>2</sub>O. In reality, not all commercial fertilizer nutrients are available to crops, but agronomic rate calculations normally assume all fertilizer N is available for uptake in the first year.

More detailed information on conventional fertilizers can be found in the *agronomy guide* for your state. The county Cooperative Extension agent is another excellent source of information.

### 13.10 Crop N Contributions from Previous Legume Crops

Nitrogen contributed by previous legume crops is another contribution to be considered when computing the agronomic rate. Table 13.7 illustrates the type of information needed when assessing N contributions from legumes. Consult the state agronomy guide for guidance specific to your area.

**Table 13.7 Residual N Contributions from Legumes for Corn Production\***

Previous Crop	% Stand	Soil Productivity Group 1 Nitrogen Credit (lbs/A)
First Year After Alfalfa	>50% Stand	120
	25%-49% Stand	80
	<25% Stand	40
Second Year After Alfalfa	<50% Stand	60
First Year After Clover Or Trefoil	>50% Stand	90
	25%-49% Stand	60
	<25% Stand	40
First Year After Soybeans Harvested For Grain		1 lb N/bu Soybeans

Source: After PSU, 1996

**Note:** This table is proved as an example only. Similar information is available for each state.

### 13.11 Crop N Contributions from Manures and Other Amendments

Manure N must also be considered when determining the agronomic rate. The procedure for manure is similar to biosolids. Current manure applications are evaluated first, based on the animal type, N content, and incorporation time. Like biosolids Org-N, past manure applications also contribute to the soil-N pool through mineralization. PAN originating from this fraction is computed separately and then added to current applications to get the total PAN from livestock manure.

Consult the *agronomy guide* (or equivalent) appropriate for your area to determine the correct method for determining PAN originating from livestock manure. Often, more than one method for manure PAN computation is provided.

Finally, nitrogen contributions from all other possible sources must be considered in calculating the overall N budget available to growing crops. Unusual or non-conventional sources that should be considered may include irrigation water; pesticide carrier solutions; and other organic fertilizer materials such as food processing residuals.

### 13.12 Determining the Biosolids Agronomic Rate

PAN contributions from all past and current planned non-biosolids sources must be subtracted from the calculated Crop-N Fertilizer Rate to determine the Crop-N Deficit (CND) that may be supplied by biosolids applications for a particular field crop. Nitrogen sources that must be considered include:

- Manure-N, if applicable (including current and historical applications)
- Residual legume-N, if applicable (carry-over from previous legume crops)
- Starter fertilizer-N, if applicable
- Conventional N-containing chemical fertilizer(s)
- Biosolids Org-N carry-over (including N originating from the previous three years applications)
- Other N sources (e.g. land applied crop or food processing residuals, irrigation water, N-solution pesticide carriers, other non-conventional fertilizer materials, etc.)

### **Agronomic Rate Basics:**

1. Select a realistic crop yield goal
2. Determine N needs of this crop
3. Estimate residual N in the soil from past manures/legumes/biosolids
4. Determine the amount of supplemental N needed to meet the crop need
5. Calculate the amount of biosolids necessary to supply this amount

All of the above listed Crop-N sources have been discussed in previous sections of this chapter.

Note that the principal source for historical data is the farm operator.

The agronomic rate is calculated using the first year PAN content of the biosolids intended to be recycled and the Crop-N Deficit. Any change in either of these factors will impact the computed Agronomic Rate. Equation 13.3 describes the calculation of Agronomic Rate:

$$\text{Equation 13.3 } AR = (CND) / PAN_{0-1}$$

Where:

AR	=	Agronomic Rate, (dry T/ac)
PAN <sub>0-1</sub>	=	Biosolids 1st year PAN content, (lbs per dry ton)
CND	=	Crop-N Deficit = Anticipated Crop-N Fertilizer Rate minus all historical PAN sources and current planned non-biosolids PAN sources, (lbs/ac) (Previous biosolids carry-over N is included in this calculation).

Example 3, found at the end of this chapter, illustrates Crop-N Deficit (CND) calculation incorporating the factors listed above.

### **13.13 Step-by-Step Agronomic Rate Calculation**

This section provides a detailed example agronomic rate calculation using all of the separate components. In practice, this analysis must be repeated for each farm field contained in a land application program.

There are four basic steps involved in determining the Agronomic Rate: (1) CNFR Determination, (2) CND Determination, (3) Biosolids PAN Determination, and (4) Agronomic Rate Calculation. Example 4, below, guides you through these steps and provides references for each individual element. Reference Tables 1, 2, and 3 are also included to support the agronomic rate calculation in Example 4.

Blank worksheets for manual agronomic rate calculations (on a single application field) are provided at the end of this chapter, for use in making agronomic rate calculations. The worksheets follow the same layout as provided in Example 4. These blank sheets may be copied as necessary.

***Computer-Based Agronomic Rate Determination***

While the agronomic rate calculations are straightforward, they become cumbersome when dozens of fields and multiple biosolids applications are involved. For this reason, land appliers may wish to develop a computer-based spreadsheet or purchase one of several commercial versions available to calculate application rates. To be useful, such computer programs must be able to generate biosolids application rates for individual farm fields based on crop type, yield goals and nutrient requirements. They must be able to account for residual N inputs from past applications of manures, legumes, and biosolids. In addition, the programs should be able to assess analytical results and develop separate field application rates for varying biosolids characteristics.

**Example 4: Agronomic Rate Calculation**

Given: Planned crop: Corn, silage  
 Predominant soil series: Allenwood  
 Target crop yield (based on soil productivity group): 25 T/A  
 Unit-N Fertilizer Rate (UNFR): 7.0 lbs N/T yield  
 Previous year legume crop and yield: Soybeans / 45 bu/A  
 Starter fertilizer usage: 100 lbs/A of 11-52-0  
 Historical manure usage information: Manure type: Dairy Frequency of application: 5 out of last 10 years Typical manure application rate: 10 WT/A Typical manure-N content: 10 lbs N/WT

Past biosolids applications:

Data From Records	Previous Year 2000	Two Year Ago 1999	Three Years Ago 1998
Total Biosolids Applied (DT/A)	2.5	3.0	4.0
Biosolids Org-N Content (%)	4.3	4.6	4.9
Biosolids Org-N Applied* (lbs/A)	215	276	392

\* Biosolids Org-N lbs/A = (DT/A) x (Org-N %) x 20

Biosolids characteristics:

Biosolids stabilization method: Aerobic digestion  
 Biosolids application method: dewatered and surface applied  
 Biosolids Org-N content: 4.9%  
 Biosolids NH<sub>4</sub>-N content: 0.1%  
 Biosolids NO<sub>3</sub>-N content: 0.0%  
 Biosolids solids content: 20%

Find: Agronomic Rate given the above conditions. Solution: See calculation procedure below.

**Example 4 - Calculation Procedure**

<b>STEP 1: CNFR DETERMINATION</b>	<b>Units</b>	<b>Enter Value</b>	<b>Totals (Remarks)</b>
1a. Planned Crop	crop name	Corn, silage	
1b. Predominant Soil Series (optional)	soil series name	Allenwood	
1c. Soil Productivity Group (optional)	soil group no.	Group I	(Re: Table 13.1*)
1d. Target Crop Yield	bu/A or T/A	25 T/A	(Re: Table 13.1*)
1e. Unit-N Fertilizer Rate (UNFR)	lbs N/A	7.0	(Re: Table 13.2*)
1f. Crop-N Fertilizer Rate (CNFR)	lbs N/A	(1d x 1e) =	175
<b>STEP 2: CND DETERMINATION</b>	<b>Units</b>	<b>Enter Value</b>	<b>Totals (Remarks)</b>
2a. PAN from Legumes	lbs N/A	45	(Re: Table 13.7*)
2b. PAN from Conventional Fertilizers	lbs N/A	11	= (100 x 11%)
2c. PAN from Recent or Panned Livestock Manure Applications	lbs N/A	0	
2d. PAN from Historical Livestock Manure Applications	lbs N/A	15	(Re: See note below)
2e. PAN from Past Biosolids Applications **	lbs N/A	43	(Re: Example 4 Km table below)
2f. PAN from Other Sources	lbs N/A	0	
2g. Total PAN (from above)	lbs N/A	114	= (sum of above sources)
2h. Crop-N Deficit (CND)	lbs N/A	61	= (1f - 2g)

\* Referenced table is provided as an example only. Similar information is available for each state.

\*\* Insert value from Biosolids Mineralization Worksheet provided below.

Note: Dairy manure applied at 10 WT/A for 5 out of the last 10 years with a Nitrogen content of 10 lbs N/WT. (10 WT/A x 10 lbs N/WT x 0.15 = 15 lbs N/A Available)

## NATIONAL MANUAL OF GOOD PRACTICE FOR BIOSOLIDS

STEP 3: BIOSOLIDS PAN DETERMINATION	Units	Enter Value	Totals (Remarks)
3a. Biosolids Stabilization Method		Aerobic	
3b. Biosolids Application Method		Surface	
3c. Biosolids Org-N, PAN % = 0.3	lbs N/DT	29.4	(Re; Table 13.4, F(0-1) = 0.3) = (4.9 x 20 x 0.3)
3d. Biosolids NH <sub>4</sub> <sup>+</sup> -N, PAN % = 0.5	lbs N/DT	1.0	(Re: Table 13.3, K <sub>v</sub> = 0.5) = (0.1 x 20 x 0.5)
3e. Biosolids NO <sub>3</sub> <sup>-</sup> -N, PAN % = 0.0	lbs N/DT	0.0	= (0.0 x 20)
3f. Total Biosolids PAN(0-1)	lbs N/DT	30.4	= (3a + 3b = 3c)
<b>STEP 4: CALCULATE AR</b>			
4a. Agronomic Rate	DT/A	2.0	= (2h / 3f)

The agronomic rate is 2.0 DT/ac (equivalent to 10 WT/A), as demonstrated in the Agronomic Rate Calculation above. The Agronomic Rate in Dry Tons per acre is converted to Wet Tons per Acre by dividing DT/A by the solids content (in decimal form). For example: 2 DT/A is equivalent to 10.0 WT/A when the solids content is 20 percent.

### Example 4 Biosolids Org-N Mineralization Km “Shortcut” Factor Method

	T	U	V	W	X	Y	Z
	Crop Year (CY)	No. Of Years Prior To Plan Yr.	Equivalent Years Since Application	Km Factor (from Table 13.5)	Total Applied Biosolids (DT/A)	Biosolids Org-N Content (%)	Mineralized PAN From Past Biosolids (lbs/A)
1	(CY) 1998	3	3-4	Km(3-4) value 0.42	DT/A 4.0	Org-N % 4.9	= W <sub>1</sub> x X <sub>1</sub> x Y <sub>1</sub> 8.2
2	(CY) 1999	2	2-3	Km(2-3) value 0.90	DT/A 3.0	Org-N % 4.6	= W <sub>2</sub> x X <sub>2</sub> x Y <sub>2</sub> 12.4
3	(CY) 2000	1	1-2	Km(1-2) value 2.1	DT/A 2.5	Org-N % 4.3	= W <sub>3</sub> x X <sub>3</sub> x Y <sub>3</sub> 22.6
4	Plan CY 2001					Total	= Z <sub>1</sub> + Z <sub>2</sub> + Z <sub>3</sub> 43.2

Total Carry-Over N From Biosolids Applied In Three Previous Years Equals (Cell Z<sub>4</sub>)



## Reference Tables for Calculation of Agronomic Rate

**Reference Table 1 - Important Abbreviations and Terms**

Term	Definition
AR	Agronomic Rate, (dry tons per acre)
Yield	Crop yield, (bushels or wet tons per acre harvested)
Org-N	Organic-N content, (lbs per dry ton of biosolids)
NH <sub>4</sub> <sup>+</sup> -N	Ammonium-N content, (lbs per dry ton of biosolids)
NO <sub>3</sub> —N	Nitrate-N content, (lbs per dry ton of biosolids)
Fyear	Biosolids Org-N availability factor for the period (year) identified in subscript -- based on the method of biosolids treatment shown in Table 8.4. (This factor has no units.)
Km	“Shortcut” biosolids Org-N availability factor -- based on the method of biosolids treatment shown in Table 8.5. (This factor has no units.)
Kv	NH <sub>4</sub> <sup>+</sup> volatilization factor – based on the method of application shown in Table 8.3. (This factor has no units.)
PAN(0-1)	Biosolids 1st year PAN content, (lbs per dry ton)
UNFR	Unit-N Fertilizer Rate, (lbs N removed per unit crop yield)
CNFR	Crop-N Fertilizer Rate, (lbs N removed per acre by crop harvest)
CND	Crop-N Deficit: Anticipated Crop-N Fertilizer Rate (N removed by harvest), minus all historical PAN sources and current planned non-biosolids PAN sources, (lbs per acre) (Previous biosolids carry-over N is included in this calculation).

**Reference Table 2 - Calculation Procedure**

STEP 1: CNRR DETERMINATION	Units	Reference
1a. Planned Crop	crop name	• Data from farm operator
1b. Predominant Soil Series (optional)	soil series name	• Data from site mapping
1c. Soil Productivity Group (optional)	soil group no.	• Section 13.7 • Latest <i>Agronomy Guide</i> .
1d. Target Crop Yield	bu/A or T/A	• Data from farm operator and/or • Section 13.7 and Table 13.1* • Latest <i>Agronomy Guide</i> .
1e. Unit-N Fertilizer Rate (UNFR)	lbs N/A	• Section 13.7 and Table 13.2* • Latest <i>Agronomy Guide</i> .
1f. Crop-N Fertilizer Rate (CNFR)	lbs N/A	• Section 13.7 • Equation 13.1: CNFR = Yield x UNFR • Items 1d x 1e, from above
STEP 2: CND DETERMINATION	Units	Reference
2a. PAN from Legumes	lbs N/A	• Data from farm operator • Section 13.10 and Table 13.7 • Latest <i>Agronomy Guide</i> .

## NATIONAL MANUAL OF GOOD PRACTICE FOR BIOSOLIDS

2b. PAN from Conventional Fertilizers	lbs N/A	<ul style="list-style-type: none"> <li>Data from farm operator</li> <li>Section 13.9 and Table 13.6</li> <li>Latest <i>Agronomy Guide</i>.</li> </ul>
2c. PAN from Recent or Planned Livestock Manure Applications	lbs N/A	<ul style="list-style-type: none"> <li>Data from farm operator</li> <li>Latest <i>Agronomy Guide</i>.</li> </ul>
2d. PAN from Historical Livestock Manure Applications	lbs N/A	<ul style="list-style-type: none"> <li>Data from farm operator</li> <li>Section 13.11</li> <li>Latest <i>Agronomy Guide</i></li> </ul>
2e. PAN from Past Biosolids Applications	lbs N/A	<ul style="list-style-type: none"> <li>Past biosolids application records</li> <li>Section 13.8 and Table 13.5</li> <li>Biosolids Org-N mineralization worksheet, below</li> </ul>
2f. PAN from Other Sources	lbs N/A	<ul style="list-style-type: none"> <li>Data from farm operator</li> </ul>
2g. Total PAN (from above)	lbs N/A	<ul style="list-style-type: none"> <li>Sum of items 2a through 2f, above</li> </ul>
2h. Crop-N Deficit (CND)	lbs N/A	<ul style="list-style-type: none"> <li>Section 13.12</li> <li><math>CND = CNFR - Total\ PAN</math></li> <li>Item 1f - 2g, from above</li> </ul>
<b>STEP 3:</b>		
<b>BIOSOLIDS PAN DETERMINATION</b>	Units	Reference
3a. Biosolids Stabilization Method	name method	<ul style="list-style-type: none"> <li>Aerobic, anaerobic, lime stabilized, composted, etc.</li> </ul>
3b. Biosolids Application Method	name method	<ul style="list-style-type: none"> <li>Surface application or direct subsurface injection (or prompt incorporation)</li> </ul>
3c. Biosolids Org-N, PAN % = _____	lbs N/DT	<ul style="list-style-type: none"> <li>Sections 13.8</li> <li>See Table 13.4 for F(0-1) values</li> <li><math>\%/100 \times 20 \times F(0-1) = lbs\ N/DT</math></li> </ul>
3d. Biosolids NH <sub>4</sub> <sup>+</sup> -N, PAN % = _____	lbs N/DT	<ul style="list-style-type: none"> <li>Section 13.8</li> <li>See Table 13.3 for K<sub>v</sub> values.</li> <li><math>\%/100 \times 20 \times K_v = lbs\ N/DT</math></li> </ul>
3e. Biosolids NO <sub>3</sub> —N, PAN % = _____	lbs N/DT	<ul style="list-style-type: none"> <li>Section 13.8</li> <li><math>\%/100 \times 20 = lbs\ N/DT</math></li> </ul>
3f. Total Biosolids PAN(0-1)	lbs N/DT	<ul style="list-style-type: none"> <li>Sections 13.8 • Equation 13.2: <math>PAN_{0-1} = (NO_3 --N) + K_v(NH_4^{+}-N) + F_{0-1} (Org-N)</math></li> <li>Items 3e+3d+3c, from above</li> </ul>
<b>STEP 4:</b>		
<b>CALCULATE Agronomic Rate</b>		
4a. Agronomic Rate	DT/A	<ul style="list-style-type: none"> <li>Section 13.13</li> <li>Equation 13.3: <math>AR = (CND) / PAN_{0-1}</math></li> <li>Items 2h / 3f, from above</li> <li>Items 2h / 3f, from above</li> </ul>

**Reference Table 3 - Biosolids Org-N Mineralization Km “Shortcut” Factor Method**

	T	U	V	W	X	Y	Z
	Crop Year (CY)	No. Of Years Prior To Plan Yr.	Equivalent Years Since Application	Km Factor (from Table 13.5)	Total Applied Biosolids (DT/A)	Biosolids Org-N Content (%)	Mineralized PAN From Past Biosolids (lbs/A)
1	(CY)	3	3-4	Km(3-4) value	DT/A from records	Org-N % from records	= W1 x X1 x Y1
2	(CY)	2	2-3	Km(2-3) value	DT/A from records	Org-N % from records	= W2 x X2 x Y2
3	(CY)	1	1-2	Km(1-2) value	DT/A from records	Org-N % from records	= W3 x X3 x Y3
4	Plan CY					Total	= Z1 + Z2 + Z3

**Total Carry-Over N From Biosolids Applied in Three Previous Years Equals (Cell Z4)**

**Note: Column and row identifiers (e.g. W1) are used to reference specific cells in arithmetic operations in this table.**

## References

- Brandt, R.C. and Martin, K.M., (1994), "*The food processing residual management manual*", First edition. PADEP Pub. No. 2500-BK-DER-1649. Harrisburg, PA.
- Deitzman, M.M., Mostaghimi, S., Dillaha, T.A. and Heatwole, C.D., (1989), "*Tillage effects on P losses from sludge amended soils*", Journal Soil and Water Conservation. P. 247-251.
- Gilmour, et.al, (2000), *Estimating Plant-Available Nitrogen in Biosolids*, WERF Project 97-REM-3, Final Report
- Hani, H., Gupta, S.K. and Furrer, O.J., (1980), "*Availability of P fractions in Sewage Sludge*", Reidel Publishing Company, Phosphorus and sewage sludge and animal waste slurries, p. 177-181
- Pennsylvania State Conservation Commission, (1998), "*Pennsylvania's nutrient management act program technical manual*", Harrisburg, PA.
- Pennsylvania State University, (1996), "*Soil fertility management*", Agronomy Guide, Pennsylvania State University, College of Agricultural Sciences, University Park, PA (5.5M1096NVO)
- United States Environmental Protection Agency, (October, 1983), "*Process Design Manual for Land Application of Municipal Sludge*", (USEPA-625/1-83-016)
- United States Environmental Protection Agency, (February, 1993), "*Standards for the Use or Disposal of Sewage Sludge*," Fed. Regist., 58,32,40 CFR Part 503 Rule.
- United States Environmental Protection Agency, (September, 1995), "*Process Design Manual for Land Application of Sewage Sludge and Domestic Septage*", (USEPA/625/R-95/001)

## Suggested Reading

- Pennsylvania State Conservation Commission (PASCC), (1998), *Pennsylvania's Nutrient Management Act Program Technical Manual*, Harrisburg, PA

**Agronomic Rate Calculation – Blank Worksheet**

**Calculation Procedure**

<b>STEP 1: CNFR DETERMINATION</b>	Units	Enter Value	Totals (Remarks)
1a. Planned Crop	crop name		
1b. Predominant Soil Series (optional)	soil series name		
1c. Soil Productivity Group (optional)	soil group no.		
1d. Target Crop Yield	bu/A or T/A		
1e. Unit-N Fertilizer Rate (UNFR)	lbs N/A		
1f. Crop-N Fertilizer Rate (CNFR)	lbs N/A		
<b>STEP 2: CND DETERMINATION</b>	Units	Enter Value	Totals
2a. PAN from Legumes	lbs N/A		
2b. PAN from Conventional Fertilizers	lbs N/A		
2c. PAN from Recent or Planned Livestock Manure Applications	lbs N/A		
2d. PAN from Historical Livestock Manure Applications	lbs N/A		
2e. PAN from Past Biosolids Applications *	lbs N/A		
2f. PAN from Other Sources	lbs N/A		
2g. Total PAN (from above)	lbs N/A		
2h. Crop-N Deficit (CND)	lbs N/A		

\* Insert value from biosolids mineralization worksheets provided herewith.

<b>STEP 3: BIOSOLIDS PAN DETERMINATION</b>	Units	Enter Value	Totals (Remarks)
3a. Biosolids Stabilization Method	name method		
3b. Biosolids Application Method	name method		
3c. Biosolids Org-N, PAN % = _____	lbs N/DT		

**NATIONAL MANUAL OF GOOD PRACTICE FOR BIOSOLIDS**

3d. Biosolids NH <sub>4</sub> <sup>+</sup> -N, PAN % = _____	lbs N/DT		
3e. Biosolids NO <sub>3</sub> <sup>-</sup> -N, PAN % = _____	lbs N/DT		
3f. Total Biosolids PAN <sub>(0-1)</sub>	lbs N/DT		
<b>STEP 4: CALCULATE AR</b>			
4a. Agronomic Rate	DT/A		

**Prescribed Agronomic Rate** \_\_\_\_\_

**Biosolids Org-N Mineralization K<sub>m</sub> “Shortcut” Factor Method**

	T	U	V	W	X	Y	Z
	Crop Year (CY)	No. Of Years Prior To Plan Yr.	Equivalent Years Since Application	K <sub>m</sub> Factor (from Table 8.5)	Total Applied Biosolids (DT/A)	Biosolids Org-N Content (%)	Mineralized PAN From Past Biosolids (lbs/A)
1	(CY)	3	3-4	K <sub>m</sub> (3-4) Value	DT/A	Org-N %	= W1 x X1 x Y1
2	(CY)	2	2-3	K <sub>m</sub> (2-3) value	DT/A	Org-N %	= W2 x X2 x Y2
3	(CY)	1	1-2	K <sub>m</sub> (1-2) Value	DT/A	Org-N %	= W3 x X3 x Y3
4	Plan CY					Total	= Z1 + Z2 + Z3

**Total Carry-Over N From Biosolids Applied In Three Previous Years Equals (Cell Z4)** \_\_\_\_\_

**Example 1: Calculating the 1<sup>st</sup> Year PAN from Biosolids**

Given: Aerobically digested biosolids  
 Method of application - surface applied liquid  
 Biosolids-N content: Total-N = 5.0%  
                                   Org-N = 4.0% NH<sub>4</sub><sup>+</sup>-N = 1.0%  
                                   NO<sub>3</sub> -N = 0.0%

Find: 1<sup>st</sup> Year PAN per dry ton of biosolids

Solution: The solution is calculated in two steps.

Step 1 - determine the amount of N per dry ton of biosolids represented by form of N.

Org-N:	4.0% x 20 lbs per T/%	=	80 lbs N/dry ton
NH <sub>4</sub> <sup>+</sup> -N:	1.0% x 20 lbs per T/%	=	20 lbs N/dry ton
NO <sub>3</sub> -N:	0.0% x 20 lbs per T/%	=	0 lbs N/dry ton

Step 2 - use Equation 13.2

$$PAN0-1 = (NO_3 -N) + K_v(NH_4^+-N) + F0-1 (Org-N)$$

$$PAN0-1 = 0.0 + 0.5 (20) + 0.30 (80) \text{ Note: } K_v \text{ is selected from Table 13.3}$$

F0-1 is selected from Table 13.4 PAN0-1 = 0.0 + 10 + 24 PAN0-1 = 34 lbs N/dry ton This indicates that each dry ton of biosolids can supply 34 lbs of N to the crops.

**Example 2: Biosolids Carry-Over PAN Calculation Using the Shortcut Mineralization Factor K<sub>m</sub>.**

Given: Aerobically digested biosolids  
 Applied two years ago  
 Application Rate: 5 dry tons / Acre Biosolids Org-N content: 4.0%

Find: Biosolids PAN from this previous biosolids application – using the K<sub>m</sub> factor.

Solution: The solution is calculated in one step.

From Table 13.5: K<sub>m</sub> = 0.90 for the conditions given.

One Step Calculation: 5 dry tons / acre x 4.0% x 0.90 = 18 lbs/A N

This is the amount of Biosolids carry-over N available.

**Example 3: Crop-N Deficit Calculation**

Given: Planned crop = corn for grain.  
 Predominant soil in farm field = Allenwood.  
 Starter fertilizer use = 100 lb/A of MAP (11-52-0).  
 Additional conventional fertilizer = 100 lb/A of Urea (46-0-0).  
 Previous crop = soybeans with yield of 40 bu/A  
 Carry-over biosolids-N from application 2 years ago (See Example 2) = 18 lbs/A.

Find: Given the above information, what is the crop-N Deficit?

Solution: The solution is determined in two steps.

Step 1 - First Determine Crop-N Need:			<u>Reference</u>
Allenwood soil target yield	=	150 bu/A	(Table 13.1*)
Unit-N Fertilizer Rate	=	1 lb N/bu	(Table 13.2*)
Crop-N Fertilizer Rate	=	150 bu/A x 1.0 lb N/bu	(Eq. 13.1)
		= 150 lb N/A	

Step 2 - Add up All PAN sources:			
X	Manure-N	=	0
X	Residual legume-N	=	40 (Table 13.7*)
X	Starter fertilizer-N	=	11 (Table 13.6)
X	Principal N-containing chemical fertilizer(s)	=	46 (Table 13.6)
X	N-solution pesticide carriers	=	0 (Table 13.6)
X	Biosolids Org-N carry-over	=	18 (Example 2)
X	Other N sources	=	<u>0</u>
	Total PAN From Available Sources	=	<u>115 lb N/A</u>
Solution	Net Crop-N Deficit (CND)	=	<u>35 lb N/A</u>

**\* Note: These tables are used as an example only. Similar information is available for each state.**



## Chapter 14 – Environmental Considerations

---

Beneficial use programs must be managed in a manner that protects the food chain, enhances soil productivity, and maintains water quality. This chapter provides a brief overview of the environmental considerations relevant to biosolids recycling. A generalized description of the transformation and fate of biosolids constituents added to the soil is provided. Specific coverage is given to the four major categories:

- Nutrients
- Trace elements
- Pathogens
- Trace organic compounds

An understanding of the reactivity, mobility, and potential fate of these constituents is an essential cornerstone in proper regulation and management of land application programs. This information also allows individuals to address questions regarding beneficial use programs.

### 14.1 Critical Control Points / Operational Controls

The controls associated with environmental considerations include:

- The extent that biosolids constituents move from the soil to other environmental compartments.
- Impacts of biosolids application on water supplies and the food chain.
- Distribution of elements determines their behavior in the environment.

These serve as guiding principles for environmental management of beneficial use programs.

### 14.2 Possible Fates of Land-Applied Biosolids Constituents

When biosolids are land applied, they are incorporated into an extremely complex and dynamic system. In the soil, numerous chemical and biological reactions occur simultaneously. These processes modify and transform elements and compounds within the biosolids and within the soil. Some reactions will enhance the mobility and bioavailability of soil constituents, while other reactions have the opposite effect.

Once introduced to the soil environment, biosolids constituents can follow several distinct pathways. Their chemical form largely determines the predominant pathways that are followed. The distribution of an element among its various forms is called its *speciation*. Some general statements can be made regarding the major transformations of biosolids constituents but caution is warranted when extending them to specific situations.

In the natural soil environment, many substances degrade at the point of incorporation or are stored more or less permanently in the soil matrix. The chemical structure can be altered by chemical and biological reactions or radioactive decay. Some elements and compounds can be bound tightly through sorption, precipitation, or occlusion within soil minerals so as to be considered permanently immobilized. In this way we can think of the soil as a *sink*. Alternately,

we can consider the soil as a *filter*. Some elements and compounds, when applied to the soil surface, will migrate to other environmental compartments like the atmosphere, surface waters or groundwater aquifers, or into vegetation growing on the site. These materials may be transported to air, water, or vegetation largely unchanged or they may be degraded, or transformed prior to leaving the soil profile. With a few exceptions, little concern has been expressed over environmental impacts on soil organisms from land application of biosolids. Thus, environmental effects of beneficial use are of concern to the extent that biosolids constituents migrate from the soil into other media where exposure to humans or animals may occur or water quality is impaired. Because of the tremendous dilution capacity of the overlying atmosphere, air pollution effects from surface applied biosolids are minimal. Odors, of course, are an extremely important air quality issue and they are given detailed coverage elsewhere. This chapter focuses on the potential environmental impacts on animals, humans, crops, and aquatic systems. Each of the four major categories of biosolids constituents is discussed.

### **14.3 Nutrients in Biosolids-Amended Soils**

#### **14.3.1 Soil Fertility**

Understanding soil fertility is essential to biosolids recycling programs. Biosolids are a rich source of nitrogen, phosphorus and many secondary micronutrients. The nutrients in biosolids can increase crop growth. Similar to other fertilizers, if excess levels of certain nutrients are applied, they may be toxic to plants and limit crop yields.

Besides carbon (C), oxygen (O) and hydrogen (H) that come from photosynthesis, 13 nutrients are essential for healthy plant growth. The essential plant nutrients are summarized on Table 14.1.

**Table 14.1 Essential plant nutrients**

<b>Primary Nutrients</b>	<b>Secondary Nutrients</b>	<b>Micronutrients</b>
Nitrogen (N)	Sulfur (S)	Iron (Fe)
Phosphorus (P)	Magnesium (Mg)	Manganese (Mn)
Potassium (K)	Calcium (Ca)	Boron (B)
		Chlorine (Cl)
		Zinc (Zn)
		Copper (Cu)
		Molybdenum (Mo)

Source: *Agronomy Guide*, 1998.

Plants need three primary nutrients [nitrogen (N), phosphorus (P) and potassium (K)] in large amounts and shortages of these nutrients most often limit crop yields. Secondary nutrients [calcium (Ca), magnesium (Mg), and sulfur (S)] are needed in intermediate amounts and insufficient levels in the soil may also limit plant growth. Micronutrients [iron (Fe), manganese (Mn), boron (B), chlorine (Cl), zinc (Zn), copper (Cu), and

molybdenum (Mo)] are required in very small quantities. Deficiencies in these nutrients tend to be uncommon and associated with specific crops in certain localities. Optimum crop yields depend on optimum levels of available nutrients. There is a sufficiency range where the optimum amount of a nutrient is available for the crop. A nutrient is deficient when the soil supplies an insufficient amount in a water soluble, plant-available form. Plants may or may not exhibit visual symptoms of nutrient deficiencies (such as yellowed leaves), but they may still suffer reduced yields. For some nutrients, excess levels in the soil can reduce yields. A nutrient is said to be *phytotoxic* under these conditions. Diagnosing plant deficiencies and toxicities is difficult since specific symptoms can have a variety of causes. Moreover, the phytotoxicity of some elements only occurs when an imbalance or excess of another nutrient also exists.

Soil acidity plays a critical role in soil fertility as it affects uptake efficiency of virtually all plant nutrients. In many areas, modifying soil pH is essential in creating favorable conditions for crop growth. The leaching of basic components by the percolation of water through the soil profile largely determines soil acidity. In drier regions of the country, little water percolates through the soil and the large supply of bases results in near-neutral or alkaline soils. In areas of higher rainfall, the leaching of bases exceeds their release from the solid phase and soils tend to be acidic (have a lower pH). Under acidic conditions, some nutrients may be less available and other elements (like aluminum) can become phytotoxic. Thus, agricultural fields in many parts of the country are limed periodically. Conversely, highly alkaline soils may also reduce the plant availability of certain essential crop nutrients. If biosolids have been lime-stabilized, they can satisfy soil liming requirements. As with any liming materials, overly alkaline soil conditions should be avoided.

### **14.3.2 Nitrogen, Phosphorus, Potassium**

#### Nitrogen

Deficiencies in the primary nutrients (N, P, K) most often are responsible for limiting plant growth in agricultural systems and supplemental applications are usually required for optimum fertility. The ability of biosolids to supply these nutrients depends on the form, composition and treatment characteristics of the biosolids as well as a host of soil and climatic factors. The relative mobility of essential plant nutrients including N, P, K, is quite different.

The N-supplying ability of biosolids is the key agronomic benefit to the soil. Nitrogen is a dynamic element, continually being added, removed, and recycled between different soil compartments. Gains of soil N occur from the atmosphere (precipitation, atmospheric N fixation by bacteria) and materials deposited intentionally on the surface (biosolids, fertilizers). Losses occur through volatilization to the atmosphere, uptake by plants and movement off-site via erosion, runoff, and leaching.

Within the soil itself, N is exchanged among various forms by several processes. Soil microorganisms catalyze most of these reactions. Plants use inorganic (water-soluble) forms of N such as nitrates (NO<sub>3</sub>) and ammonia (NH<sub>3</sub>, NH<sub>4</sub><sup>+</sup>). When N is primarily bound in organic matter, as is the case for biosolids, conversion to inorganic forms

(mineralization) must occur before plants can use the N. Predicting the rate at which mineralization takes place in biosolids amended soil is a critical part of determining the appropriate application rate.

### Phosphorus

Phosphorus is a critical component in nucleic acid synthesis and biological energy transfer reactions and so is vital to crop growth. Phosphorus in soils can be divided into two broad categories: organic P and inorganic P. For both, there is a continuum of forms ranging from soluble P that is readily taken up by plants to stable, unavailable P that is strongly adsorbed or fixed within the soil matrix. Inorganic P is the dominant form in most soils and biosolids. In soils, P is often present in large amounts, but only a small fraction is in a form that can be used by plants. When inorganic P is added to soils, up to 90 percent can become fixed in stable, unavailable forms within the first few weeks (Sharpley and Beegle, 1999). Thus, the amount of P available to the plant is not necessarily correlated to the total soil P content.

The quantity of P required by plants is about one-tenth that of N. Therefore, when biosolids and manures are applied to satisfy the crop N requirement, the amount of P added exceeds that removed in normal crop production. Except for occasionally reducing uptake of some crop micronutrients, excess soil P does not adversely affect plant or animal health. The major environmental concern is that excess soil P will move from an application site to a water body, where the P can stimulate growth of aquatic plants (a process called *eutrophication*). Leaching of P is negligible in most soils except for heavily fertilized sands and peats that have little P-binding capacity. Controlling erosion at an application site will dramatically reduce off-site movement of P. Because P-based nutrient management may be mandated for land-applied materials, including biosolids, understanding the behavior of biosolids-P is the subject of much research.

### Potassium

Potassium (K) is an essential element in protein synthesis and photosynthesis and is absorbed by plants in greater amounts than any other nutrient except N. The forms of K in soils are usually divided on the basis of plant availability: (1) readily available, (2) slowly available, and (3) unavailable. Many soils have high total K but the amount readily available to plants is relatively small. When K is freshly added to the soil, it tends to be a soluble, readily available form. Soon after, it goes into a slowly available form. As crops remove the soluble, available K, the process is reversed and the slowly available K goes into solution.

Depending on the existing reserves of K in the soil, biosolids may or may not satisfy the needs of the crop. High available N coupled with inadequate K causes some hay and grain crops to lodge, a condition where the plant stalks are weakened and plant does not stand upright. This hinders efficient harvesting of the crop. Thus, because of the mismatch between crop requirements and nutrient content of organic residuals, it is sometimes necessary to use commercial fertilizers in conjunction with biosolids to provide a balanced supply of nutrients.

## 14.4 Trace Elements in Biosolids-Amended Soils

The earth's crust is comprised of metals and nonmetallic elements in varying proportions. Some of the most common and most important elements from an agricultural and environmental perspective are aluminum (Al), calcium (Ca), iron (Fe), magnesium (Mg), manganese (Mn), potassium (K), sodium (Na), chlorine (Cl), and sulfur (S). There are additional trace elements that comprise a large group of metals, nonmetals, and metalloids that normally exist at low levels in natural systems that can also cause beneficial or adverse health and environmental effects. Trace elements are arbitrarily defined as those that occur in a typical uncontaminated soil at concentrations less than about 0.02 percent ( $200 \text{ mg kg}^{-1}$  dry weight). Environmentally important soil trace elements include the metals: beryllium (Be), cadmium (Cd), copper (Cu), cobalt (Co), chromium (Cr), mercury (Hg), molybdenum (Mo), nickel (Ni), thallium (Tl), vanadium (V), uranium (U), lead (Pb), and zinc (Zn); metalloids such as arsenic (As) and antimony (Sb), and some nonmetals such as selenium (Se) and fluorine (F). The term *heavy metal* is sometimes used to refer to metallic elements having a density greater than about  $6 \text{ g cm}^{-3}$ .

Metals and trace elements exist naturally in soils due to the weathering of geological rock. Natural background levels of trace elements vary widely in soils. Even in the absence of human impacts, background levels may be high enough to limit crop yields, restrict biological activity, or contaminate water supplies. In contrast, cultivated soils may be deficient in certain plant-essential trace elements. For example, Cu and Zn are sometimes added to soils to maximize crop growth. Thus, it is important to understand the potential impact of soil trace elements from biosolids additions relative to levels existing naturally or added through other activities.

### 14.4.1 Trace Element Transformation Processes

Trace elements can be broadly divided into two categories based on their electrical charge. Cations carry a positive charge in the soil solution. Anions have an overall negative charge in the soil solution. The categories are not mutually exclusive. Some elements can fit into more than one category depending on soil conditions. For example, Cr can exist both as a cation,  $\text{Cr}^{3+}$ , and as an anion,  $\text{CrO}_4^{2-}$ . Elements that fall into the same electrical category tend to behave similarly in the soil.

From an environmental standpoint, cationic and anionic elements exhibit different mobilities, water solubilities and bioavailabilities due in part to the way they interact with the surfaces of soil particles. Most soil particles carry a net negative charge and attract positively charged cations. Anions, with their negative charge, are repelled and tend to remain in the soil solution. This is an important phenomenon because many potentially toxic elements exist predominantly as cations in soils. For example, cadmium is typically present in the cationic form ( $\text{Cd}^{2+}$ ) and hence it could be retained on the surface of soil particles. However, processes such as acid-base reactions, complexation, and oxidation-reduction may alter the electrical charge of trace elements, thereby influencing their distribution between the solid particle-bound phase and the solution phase.

Many trace elements that exist predominantly within the soil mineral phase are relatively inert and generally have little immediate environmental significance. However, if an element in this reservoir is mobilized by weathering reactions or an element is added to

the soil in a more mobile (soluble) form, it may then be available for incorporation into the soil biomass, plant uptake, leaching, or reactions with other soluble constituents or soil particle surfaces. Thus, environmentally significant processes like vegetative uptake and leaching to groundwater are largely depend on the levels of a trace element in the soil solution or weakly bound to soil particles.

As with nutrients, soil acidity, as measured by pH, has a profound influence on the bioavailability and leachability of trace elements. Soil reactions like adsorption and precipitation are strongly affected by the acidity of the soil. Lowering the soil pH, making it more acidic, generally causes the metals to be more soluble. This means that they are more mobile in the subsurface environment and more readily taken up by crops. Regulations for land application of biosolids often stipulate the soil pH at the time of application. Such regulations aim to ensure that potentially harmful trace elements are not present in forms that can be taken up by crops grown on the application site.

### **14.4.2 Soil-Plant Relationships**

A crucial objective of regulations governing use of biosolids on agricultural land is the prevention of food chain contamination by toxic elements. Elements can be divided into three groups in terms of their potential to be taken up by crops. Some elements (Ag, Au, Cr(III), F, Hg, Pb, Ti, Sn, Zr) are characterized by low water solubility or strong adsorption on soil surfaces that limits their potential movement to plant roots. Therefore many elements are not absorbed by plant root systems. Others in this group will bind strongly to roots tissue and are not translocated to aboveground, edible, plant parts. This prevents excessive levels in the foliage. Other elements such as (Cu, Ni, As, B, Zn) are phytotoxic to plants and do not normally enter the food chain since tissue concentrations lethal to plants are well below concentrations that would be harmful to humans, livestock, or wildlife.

The processes that limit potential food chain contamination are collectively called the “soil-plant barrier.” However, the soil-plant barrier does not exclude all potentially harmful elements from the food chain. Elements such as Cd, Mo, and Se are readily taken up by plants and could accumulate in edible crop tissues that are potentially harmful to humans or animals without causing any substantial reduction in crop quality or quantity. These elements are therefore addressed in biosolids regulations.

### **14.4.3 Trace Element Management in Biosolids**

To protect plant, animal and human health, regulatory limits and regular monitoring requirements are placed on nine metals and trace elements found in biosolids to ensure that repeated agronomic applications do not elevate soil concentrations to a level that would be of concern. These pollutants are: As, Cd, Cu, Pb, Hg, Mo, Ni, Se and Zn. The limits placed on most of these elements are to ensure that they do not build up to concentrations that could potentially harm human or animal health either through direct ingestion or through the food chain. However, the limits on Cu, Zn, and Ni are not based on health concerns but rather phytotoxic effects. The list of regulated metals is limited because other potential contaminants generally have not been found to occur in biosolids at levels that would be of concern.

## 14.5 Pathogens in Biosolids-Amended Soils

### 14.5.1 Sources and Types of Pathogens in Biosolids

Most microbes are benign or beneficial to mankind. A few, however, called pathogens, are capable of causing disease in humans, animals or crops. Raw wastewater may contain significant numbers of pathogens from infected individuals in the population served by the treatment facility. Some municipal wastewaters also include contributions from slaughterhouses or meat and poultry processing plants and thus potentially contain animal pathogens potentially infectious to humans. Although extremely important in agriculture, plant pathogens are not generally important in wastewaters or biosolids. A primary purpose of wastewater treatment is to remove pathogens before effluent is returned to surface waters. Biosolids destined for land application also undergo treatment to reduce pathogens. Some biosolids treatment processes like composting and heat drying, that inactivate virtually all pathogens, are used to produce biosolids that will be generally marketed and distributed without further regulatory controls. Treatment processes for biosolids used for agricultural land application programs significantly reduce, but do not totally eliminate pathogens. Thus, land-applied biosolids normally contain some organisms potentially capable of transmitting disease to animals or humans and are, therefore, managed accordingly.

Pathogens associated with biosolids-amended soils typically fall into four major groups:

- Bacteria
- Viruses
- Protozoa
- Helminths.

Fungal pathogens could be included but they do not generally exhibit the same degree of pathogenicity to humans and animals. Fungi are secondary or opportunistic agents of disease, causing hypersensitivity or infection in individuals weakened by other diseases. Table 14.2 lists some pathogens of concern in biosolids. Individual sources of wastewater and, therefore, biosolids, may or may not contain specific pathogens depending on the prevalence of disease in the general population.

Disease outbreaks associated with discharges of raw sewage have predominantly been caused bacterial organisms. Two of the most common types of pathogenic bacteria detected in wastewater are *Salmonella* and *Shigella*. Viruses are extremely small and include a wide spectrum of organisms responsible for a host of human and animal diseases, including gastrointestinal illnesses and other diseases such as hepatitis.

Protozoa and helminths are grouped together as “parasites”. Protozoa are single-celled organisms like bacteria and include the organisms like responsible for giardiasis and amebic dysentery. Helminths are invertebrates that include roundworms and tapeworms. Studies have shown that the eggs (ova) of helminths and the encysted (dormant) life-stage of protozoa can survive wastewater and biosolids treatment processes. The potential presence of these organisms once again depends on their prevalence in the general population and the

type of biosolids stabilization performed. Physically, parasite ova are significantly larger in size than bacteria or viruses and therefore unlikely to find their way to groundwater

**Table 14.2 Pathogens potentially found in biosolids**

Type of Organism	Pathogen	Disease
Bacteria	Salmonella	salmonellosis
	Shigella	dysentery
	Escherichia coli	gastroenteritis
	Leptospira	leptospirosis
Viruses	Enteroviruses	gastroenteritis, polio
	Adenoviruses	acute respiratory disease
	Hepatitis virus	hepatitis
Protozoa	Toxoplasma	toxoplasmosis
	Giardia	giardiasis
Helminths	Ascaris	ascariasis
	Toxacara	visceral larval migrans
	Taenia	cysticercosis
	Trichuris	trichuriasis

Source: Baker, *et al*, 1985

### 14.5.2 Pathogen Risk

Three conditions are necessary to produce infectious disease:

- The disease agent must be present in sufficient concentrations to be infectious,
- Susceptible individuals must come into contact with the agent in a manner that causes infection, and
- The agent must be able to breach the physical and immunological barriers of the individual.

Biosolids regulations are designed to address the first two of these factors by a combination of treatment and site management practices. Many pathogens do not survive the wastewater treatment process. Biosolids produced during the treatment process undergo stabilization to reduce pathogens.

### 14.5.3 Persistence of Soil Pathogens

The survival of pathogens in soils treated with biosolids depends on factors such as climate, soil properties, and the characteristics of the organism. Fortunately, soil and climatic factors make the land a hostile environment for most pathogens. Pathogens typically live in the intestinal tract of the infected individual where environmental conditions are drastically different than the soil. In the soil, desiccation, exposure to ultraviolet light, extremes of temperature, unfavorable pH or nutrient conditions, and predation by other microbes lead to pathogen die-off. Most pathogens in the soil die within a few days after biosolids are applied. Table 14.3 gives the maximum survival



time for pathogens in the soil. Pathogens that are deposited on plant surfaces or on top of the soil are deactivated more quickly because they are exposed to sunlight and desiccation. Bacteria as a group do not have long survival times in the soil. Research on viruses indicates that soil temperatures and moisture content are the two most important factors influencing their survival. Hot, dry soil conditions lead to the most rapid die-off, while cold, wet soils slow the process.

**Table 14.3 Reported pathogen survival times in soil\***

Organism	Survival Time on Plant Surface		Survival Time in Soil	
	Maximum	Common	Maximum	Common
BACTERIA	6 Months	1 Month	1 Year	2 Months
VIRUSES	2 Months	1 Month	1 Year	3 Months
PROTOZOA	5 Days	2 Days	10 Days	2 Days
HELMINTHS	5 Months	1 Month	7 Years	2 Years

\* Source: USEPA, October 1999

Some species have special adaptive features that allow them to withstand unfavorable soil conditions. Studies have shown that helminth eggs or protozoan cysts can remain viable and infective for up to several years. Despite the potential persistence of some organisms, there is no evidence to show that properly managed biosolids application programs have caused an increase in disease incidence (Kowal, 1983).

#### 14.5.4 Pathways of Exposure

Surface and Groundwater Contamination Pathogens from organic wastes deposited on the soil can potentially be transported to surface water resources. For land-applied biosolids, several factors reduce the likelihood of transport:

- Biosolids are treated to significantly reduce pathogen levels
- Restrictions on land application programs reduce the potential for runoff to reach water resources except during extreme precipitation events
- Pathogens present in land-applied residuals are immediately subjected to sunlight and other environmental conditions that reduce their viability.

For these reasons, the risks posed by land-applied biosolids are minimal, especially when compared to other potential pathogen sources such as direct surface water discharge of wastewater effluents or stormwater runoff.

Another concern is the potential transport of pathogens in water percolating through the soil to groundwater and wells. Parasites are large enough that physical straining and adsorption in the soil matrix effectively remove them. Smaller microbes, like bacteria and viruses, generally adsorb to the surfaces of soil particles, but can potentially infiltrate through the soil. Studies show that bacteria are normally removed within the top few inches of soil. Under certain environmental conditions, viruses may migrate several meters through the soil profiles. While water generally moves slowly between soil

particles, it may also move more rapidly through large cracks, worm holes, or root channels where opportunities for adherence to soil colloids are less (short circuiting). To provide protection, land application programs must observe buffers between application sites and wells. This physical barrier reduces the potential that pathogens will reach a well and, since ground water movement is a relatively slow process, it provides time for the physical and chemical conditions of the soil to destroy any pathogens. In addition, to minimize short-circuiting, buffers are required around sinkholes. While the potential movement of pathogens in biosolids to ground water is an issue of potential concern, no studies have linked this phenomenon to disease incidence under current regulatory requirements.

### Aerosol Transport

There is a possibility that individuals living around biosolids application sites might be exposed to microbial pathogens via aerosols, or small droplets of water. Dowd et al (2000) recently investigated the concentration of aerosols downwind of areas undergoing land-spreading operations. They concluded that the risk of viral or bacterial infection is quite small under realistic conditions, particularly for populations greater than 10,000 m away.

### Crop Contamination

The major human exposure route of concern for pathogens is through consumption of root crops and low-growing crops that might be eaten with little or no processing (washing or cooking). The potential risk is much lower when the edible portion of the crop does not come into contact with the soil, e.g., grains and orchard crops. When biosolids are sprayed or broadcast over a vegetated surface, direct foliar contamination by pathogens can occur. Although pathogen survival may be extended in leaf folds and cracks, desiccation and sunlight will hasten die off. To protect against this risk, biosolids regulations impose waiting periods on the harvesting of specific crops after biosolids application to allow adequate time for pathogen die-off.

### Infection of Grazing Animals

Because grazing animals ingest soil along with vegetation, soil-borne pathogens can be consumed directly by animals. The greatest threat to cattle grazing at land application sites is infection by tapeworms. Increased incidence of tapeworm infections has been documented when pastures are treated with biosolids. Because of the longevity of helminth eggs in soils, pretreatment of biosolids to inactive helminths is important in reducing risk to grazing animals. Restrictions that prohibit grazing of animals for 30 days or more following biosolids application are also effective.

## **14.6 Trace Organic Chemicals in Biosolids-Amended Soils**

### **14.6.1 Sources and Types of Trace Organic Chemicals**

The production and use of synthetic organic chemicals as pesticides, solvents, dyes, and plasticizers have increased dramatically over the past few decades. Thousands of trace organic compounds are used today. Since synthetic organic compounds are widely used in homes and businesses, it is inevitable that many of these compounds are detectable in

domestic and industrial wastewater and biosolids. These compounds are then soil incorporated during biosolids application. Trace organics also can be deposited on soils naturally in rainfall or deliberately through pesticide application, fertilizer and manure applications and other human activities.

Compounds of environmental concern can be grouped into major categories based on similarities in chemical structure, environmental behavior, and potential health effects. Environmentally important organic compounds are presented in Table 14.4

**Table 14.4 Environmentally important organic compounds**

Type	Source/Use	Examples	Bio-degradability	Relative Threat to Environment/Human Health
Hydrocarbons	Petroleum Products	Lubricants, crude oil	Moderate	Low
Substituted benzenes	Solvents, Wood preservatives, cleaning agents	Pentachloro-phenol	Low	Moderate
Polycyclic aromatic hydrocarbons (PAHs)	Burning of fossil fuels	Benzo(a)pyrene	Low	High
Dioxins and furans	Contaminants in pesticides	TCDD	Very Low	High
Biphenyls	Contaminants in pesticides	PCBs	Very Low	High
Pesticides	Herbicides, insecticides, fungicides	2,4,5-T, 2,4-D, carbamates	Variable	Moderate - High
Phthalic acid esters	Plasticizers	Bis (2ethylhexyl) phthalate	Moderate	Moderate
Surfactants	Detergents	Sodium stearate	Moderate	Moderate
Halogenated aliphatics	Solvents	TCE	Low	Moderate

**14.6.2 Trace Organics in Biosolids**

National surveys have found that the concentrations of toxic organic compounds in biosolids are low. Stringent industrial pretreatment programs prevent significant levels of organic compounds from entering wastewater in larger communities. In addition, many organic compounds entering a treatment facility are removed or destroyed during wastewater treatment. For instance, aeration removes certain organic compounds by evaporation, and natural biological decomposition destroys others. While many of these compounds can be detected in biosolids, they are generally present as minor constituents, and as action is taken to reduce their production and use, levels of organic contaminants in biosolids are expected to decline. Because of the low levels in biosolids, application has a minor impact on the soil concentrations of priority pollutants like PAHs, PCBs, dioxins, and chlorinated hydrocarbons (Smith, 1996).

### 14.6.3 Transformation and Exposure Pathways

Trace organic compounds can undergo a variety of transformations that influence their environmental behavior and ultimate fate. The extent of this influence depends on many factors including the compound properties, soil characteristics, and climatic factors. From basic information about compound properties, some general observations can be made regarding the relative importance of various transport pathways. One feature distinguishes organic contaminants from trace elements. Many trace elements remain in the soil for extremely long times. Organics are, however, unstable and will be decomposed to simpler, usually less toxic, products. While the structure of the trace organics can make them very persistent in the soil, eventually they will be degraded.

Unlike most trace elements, organic compounds can volatilize, or evaporate, directly to the air. The volatilization potential is expressed by the vapor pressure of a compound. A large vapor pressure means the compound has a strong tendency to be released to the atmosphere. Warmer soil temperatures and surface application of biosolids without incorporation promote compound volatilization. Loss of toxic organic compounds through volatilization is unlikely to pose a significant health risk (Kowal, 1983).

Leaching and runoff are hydraulic processes that can transport trace organics from the site of application. Hydraulic transport is affected by many factors, but the water solubility of the compounds is of overriding importance. Chemicals that tend to be soluble in the water phase will be hydraulically transported. Compounds that are largely insoluble in water (and conversely, soluble in organic solvents) will have a high affinity for soil components, particularly soil organic matter. Research suggests there is little risk of organic contaminants in biosolids being transferred to groundwater supplies (Smith, 1996).

Biodegradation by soil microorganisms plays a key role in the fate of trace organics in soils. For many water-insoluble compounds of low vapor pressure, biodegradation controls behavior in the soil. Susceptibility to biodegradation depends strongly on compound structure. Generally, the more chlorinated and the more aromatic a compound is, the more slowly microorganisms will degrade it.

When all of the mechanisms responsible for removing a compound from the soil are considered together, we can define the half-life of the compound under a given set of conditions. The half-life is the time required to reduce the concentration of the compound by one-half. The half-life of trace organics in soils range from a few days for water soluble, volatile pesticides, to 10-15 years for highly chlorinated aromatic compounds like PAHs and PCBs. But since the concentrations of trace organic compounds are low in biosolids and they are placed into an environment where they are eventually degraded, potential impacts from trace levels of these compounds have not been shown to be significant.

The uptake of trace organic contaminants by plants from biosolids-treated soils has been the exposure pathway most studied. The general conclusion is that contamination of aboveground portions of plants at land application sites will occur only to a very limited

extent (Kowal, 1983; Smith, 1996). Application of biosolids to root crops like carrots is probably the worst-case scenario because trace organics can be partitioned from the soil to the lipid-rich peel. Because application to vegetable crops is not a recommended practice, and the peel is normally removed, this is not a common exposure pathway. It is unlikely that biosolids recycling will be limited in practice by the content of PCBs and most other trace organic contaminants (Smith, 1996). The USEPA is currently debating the dioxin standard for biosolids, so the practical implications of a dioxin regulation are yet to be determined.

### 14.7 Conclusions

The soil is an ideal repository for biosolids, not only because it allows the nutrients to be beneficially recycled, but because the potentially harmful constituents can be effectively degraded, detoxified, or stored in the soil profile. An understanding of the reactivity and mobility of biosolids constituents in soil systems is essential for maintaining soil productivity, protecting the food chain, and maintaining water quality. These issues have been intensively investigated. A wealth of research suggests that potential health and environmental risks associated with land application of biosolids can be minimized or abated with proper planning, management, and monitoring of the various system components. With increased understanding of the reactions and fate of constituents in the soil environment, we are better able to maximize the benefits and minimize the risk associated with the use of biosolids.

## References

Baker, D.E. et al, (1985), "*Criteria and Recommendations for Land Application of Sludges in the Northeast*", Bull 851, Penn Agr. Experiment Station. University Park, PA

Dowd, S.E., Gerba, C.P., Pepper, I.L. and Pillai, S.D., (2000), "*Bioaerosol transport modeling and risk assessment in relation to biosolids placement*", J. Environ. Qual. 29:343-348

Kowal, N.E, (1983), "*An Overview of Public Health Effects*", In A.L. Page, et al (Eds), *Utilization of Municipal Wastewater and Sludge on Land*, Univ. of Calif., Riverside, CA.

Pennsylvania State University, (1998), *Agronomy Guide* Pennsylvania State University, College of Agricultural Sciences, University Park, PA

Sharpley, A.N. and Beegle, D., (1999), "*Managing phosphorus for agriculture and the environment*", Cooperative Extension Service, Pennsylvania State University. University Park, PA.

Smith, S.R, (1996), "*Agricultural recycling of sewage sludge and the environment.*" CAB International, Wallingford, UK.

United States Environmental Protection Agency, (1999), "*Control of Pathogens and Vector Attraction in Sewage Sludge,*" (USEPA/625/R-92/013)

## Chapter 15 - Biosolids Incineration Systems

Incineration has been used as a wastewater residuals management process since 1936. Incineration is an environmentally sound and cost effective means of biosolids management at a number of small, medium and large wastewater treatment facilities. Recent advances in dewatering ash management and air pollution control technologies have increased the efficiency and benefits associated with incineration.

There are a number of advantages associated with incineration. The volume and weight of the biosolids are significantly reduced. Because biosolids incineration requires a relatively small land area, biosolids can often be incinerated on-site without having to be transported to distant locations. Air quality can be maintained by controlling air discharges. Pathogens cannot survive the process.

These advantages have resulted in the construction of new incinerators. USEPA consultant, Pacific Environmental Services found that at 24 new incinerators were built between 1993 and 1997.

The purpose of this chapter is to identify alternative types of incineration systems as well as ancillary systems such as emission controls or wasteheat recovery systems. The major types of incinerators are identified and described. The operational controls that should be considered when selecting the type of incinerator and/or ancillary systems to implement are also discussed. There are two primary technologies used to incinerate biosolids, Multiple Hearth Furnaces (MHF) and Fluidized Bed Incinerators (FBI). The operation of a MHF involves a two step process consisting of drying and then combustion. In a FBI, water flashes off and the biosolids burns in one process.

Drying, as used in this context, should not be confused with the mechanical dewatering step that precedes incineration. Drying consists of raising the temperature of the solid/liquid matrix to 212 F to drive off liquid. The temperature of the remaining solid material is then raised to the ignition point. Two major types of incinerators are in use in the United States: the MHF and the FBI. A third type, electric arc has had limited application.

**Table 15.1**

Multiple Hearth Furnace (MHF)	197
Fluidized Bed Incinerator (FBI)	55
Electric Arc (EA)	2

Source: R. Dominak, 2001

### 15.1 Multiple Hearth Furnace

The Multiple Hearth Furnace (MHF) is the most widely used type of incinerator in the United States. Early installations were at Dearborn, Michigan, in 1934; Minneapolis-St. Paul,

Minnesota, 1938; and Cleveland, Ohio, 1941. MHFs are durable, and relatively simple to operate. However, they have difficulty to handle fluctuations in feed characteristics.

A sectional view of a MHF is presented as Figure 15.1. MHFs consist of a vertically oriented, cylindrically shaped, refractory-lined steel shell containing a series of horizontal refractory brick hearths, one above the other. MHFs are available with diameters ranging from 4.5 to 29 ft and can have from 4 to 14 hearths. For biosolids combustion, MHF's usually contain no more than eight hearths.

A central shaft extends from the bottom of the furnace to the top and supports rabble arms above each hearth. There are either two or four rabble arms per hearth. Each arm contains several rabble teeth, or plows, which rake the biosolids across the hearth in a spiral pattern. Biosolids are fed at the periphery or center of furnace depending on top hearth configuration. If the top hearth is an "in" hearth, the feed is at the periphery, if the top hearth is an "out" hearth, the feed is near the center. The top of the hearth and rabbled across toward the opening in the hearth, where they drop to the hearth below. On the second hearth, the solids are rabbled across the hearth to the holes at the other side of the hearth. Here the biosolids drop to the next hearth. The alternating drop hole locations on each hearth and the countercurrent flow of rising exhaust gases and descending biosolids provide contact between the hot combustion gases and the solids. Good contact ensures effective drying and complete combustion.

The central shaft of the furnace is a hollow cast steel column. Shaft speeds are usually adjustable from about 0.3 to 3.0 rpm. The hollow rabble arms are inserted into machined arm sockets in the center of the shaft. Air lances extend from the cold air tube out to the ends of each rabble. A blower forces ambient air through the cold air tube and lances. The cold air exits from the tips of the lances, flowing inward through the space between the lances and the rabble arm shell to the annular space in the central shaft. This flow of air cools the arms. The heated air is either discharged into the atmosphere via the exhaust gas stack or returned to the bottom hearth of the furnace, or both if only part of this heated air is needed for combustion. It may also be used for building heat as its temperature is typically 350° to 450°F.



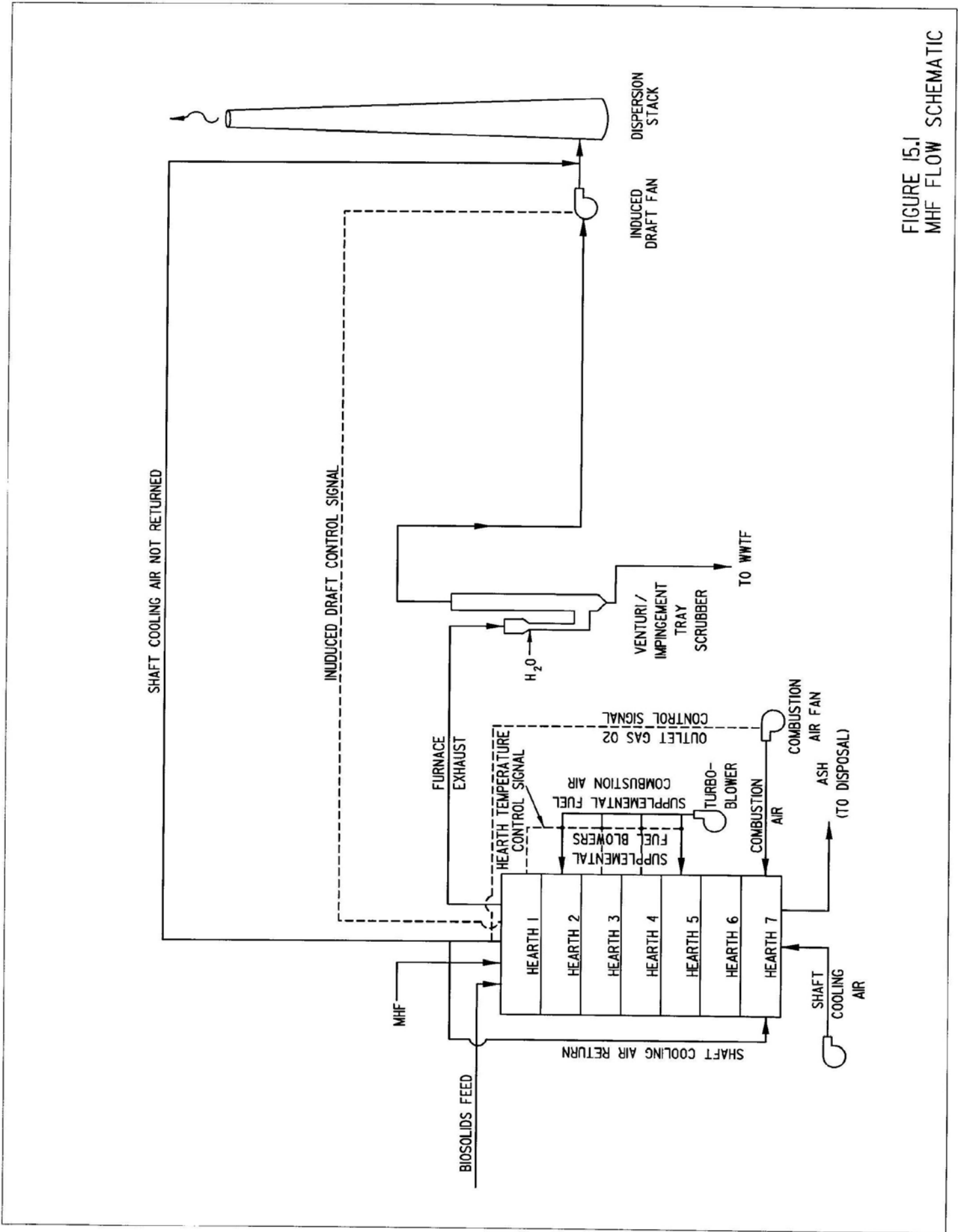


FIGURE 15.J  
MHF FLOW SCHEMATIC

MHFs can be divided into four zones. The first, which consists of the upper hearths, is the drying zone. Most of the water is evaporated in the drying zone. The second, generally consisting of the central hearths, is the combustion zone. In this zone, the majority of combustibles are burned, and the temperature reaches 1,400° to 1,700°F. The third, is the fixed carbon burning zone, where the remaining carbon is oxidized into carbon dioxide. The fourth, includes the lowest hearths and is the cooling zone, where ash is cooled by the incoming combustion air. The sequence of these zones is always the same, but the number of hearths in each zone is dependent on the quality of the feed, the design of the furnace, and the operational conditions. The zone transition often occurs partway across the hearth.

Autogenous combustion occurs when the heating value of solids is sufficient to dry and ignite the material. When the heating value of the solids is insufficient to sustain autogenous combustion, the additional heat required is supplied by firing supplemental fuel in burners located at various points in the furnace wall. Burners may operate either continuously or intermittently and on any selected hearths. (USEPA 1979)

### 15.2 Fluidized Bed Incinerator

Fluidized Bed Incinerators (FBI) are a vertically oriented, cylindrically shaped, refractory-lined steel shell that contain a sand bed and fluidized air diffusers called tuyeres. Experience and hardware developed by FBI manufacturers in the metallurgical and chemical industries have been applied in the combustion of biosolids. The FBI is normally available in sizes from 9 to 34 ft in diameter. The sand bed in a FBI is approximately 3.5' ft thick and sits on a refractory-lined or metal grid. This grid contains tuyeres through which air is injected into the furnace at a pressure of 3 to 5 psig to fluidize the bed. The bed expands to approximately 200 percent of its at-rest volume. The temperature of the bed is controlled between 1,400° and 1,500°F by injecting fuel into the sand bed. In some installations, a water spray system in the bed is used to control the furnace temperature.

A sectional view of a FBI is presented as Figure 15.2. The incinerator is a single chamber unit in which both drying and combustion occur in a fluidized sand bed. The residence time within the combustion zone is several seconds at 1,400° to 1,500°F. Ash is carried out the top of the furnace and is removed by air pollution control devices, usually Venturi/Impingement Tray scrubbers. Sand carried out with the ash must be replaced. Sand losses are typically 5 percent of the bed volume for every 300 hours of operation. Feed to the furnace is introduced either above or directly into the bed.

Airflow in the furnace is determined by several factors. Fluidizing and combustion air must be sufficient to expand the bed to a proper density yet low enough to prevent the biosolids from rising to and floating on top of the bed. Too much air blows sand and products of incomplete combustion into the off-gases. This depletes the stored heat energy and increases fuel consumption unnecessarily. Minimum oxygen requirements must be met to assure complete oxidation of all combustible biosolids. Temperatures must be sufficiently high to assure complete deodorizing but low enough to protect the refractory, heat exchanger, and flue gas ducting and to prevent slag formation.

The quantity of excess air is maintained in the range of 20 to 45 percent of the quantity required for combustion to minimize fuel cost. FBIs operate at much lower excess air rates than typical MHF operations. This results in a greater heat efficiency of the fluidized-bed system at similar exit temperatures.

There are two basic process configurations for the FBI. In one design, the fluidizing air passes through a heat exchanger, or recuperator, prior to injection into the combustion chamber. This arrangement is known as a hot windbox (HWB) design. In the other design, the fluidizing air is injected directly into the furnace. This arrangement is known as the cold windbox (CWB) design. The first arrangement increases the thermal efficiency of the process by using the exhaust gases to preheat the incoming combustion air but adds substantial capital costs.

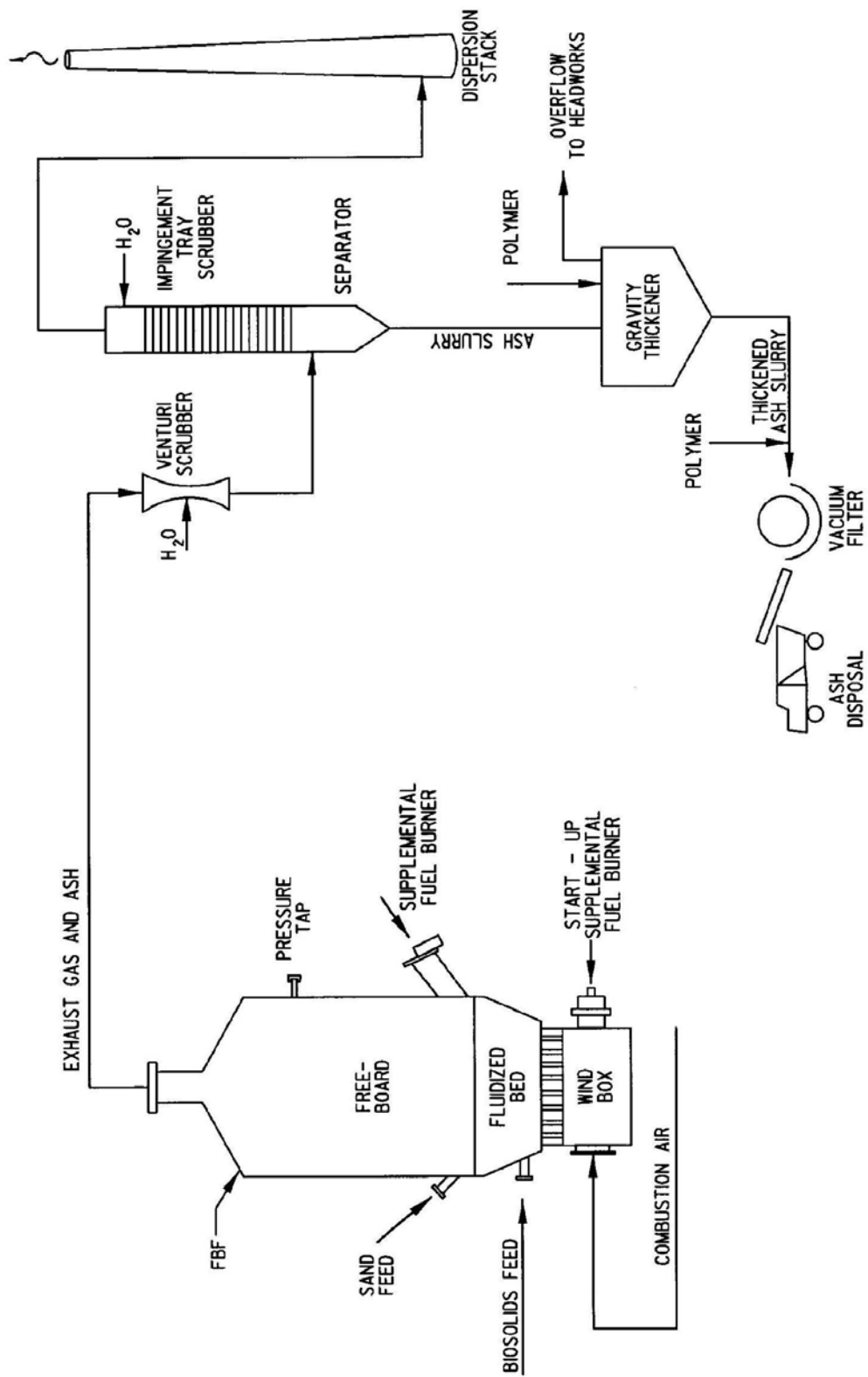


FIGURE 15.2  
FBI FLOW SCHEMATIC

Mixing in the fluidized bed assures rapid and uniform distribution of fuel and air and consequently good heat transfer and combustion. The bed itself provides substantial heat capacity, which helps to reduce short-term temperature fluctuations that may result from varying feed heating values. This heat storage capacity also enables quicker startup, if the shutdown period has been short. Organic particles remain in the sand bed until they are reduced to mineral ash. The mixing of the bed comminutes the ash material, minimizing the buildup of clinkers. The resulting fine ash is constantly stripped from the bed by the upflowing gases.

The FBI is relatively simple to operate, has a minimum of mechanical components, and typically has a slightly lower capital cost than the MHF. Experience indicates that although the capital cost for the fluid bed incinerators may be slightly lower than the multiple hearth furnaces, the cost of ash system, which requires thickening and dewatering, results in comparable capital costs. Normal operation of the FBI results in exhaust temperatures in excess of 1,400°F. Because the exhaust gases are exposed to this temperature for several seconds, odors and carbonyl and unburned hydrocarbon emissions are minimal. This results in the ability to meet hydrocarbon emission regulations without the use of an afterburner.

### 15.3 Critical Control Points / Operational Controls

The previous sections described the major options available to incinerate biosolids and other wastewater treatment residuals. Selection and design of the system that best meets the needs of an agency is dependent on many factors. The relative importance of each of these factors will vary. For example, being able to accommodate short term shut downs may be important at one location while accommodating fluctuations in feed biosolids characteristics may be the driving factor at another location.

This section identifies and discusses some of the controls that should be considered in selecting, implementing and operating a biosolids incinerator. The list is not exhaustive. Entities considering a biosolids incinerator should develop qualified teams to identify and evaluate site specific control points. This may be accomplished by retaining the services of experienced consultants, obtaining information from incinerator manufacturers, and conducting site visits and interviews with operators of incinerators throughout the country.

The controls discussed included:

- Operating Schedule
- Moisture Content
- Conditioning Agents
- Metals Concentration
- Grit, Screenings And Scum
- Energy Content
- Supplemental Energy Requirements
- Ash Management
- Emission Controls

#### *Operating Schedule*

The operating schedule of the wastewater treatment facility and solids handling train must be

considered when selecting any biosolids management technology. The operating schedule becomes particularly important when incineration is being considered. All thermal processes are best suited to continuous operation.

MHFs require long operating periods and are typically shut down only when maintenance or repair is needed. Startup fuel requirements and the extended time needed to bring the hearths and internal equipment in an MHF up to temperature make intermittent operations impractical. Generally the temperature is maintained at “hot standby”, usually 427°C (800°F), during loading stoppages of up to a few days.

FBI's are better suited to short term shutdowns because the hot bed acts as a thermal reservoir. This allows for relatively quick start-ups following one or two days of down time. Significantly longer periods are required for start-up once the bed has cooled down.

The decision to implement incineration is often coupled with a commitment to staff the facility 24 hours per day, seven days per week. Fluidized bed incinerators do have the ability to be operated in an intermittent basis. Consideration must be given to biosolids management train operating schedules if adequate cake storage is not available to permit continuous operation of the incinerator with intermittent operation of the dewatering equipment.

### *Moisture Content*

Moisture content of the biosolids is one of the key characteristics that impacts the capacity of the incinerator and the demand for supplemental fuel. Traditionally, combined primary and waste activated solids are dewatered to between 16 and 30 percent solids using technologies such as centrifuges and belt filter presses. Dewatering to this solids concentration means that for every pound of solids to be incinerated, there are 3 to 5.25 pounds of water that must be evaporated. Incineration is most fuel efficient when the solids burn autogenously, without the need for supplemental fuel for combustion. This usually occurs when the solids concentration of the cake entering the unit is greater than about 28 percent.

A thermal dryer can be used to further dewater the biosolids. Biosolids dryers can produce a product with a sufficient solids concentration to burn autogenously. Recently, conductive, or indirect, dryers have been used to enhance incineration. The indirect dryers transfer heat to the biosolids by conduction through a metallic surface. The surface may be the wall of the dryer, hollow screws, paddles or disks. The interior of the heat transfer surface is usually heated with hot oil or steam. Because the heating medium is not in direct contact with the biosolids, there is a lower volume of off-gases to treat when compared with direct drying.

The Buffalo Sewer Authority has used an indirect dryer to successfully “scalp” a portion of their dewatered solids as they are transferred from the dewatering equipment to the MHFs. The dryer increases a portion of the solids from between 18 and 20 percent solids to approximately 40 percent solids. This increase has made a significant impact on the operation of their incinerators, increasing capacity on a dry weight basis and reducing the amount of supplemental fuel required. While reducing the overall fuel requirement, the authority has found the indirect dryer to be a high maintenance piece of equipment.

The energy savings realized by increasing the solids concentration above the traditional range must be carefully weighed against the extra costs incurred in the dewatering and thermal drying processes and the materials handling problems that are often associated with very dry biosolids. The handling and storage of dried biosolids can result in dust and explosion potential.

### *Conditioning Agents*

The choice of conditioning agents for wastewater treatment and biosolids thickening and dewatering operations can have a very large impact on the operation of the incinerator. Inorganic chemicals such as aluminum salts, iron salts and lime are often used in both the liquid treatment and solids management trains at wastewater treatment facilities. These chemicals can increase the weight of the dewatered cake that requires disposal by 20 to 50 percent or more when compared with organic conditioning agents such as polymer. This means that additional heat is required to raise the temperature of the mass to combustion temperature. In addition, the quantity of ash requiring disposal may be increased by 50 to 150 percent when compared with facilities that rely primarily on organic conditioning agents. The use of polymers to enhance dewatering, results in a drier cake without the addition of solids.

*The problem of slagging and clinker formation has been found in biosolids incinerators burning cake dewatered through processes that incorporate either polymer or thermal conditioning.*

A significant problem facing incinerator operators that is related, at least in part, to conditioning agents is ash fusion that results in formation of glassy slag or porous agglomerates called clinkers. Slagging is caused by the low melting point compounds of sodium, potassium, and phosphorous in biosolids. Lime in biosolids increases the melting temperature of these compounds. Therefore, switching from lime conditioning to polymer or thermal-conditioning increases the slagging potential. The

polymers or thermal-conditioning are not the cause for slagging, but the absence of lime.

### *Metals Concentration*

Subpart E of the 40CFR Part 503 Rule establishes maximum limits for five metals that must not be exceeded, on an annual, quarterly, bi-monthly or monthly average basis. The regulated metals are arsenic, cadmium, chromium, lead and nickel, in biosolids to be incinerated. The regulated metals are arsenic, beryllium, cadmium, chromium, lead, mercury and nickel. The numerical limit for each metal is calculated for each incinerator based on a number of factors such as:

- Regulatory limits such as the National Emission Standard for Hazardous Air Pollutants (NESHAPs 40 CFR Part 61) and National Ambient Air Quality Standards.
- The dispersion characteristics of a given incinerator and site.
- Existing ground level ambient air concentrations of some of the metals such as arsenic and cadmium.
- Certain characteristics of the incinerator itself such as the type (MHF or FBI) and the control efficiency of the incinerator.
- The type of emission controls used.

Additional information may be found in “A Plain English Guide to the USEPA Part 503 Biosolids Rule” (USEPA/832/R-93/003, 1994). The permitting authority should be contacted for more detailed information on establishing numerical limits for the seven regulated metals in the

feed biosolids for an incinerator.

*Grit, Screenings and Scum*

When selecting the primary means of biosolids management, it is important to plan for the disposal of other residuals generated by the wastewater treatment process. Incinerators sometimes process grit, screenings and scum, however, each material presents unique challenges as summarized below:

- Grit often contains fairly large quantities of organics and is relatively dry, making it acceptable for incineration if other means of disposal are not available. The extremely abrasive nature of grit can cause erosion of incinerators and associated conveyance systems.
- Screenings tend to clog feed mechanisms and should be preprocessed before incineration. Preprocessing may consist of sorting to remove large inorganic objects and shredding to reduce particle size.
- Scum and grease are very difficult to handle because of their adhesive properties; however, they have a very high heating value. In addition to materials handling problems, scum can cause hot spots in the incinerator and damage refractory linings.

Because these materials are generated separately, it may be preferable to manage them separately. In some cases, they can be blended with feed biosolids and disposed of in an incinerator with few problems. Generally, FBIs can accommodate these materials better than MHFs because the fluidized bed provides better contact with combustion air.

*Feed Energy Content*

The amount of heat released from a given biosolids is a function of the amount and type of combustible elements present. In most biosolids, the primary combustible elements are carbon and hydrogen. Biosolids with a high fraction of combustible material, such as grease and scum, have a high fuel value. Those that contain a high fraction of inert material, such as chemical precipitants, have low fuel value. Table 15.2 presents typical heating values for biosolids and other material that may be incinerated with biosolids.

**Table 15.2 - Typical Heating Values of Wastewater Treatment**

<b>Residuals Material</b>	<b>Heating Value (Btu per pound of dry solids)</b>
Fine Screenings	9,000
Grit	4,000
Grease and Scum	16,700
Dewatered Raw Biosolids	10,300
Chemical Precipitated Biosolids	7,500
Dewatered Digested Biosolids	5,300

Accurate estimates of the energy content of biosolids and other residuals that will be fed to the incinerator are essential to the economic evaluations that should be conducted as part of any incinerator feasibility analysis as well as to the final design of the incinerator. Average energy contents, such as those presented in Table 15.2, should not be reused upon. Extensive sampling



and analysis must be conducted at times that represent the changing conditions that are often present at municipal wastewater treatment facilities. Annual operational changes that should be considered when developing a sampling program include, but are not limited to, seasonal nitrification and/or denitrification requirements, phosphorus removal requirements and variations in grit content.

Once a sampling and analysis program is complete, the average, minimum and maximum heating value of the wastewater residuals to be incinerated can be estimated using accepted formulas and/or bomb calorimeters.

*Supplemental Energy Requirements*

Economics dictates that the materials to be incinerated must have sufficient fuel value to be the primary fuel for combustion. Typically, about 70 percent of the heat required for biosolids incineration comes from the biosolids and 30 percent must be supplied by the auxiliary fuel and/or combustion air. This ratio varies greatly with the water and volatile solids content of the biosolids. That is why accurate assessment of the feed material energy content is so important. In most cases, biosolids will not contain all of the energy required to bring the incinerator up to operating temperature or to maintain combustion, therefore, a reliable source of auxiliary fuel must be available. A number of supplemental fuel sources are available. Common fuel sources are presented in Table 15.3

**Table 15.3 – Typical Auxiliary Fuel Sources**

<b>Source</b>	<b>Comment</b>
<b>Natural gas</b>	Normally the lowest cost fuel
<b>Fuel oil</b>	More expensive than natural gas
<b>Air</b>	Hot air from the MHF shaft cooling system exhaust; preheated air from the fluidized-bed windowbox
<b>Scum</b>	Requires a special concentrator for waste removal and a metering pump for controlled feeding
<b>Coal</b>	Requires dustproof construction within the plant for handling; must use gas or oil for MHF temperature control

Natural gas is the auxiliary fuel of choice for most MHF operators. Experience has shown that there is less maintenance associated with furnaces firing gas than with oil or other fuels. In FBI, the auxiliary fuel is added directly to the fluidized bed. In this case, a fuel with a lower ignition temperature, such as No. 2 fuel oil, is preferred to control bed temperature.

Coal has been used as an auxiliary fuel in FBI by direct injection into the fluidized bed. The use of solid auxiliary fuels other than coal has been limited. Sawdust, woodchips and municipal solid waste hold promise. The primary barrier to their use has been that the materials handling systems on most biosolids incinerators are not designed for these mixtures.

Information on the feed material and subsequent auxiliary fuel requirement is not always available when selecting equipment. If specific information is not available, specify various possible modes of plant operation. Decide on factors that impact auxiliary fuel usage such as minimum and maximum furnace exhaust temperature.

Heat and material balances should be prepared for each operating mode. A summary table should indicate minimum and maximum values of the following items:

- Combustion air requirement - mass flow and volume rate
- Shaft cooling air recycle
- Ambient air
- Auxiliary fuel requirement
- Auxiliary fuel combustion air requirement
- Furnace exhaust flue gas volume

Consideration must also be given to the design of the auxiliary burners, especially in an MHF. Slag can build up in a MHF whenever the local temperature exceeds the fusion temperature of the biosolids. Closed-register burners have excellent secondary air mixing, resulting in flame temperature of about 2,000<sup>0</sup>F and less slagging.

### *Ash Management*

While incineration provides the greatest volume reduction of all biosolids management techniques, there is still a significant quantity of ash to be managed. The quantity of ash generated is essentially equal to the inert fraction of the feed material and generally ranges from 400 to 800 pounds per dry ton of biosolids incinerated, not including grit. Factors impacting the quantity of ash generated include the degree of inflow/infiltration (I/I) in the collection system; the effectiveness of the grit removal system at the wastewater treatment facility; and the types of conditioning agents used in wastewater treatment and biosolids conditioning.

The type of incinerator has some impact on the characteristics of the ash generated. In a FBI, the ash is collected wet after being exposed to temperatures of 1,500<sup>0</sup> to 1,600<sup>0</sup>F. In an MHF, the ash is collected dry after being exposed to temperatures of 1,200<sup>0</sup> to 1,400<sup>0</sup>F in the lower hearths of the incinerator.

Planning must be conducted for the management of ash as part of the alternative selection process and final design. A more detailed discussion of ash management is provided in Chapter 18.

### *Emission Controls*

Air emissions are a major criteria to consider during the evaluation and implementation of an incineration system. Emissions from incineration and typical controls are discussed in detail in Chapter 17 - Emissions. It is recommended that the emissions and associated air pollution control devices be considered when evaluating alternatives.

### *Waste Heat Recovery*

Incinerators use large quantities of fuel and electricity that ultimately produce heat, much of which is wasted either to the atmosphere or to water. Many types of equipment have been

developed to reuse some of this waste heat. Waste heat recovery can reduce a facility's dependence on auxiliary fuel and, in some cases, reduce emissions.

The first fluidized bed unit for biosolids combustion was built at Lynwood, Washington. This small CWB unit with no internal heat recovery went into operation in 1965. Later the original unit was replaced with a larger incinerator. The development of the HWB air preheating unit occurred in the mid-1960s. This provided improved thermal efficiency and increased system unit capacity when combusting dewatered primary plus secondary biosolids.

Energy recovery in one form or another is being practiced in the majority of the installed units by combustion air preheating, steam generation, or hot water economizers. Preheating the incoming air from 70° to 1,000°F can yield a reduction in fuel costs of approximately 60 percent. Air preheating equipment costs can represent 15 percent of the system cost; therefore, a careful economic analysis is needed to determine cost-effectiveness for a given situation to determine if the extra cost of the recuperator is justified.

The first use of waste heat boilers for energy recovery in fluidized bed combustion of wastewater treatment facility biosolids took place in 1968. The exhaust gases are cooled to about 350°F in the waste heat boiler. This gas cooling makes it possible to use the bag filters and electrostatic precipitators, as well as wet scrubbers for exhaust gas cleaning as necessary to meet air quality standards.

The ability to recover heat energy from an incinerator is impacted by temperature; the higher the temperature of the exhaust gas, the higher the quality or value. Most waste-heat-recovery devices transfer heat from a high-temperature effluent stream to a lower-temperature input stream. They can either increase the temperature of the input stream, or change the input stream from a liquid to a vapor, as in a boiler. All these devices can be broadly categorized as heat exchangers. Waste heat can also be utilized by passing hot gases or steam through a turbine, to generate electricity or to drive mechanical equipment.

Heat recovery equipment must take into account temperature and pressure ranges, corrosiveness of the effluent and input streams, presence of materials that could foul the heat exchange surfaces, and thermal cycling. Extreme values of any of these may dictate the use of special materials and design, resulting in high implementation costs.

### *Waste-Heat Boilers*

Waste heat boilers are typically water tube boilers in which hot exhaust gases pass over a number of parallel tubes containing water. The water is vaporized and collected in a steam drum for distribution to a steam load. Capacities range from less than a thousand to almost a million cubic feet per minute of exhaust gas.

In the 1970's several MHF's were installed with the finned-tube wasteheat boilers. The wasteheat failed due to the plugging of fins with ash and ultimately corrosion. Only water tube boilers are currently used. The pressure and rate of steam production depend on the temperature and flow rate of the hot gases and the efficiency of the boiler. If the waste heat in the exhaust gases is insufficient to generate the required process steam, it is sometimes possible to add

auxiliary burners which burn fuel in the waste-heat boiler or to add an after-burner. Waste-heat boilers have the advantage of being less expensive than installing a new combustion boiler because they need no burners; their disadvantage is that they are large and, in retrofits, it may be difficult to implement. (Industrial Heat Recovery Strategies, PG&E)

Field monitoring can be used to verify potential applications for waste-heat recovery; the following list contains a number of the characteristics that should be considered.

- Quantity, temperature, duration and moisture content of the source. The higher the values, the more heat available
- Proximity to the source
- Relationship of availability of heat at the source to the need
- Where significant volumes of steam are sent through pressure-reducing valves (PRV), it may be possible to replace the PRV with a steam turbine to extract work. To the extent possible, the turbine should match the steam requirements of the process.
- Turbines should be sized for the minimum steam load so that they can operate most of the time; excess process steam can be passed through a PRV in parallel with the turbine.
- The proximity of waste-heat uses influences total energy savings, due to heat loss in transit from the source, and any energy required to move the fluid.
- Latent heat from the condensation of moisture in exhaust gas can be significant, but condensation is often undesirable due to the potential for corrosion down-stream of the heat-recovery device. (PG&E)
- Reviewing process input and output characteristics will help in estimating possible energy savings from waste-heat recovery. Characteristics include:
  - The greater the temperature, flow rate and moisture content, the greater the quantity of heat in the stream.
  - The closer the waste-heat uses the greater the total energy savings.
  - Latent heat from the condensation of moisture in exhaust gas can be significant.
  - Condensation is often corrosion down-stream of the heat-recovery device.

Flow streams that provide large energy savings generally also result in increased implementation costs. Larger flows require larger heat exchangers and higher temperatures may require special materials. Usually energy savings will more than offset the additional cost. Other considerations related to implementation include:

- Special materials to address corrosive effluent streams will increase cost without increasing energy savings.
- If the source and use are separated, the cost of piping, ductwork, pumps and/or fans to deliver the recovered heat will increase costs.
- Heat exchangers conserve fuel and their original cost is relatively modest, but they may involve significant other expenditures. For example, combustion air preheat may require high-temperature burners, larger combustion air ducts with expansion/contraction fittings and cold air lines for cooling the burners.

As with waste-heat boilers, potential energy savings must be carefully considered. If electricity is generated, electrical demand will be reduced by the generated kW. If mechanical energy is generated, electrical savings will equal the kW and kWh that would have been consumed by any replaced electrical equipment, less electricity consumed by the ancillary equipment.

A series of tests were conducted on a MHF equipped with an exhaust gas to air heat exchanger for preheating the combustion air to the 700° to 900°F range. Performance was monitored with and without the use of preheated air. The general findings from these tests include:

- The use of preheated combustion air significantly reduced auxiliary fuel consumption (40 to 50 percent) within a top hearth or afterburner temperature range of 900° to 1250°F;
- The NO<sub>x</sub> emission rates were reduced when using preheated air while operating within the top hearth/afterburner temperature test range;
- The use of preheated air reduced the total exhaust gas flow rate for a given top hearth or afterburner exit gas temperature due to the reduction in combustion products resulting from reduced auxiliary fuel combustion; and
- The use of the heat exchanger demonstrated that lower average NO<sub>x</sub> emission rates and THC emissions below the 100 ppmv limit contained in the Part 503 Rule could be achieved at moderate top hearth/afterburner temperatures in the range of 950° to 1050°F.

## References

Dominak, R.P., (February, 2001), "*Current Practices and Future Direction for Biosolids Incinerators*", Proceedings of the Residuals and Biosolids Management Conference, February,

Goldstick & Thumann, EMBIE,

Ky, D., Mullen, J. and Mayrose, D., (February, 2000), "*A Comparison of Fluid Bed and Multiple Hearth Biosolids Incineration*", 14<sup>th</sup> annual Residuals and Biosolids Management Conference

Pacific Gas & Electric "*Industrial Heat-Recovery Strategies*" Saint, W. W., (July, 1996), "*Thermal Dewatering of Biosolids at Bird Island STP, Buffalo, NY*", ES&E

United States Environmental Protection Agency, (September, 1979), "*Process Design Manual for Sludge Treatment and Disposal*", (USEPA 625/1-79-011)

United States Environmental Protection Agency, (September, 1994), "*A Plain English Guide to the USEPA Part 503 Biosolids Rule*", (USEPA/832/R-93/003)

Water Environment Federation, (1992), "*Sludge Incineration: Thermal Destruction of Residues*", (MOP FD-19)

## Chapter 16 - Incineration System Optimization

---

Incinerator system optimization refers to operation and maintenance (O&M) factors that can be influenced directly by the shift and chief operators at a facility. The term does not refer to options that may be available during design of a facility, such as the type(s) of auxiliary fuel that will be used, or to factors that may be decided during a major upgrade, such as the type of emission control systems to be installed. For the most part, these factors are beyond the control of an operator facing a challenge on a given day. This chapter provides recommendations regarding the optimization of a system as constructed.

### 16.1 Critical Control Points / Operational Controls

The controls associated with running an incineration system as efficiently as possible vary with the many different types of equipment and combinations of equipment used today. A different list of controls should be established for each individual incineration system. The controls discussed in this chapter are divided into three major categories: controls that are general in nature and apply to any type of incineration system; controls that apply to only MHFs; and controls that apply to only FBIs.

#### General Controls

- Operator Training
- Record Keeping and Reporting
- Feed Characteristics
- Feed Rate

#### MHF Controls

- Air Entry Rate
- Hearth and Breech Temperature
- Rotational Speed of the Central Shaft
- Emergency Controls

#### FBI Controls

- Airflow
- Bed Material
- Bed Depth
- Bed and Freeboard Temperature
- Emergency Controls

### 16.2 General Controls

General controls apply to any type of incineration system. For the most part, they consist of common sense operational rules. However, because these factors are obvious, they are sometimes taken for granted and overlooked or not adequately planned for. For example, the importance of effective communication as part of an ongoing operator training program can sometimes be considered a lower priority when compared to daily challenge of managing a large

incinerator or wastewater treatment facility.

### 16.2.1 Operator Training

*The best designed and constructed incinerator systems will not operate to their maximum efficiency without properly trained operators*

The best designed and constructed incinerator systems will not operate to their maximum efficiency without properly trained operators. As a result, any incinerator optimization program should begin with operator training. All personnel who work around the incinerator and/or ancillary systems should be trained to know what normal operating conditions are and who to notify if an operating parameter appears to be outside of its normal range. Operators in charge of the incinerator must receive

thorough training. All employees who may affect how the incinerator operates must also receive training in their specific tasks and how their work may affect the entire system. These positions include load handlers, ash handlers and maintenance personnel.

Training at a particular facility should begin with development of a thorough, and up to date, operation and maintenance (O&M) manual. An O&M manual should have been developed during construction of the incinerator system by the equipment manufacturer and design engineer. Unfortunately, these manuals often become outdated as modifications are made or as facilities refine the recommended operating procedures to meet their unique circumstances. Facility administrators should keep the O&M manual up to date and make it a useful training tool for newer employees and a valuable reference for experienced operators. While some of the writing can be completed by outside consultants, it will be necessary for key employees to play a role in maintaining the O&M manual. Consider a task force consisting of the key employees to periodically review the O&M manual, and recommend changes. This activity will serve not only to keep the manual up to date, but also will encourage discussion and review O&M procedures. The information contained in the O&M manual should be included with the agencies Environmental Management System.

The following items should be considered when developing included in an O&M manual. Other items may be added as needed for a specific site.

- A summary of requirements for the facility such. These may include self-imposed limitations such as a minimum solids content of the feed biosolids.
- An overall description of the entire system with figures that identify key components and narrative that describes the basic function of each unit process.
- A description of the basic combustion principles for the type of incinerator used.
- Procedures for receiving, handling and feeding biosolids to the incinerator.
- Procedures to be followed during startup and shutdown of the incinerator.
- Procedures for operating the incinerator and ancillary systems to maintain compliance with regulatory requirements.
- Procedures for responding to periodic upsets or malfunction of the incinerator and/or ancillary systems.
- Procedures for handling ash.
- A list of agencies and personnel to notify in case of emergency. This may include



- different contacts for different unit processes.
- Procedures for record keeping and reporting.

The manual should be kept in easily accessible locations at the facility such as the control room, main office and break room.

Another useful training tool for facility administrators and key operating personnel that is often underutilized is exchanging information with similar facilities. Develop a relationship with other incinerator operators in your area. Administrative, operational and maintenance personnel should meet on a regular basis to discuss things like new regulatory initiatives and recent operational challenges. Exchange programs should be established to allow O&M personnel to learn from one another.

*Graphs and moving averages are powerful tools in understanding the cause and effect relationship that exists between many operational parameters*

### 16.2.2 Record Keeping and Reporting

Maintenance of accurate records is important for three major reasons. First, periodic review of operational records allows operators to troubleshoot and optimize system performance. Graphs and moving averages are powerful tools in understanding the cause and effect relationship that exists between many operational parameters. Second, operational records are an invaluable tool to the engineer designing improvements for the incinerator or ancillary systems. Finally, accurate record keeping and reporting are required to illustrate compliance to regulatory agencies.

Federal regulations require operators to compile and keep the data listed below for at least five years.

- Concentration of arsenic, cadmium, chromium, lead and nickel in the biosolids fed to the incinerator.
- Information showing how the requirements for beryllium and mercury in the National Emission Standards for Hazardous Pollutants (NESHAPs) are being met.
- Biosolids feed rate on a dry weight basis.
- Stack height.
- Dispersion factor.
- Control efficiency for arsenic, cadmium, chromium, lead and nickel.
- The risk specific concentration for chromium.
- The THC or CO monthly average concentration in the stack exhaust gas.
- The oxygen concentration in the stack exhaust gas.
- Information used to measure the moisture content in the stack exhaust gas.
- Combustion temperatures, including maximum daily combustion temperature.
- Measurements for required air pollution control device-operating conditions.
- Calibration and maintenance log for instruments used to measure:
  - THC or CO in stack exhaust.
  - Oxygen levels in stack exhaust.
  - Moisture content in stack exhaust.
  - Combustion temperatures in furnace.

Treatment facilities serving a population greater than 10,000 or with a design flow of greater than one million gallons per day; must provide the above listed information to the permitting authority every February 19<sup>th</sup>. Reporting requirements may be more stringent in certain states.

### 16.2.3 Feed Characteristics

As discussed in Chapter 16, the characteristics of the feed material can have an impact on the operation of the incinerator. The incinerator operator can influence the factors that impact the characteristics of the biosolids by maintaining close coordination with the operator of the dewatering facility, the wastewater treatment facility, the collection system and the industrial pretreatment program. Examples of activities that should be monitored by operators of the incinerator include:

- Dewatering System: Depending on the availability of storage, the rate that biosolids are dewatered may dictate the feed rate to the incinerator. The incinerator operator should have input on the operation of the dewatering equipment. The dewatering system must be operated to maintain a consistently high solids concentration. The impact on incinerator operations must be carefully considered if planning is being conducted to replace the major components of the dewatering system. For example, if an operator of a recessed chamber or plate and frame press changes from lime and ferric chloride as the conditioning agents to an organic polymer, the softening and fusion points of the ash may be much lower and the formation of clinkers and slag may increase.
- Wastewater Treatment System: Operational changes at the wastewater treatment facility can impact the characteristics of the feed biosolids and operation of the incinerator. For example, a change in the mode of operation of an activated sludge facility from a low sludge age to a higher sludge age could reduce the volatile solids content, and thus the fuel value, of the biosolids. Another example of an operational modification that would impact the incinerator is initiation of chemical phosphorus removal. The addition of aluminum or iron salts, commonly used to precipitate phosphorus, may increase the quantity of waste activated sludge produced relative to the quantity of primary solids. This in turn will increase the overall quantity of dry solids fed to the incinerator and may decrease the solids concentration of the dewatered cake.
- Collection System: If significant seasonal variations in the quantity of ash are observed, there is a good chance that the collection system is experiencing significant inflow and infiltration problems. The incinerator operator can support the collection system manager's efforts to correct collection system deficiencies by identifying the cost implications of passing the inert material through the incinerator and disposing of it along with the biosolids ash.
- Industrial Pretreatment: Part 503 Rule places restrictions on the concentration of five metals in the biosolids to be fed to incinerators. In most instances, the only control an incinerator operator has on the concentration of these metals in the

biosolids is through the industrial pretreatment program. As a result, careful coordination with the pretreatment coordinator is required.

### 16.2.4 Feed Rate

The feed rate is an important parameter for the incinerator operators. The rate at which biosolids are incinerated is normally dictated by the quantity of material requiring disposal. A continuous steady-state feed rate is desirable from a control standpoint. If the feed rate is to be changed, a gradual increase or decrease to allows the incinerator to change gradually as well.

The manner in which the feed rate is monitored will vary depending on the conveyance system used. Facilities that incorporate conveyor systems often include weight belts to monitor feed rate. Facilities that incorporate pump systems need to rely on solids flow rate and pre-determined unit weights to calculate feed rates.

## 16.3 MHF Controls

There are number of controls that should be considered when optimizing MHA Operation. They include:

- Air Entry Rate
- Hearth and Breach Temperature
- Shaft Rotational Speed
- Control Llogic

### 16.3.1 Air Entry Rate

Airflow into a MHF serves two major functions:

- It provides a source of oxygen for the combustion process; and
- It maintains the furnace under negative pressure to prevent injury to operators. The air is generally supplied from three separate sources: recirculated shaft cooling air; the combustion air supply fan; and the induced draft fan and associated leakage.

*To ensure complete combustion, a MHF requires 50 to 150 percent excess air over the stoichiometric amount.*

The overall quantity of air required by the incinerator is equal to the air required by the combustion process plus a volume of excess air. The amount of oxygen and therefore quantity of air, required to incinerate the biosolids can be calculated. As a rule of thumb, 7.5 pounds of air are required to release 10,000 BTU from biosolids and supplemental fuel. In practice, incinerator operation requires air in excess of the theoretical amount for complete combustion. The excess air increases the contact between the fuel and the oxygen. To ensure complete combustion, a MHF requires 50 to 150 percent excess air over the stoichiometric amount. The quantity of excess air entering a conventional MHF plays an important role in the overall efficiency of the incinerator. If insufficient air is supplied, the combustion process will be incomplete and carbon monoxide, soot and

odorous hydrocarbons will be produced. An exception is the starved air combustion (SAC) previously process described. In this process, the incomplete combustion process is carefully controlled to increase the capacity of the MHF and reduce supplemental fuel use. If too much air is introduced to the incinerator, additional energy will be needed to raise the temperature of the air to the temperature of the hottest hearth.

An assessment can be made on the adequacy of the combustion air quantity based on the oxygen content of the MHF outlet gas or the oxygen content of the gases in any given hearth. Control of the amount of excess air is necessary to minimize fuel usage and, in a conventional MHF, provide adequate oxygen for complete combustion of the biosolids. In a MHF being operated in the SAC mode, a lower oxygen content would be targeted. The typical operating target for oxygen content is 6 to 9 percent dry gas basis. In a typical MHF, the majority of combustion air is introduced into the bottom hearth. It rises to the upper combustion hearths as it warms. In the process, it also serves to cool the ash in the bottom hearth prior to discharge. Control of the air supply from each source is summarized below.

### *Shaft Cooling Air*

The quantity of shaft cooling air available is based on the design of the MHF. In general, it is advantageous to maximize the usage of shaft cooling air as combustion air because it has been preheated as it passed up through the shaft and rabble arms. Thus, it helps to close the energy balance and minimize the use of supplemental fuel. The shaft cooling air duct on some MHFs is equipped with a damper that is automatically controlled by the oxygen content of the outlet gas or from a lower hearth.

### *Induced Draft Air*

A number MHFs rely on induced draft fans to supply combustion air to the incinerator. Under this scenario, the amount of air entering the MHF is normally regulated by controlling the draft, or the negative pressure, within the furnace. Typically, the induced draft fan speed is automatically controlled to maintain a negative pressure of 0.05 to 0.2 inches of water column. Control over the quantity and location of air supply is often accomplished by leaving poke and peak holes open or furnace doors ajar. The degree of control available depends on how tight the incinerator shell is.

The draft, or negative pressure, should be monitored on the top and bottom hearths. The top hearth is normally used to control the induced draft fan speed.

### *Combustion Air Fan*

Control of excess air is easier to manage in relatively airtight MHFs. The oxygen content of the outlet gas or air from a lower hearth can be used to control the combustion airflow by adjusting the position of a damper on the combustion air fan or the speed of the fan if it is equipped with a variable frequency drive. This method of control ensures that the right amount of combustion air is being supplied. Manual controls to start, stop and adjust the airflow should also be provided.

An induced draft fan is still used to ensure that the furnace is not pressurized. Keeping

the furnace under negative conditions results in drawing air in through any openings in the furnace shell and not out, which could result in operator injury.

The combustion air fan should be interlocked with the emergency by-pass damper. The combustion air fan should be prevented from operating when the by-pass damper is open to prevent “fanning the fire” during an emergency.

### 16.3.2 Hearth and Breech Temperature

A MHF can be divided into four zones, as shown on Figure 16.1. The first zone that the biosolids are exposed to occurs in the upper hearths. It is the drying or evaporation zone where most of the water is removed. The second zone generally of the central hearths. This is the zone where the volatile solids are burned. The third zone, also in the central hearths, is the fixed carbon-burning zone, where the remaining carbon is oxidized to carbon dioxide. The fourth and final zone is the cooling zone. Incinerator ash is cooled in this zone by incoming combustion air. The sequence of these zones is always the same, but the location within the MHF varies depending on the quality of the feed, the design of the furnace and current operating conditions.

**Figure 16.1 Process Zones in a MHF**

Normal Biosolids/Ash Temperature		Normal Air Temperature
160°F	Drying Zone	600°F to 900°F
1,400°F to 1700°F	Volatile Solids Combustion Zone	1,400°F to 1,700°F
1400°F to 1800°F	Fixed Carbon Burning Zone	1400°F to 1800°F
100°F to 400°F	Ash Cooling Zone	300°F

Biosolids Flow
Air Flow

Temperature should be monitored at each hearth, the outlet flue and in the emission control devices if necessary. The temperature of individual hearths is often used as control points for supplementary fuel burners. Outlet temperature is monitored and tracked to determine if the MHF is operating efficiently, and to ensure that downstream air pollution control devices are receiving an inflow that is below the maximum temperature recommended by the manufacturer. Control of the outlet temperature, is generally accomplished by regulating the entire MHF temperature.

*For safety reasons, it is recommended that burners be ignited by the MHF operator and not by the control system.*

Control of these temperatures is primarily through operation of the auxiliary fuel burners. In the event that the biosolids are autogenous, temperature control is exerted through a combination of biosolids and combustion air feed rates. The overall control of these factors must be incorporated into the incinerator’s combustion control logic to ensure that all factors are considered when changing one

variable.

The temperature of a hearth can be altered rapidly when a burner is being fired in that hearth or the one below it by changing the firing rate. Burner firing rates should be controlled by thermocouples. Controlling the burners with thermocouples located in the hearth above it produces the most stable temperature profile.

For safety reasons, it is recommended that burners be ignited by the MHF operator and not by the control system. When the combustion control logic circuit determines that a burner should be ignited, a signal will indicate which burner should be started. For safety reasons the control circuit should be able to automatically turn burners off.

When the combustion control logic circuit determines that more auxiliary fuel is required, it will signal the operators and indicate which burner to light. Once this is done, the combustion control logic circuit should adjust the fuel delivery until the desired temperature is achieved. The control circuit increases the fuel delivery by increasing the burner set point temperature on the “selected” fired hearth. When less fuel is required, the control circuit decreases the amount of auxiliary fuel being fired into the furnace. This type of control loop is commonly referred to as cascade control.

### **16.3.3 Shaft Rotational Speed**

The center shaft rotational speed and subsequently the rabble arm speed are typically adjusted manually. Proper speed of the center shaft is important for three reasons. First, it is the mechanisms by which biosolids are conveyed through and out of the incinerator. Increases in center shaft speed increase the rate at which the rabble arms push biosolids from one hearth to the next lower hearth.

The second function of center shaft rotational speed is to enhance evaporation in the upper hearths. An optimum rabble arm speed is necessary to maximize the surface area of furrows exposed to the hot gases and radiation from the roof. If the speed is too fast, the width of the furrows will increase, reducing the exposed surface area. If the speed is too slow, the valleys between furrows will fill in with solids, again decreasing the surface area of the biosolids.

Finally, the operators can exert some control over the location of the burning zone of the furnace by adjusting the speed of the center shaft rotation. As the speed of the rotation increases, the location of the burning zone falls to lower hearths, at least initially. The amount of lowering of burning in the furnace does not always change significantly. Since the rotation speed does change the location of the burning zone, rabble arm speed has been eliminated by most operators and engineers as a variable from the list of parameters considered in the hearth-by-hearth heat and material balance.

### **16.3.4 Control Logic**

The incinerator should be equipped with automatic purge and shutdown features. Emergency conditions such as high temperature at the incinerator outlet or within the incinerator itself should shut down the induced draft fan and open the emergency by-pass

chamber. Controls should be provided to shut down the auxiliary fuel burners and biosolids feed equipment upon any interruption in operation of the incinerator.

A troubleshooting guide for a MHF is presented in Table 16.1 (USEPA, September 1979). The table summarizes problems that have been experienced with MHFs, probable causes and potential solutions.

**Table 16.1 - MHF Troubleshooting Guide**

<b>Problem</b>	<b>Probable Cause</b>	<b>Solution</b>
Furnace or stack gas temperature too high	Excessive fuel feed rate. Greasy feed material.  Thermocouple faulty	Decrease fuel feed rate.  Raise air feed rate or reduce biosolids feed. Investigate cause of excessive grease with WWTF operator.  Replace thermocouple
Furnace or stack gas temperature too low	Moisture content of biosolids has increased.  Fuel system malfunction.  Excessive air feed	Increase fuel feed rate. Coordinate with dewatering system operator to increase cake solids content.  Check supplemental fuel system.  If O <sub>2</sub> content in stack gas is high this is the likely cause; reduce air feed rate
Oxygen content in stack gas is too high	Biosolids feed rate is too low.  Air feed rate is too high.  Air feed above burn zone is excessive	Check for blockages or equipment failure and reestablish proper feed rate.  Decrease air feed rate.  Check poke and peepholes and doors in upper hearths. Close as necessary
Oxygen content in stack gas is too low	Volatile solids content of grease and/or biosolids feed has increased.  Air feed rate is too low	Increase air feed rate and/or decrease biosolids feed rate. Investigate causes with WWTF operator.  Increase air feed rate
Furnace refractories have deteriorated	Furnace has been started up and shut down too quickly	Replace refractories and review start up/shut down procedures. Conduct operator training.
Unusually high cooling effect from one hearth to another	Air leak	Check hearth doors, poke and peep holes etc. Stop leak.
Short hearth life	Uneven firing	Make sure that supplemental fuel burners are firing evenly on all sides
Center shaft shear pin failure	Rabble arms are dragging or a foreign object is caught in the furnace	Inspect and correct problem

Rabble arms drooping	Excessive hearth temperature.  Loss of cooling air	Refer to high temperature problems above.  Inspect and repair cooling air supply.
----------------------	--	---

## 16.4 FBI Controls

There are a number of controls that should be considered when optimizing FBI Operation they include:

- Air Flow
- Bed Material and Bed Depth
- Bed and Freeboard Temperature
- Control Logic

### 16.4.1 Air Flow

Air flow is determined by two major factors: providing sufficient oxygen for combustion and fluidizing the bed.

*To ensure complete combustion, a FBI requires 20 to 45 percent excess air over the stoichiometric amount*

Minimum oxygen requirements must be met to assure complete oxidation of all volatile solids in the biosolids cake. The amount of oxygen and therefore quantity of air, required to incinerate the biosolids can be calculated. As a rule of thumb, 7.5 pounds of air are required to release 10,000 Btu from biosolids and supplemental fuel. In practice, incinerator operation requires air in excess of the theoretical amount for complete combustion. The excess air increases the contact between the fuel and the oxygen. To ensure complete combustion, a FBI requires 20 to 45 percent excess air over the stoichiometric amount. This represents a significant advantage of FBI as compared to MHF, which can use up 150 percent excess air. The quantity of excess air entering a conventional FBI plays an important role in the overall efficiency of the incinerator. If insufficient air is supplied, the combustion process will be incomplete and carbon monoxide, soot and odorous hydrocarbons will be produced. If too much air is introduced to the incinerator, excess bed material may be lost with the incinerator exhaust and additional energy will be needed to raise the temperature of the air to the temperature of the exhaust gas.

The size of a FBI is selected by determining the airflow required for efficient combustion at the required capacity, and then sizing the FBI such that the resulting air velocity sustains a properly fluidized bed. The design air flow rate is generally set between 2.3 and 3 feet per second. The operator can vary the airflow rate, and therefore the velocity, within a reasonable range of the design set point to increase or decrease incinerator capacity. The higher the air velocity through the FBI, the greater the combustion capacity.

Maintaining a properly fluidized bed is critical to the efficient operation of a FBI. Therefore, a basic understanding of the term “fluidized bed” is required. As air is passed upward through a bed of sand at a low rate, it percolates through the void spaces between



the stationary particles. This is considered to be a fixed bed. When the air flow rate is increased, some of the particles of sand vibrate. This is an expanded bed approaching fluidization. As the airflow is increased further, a point is reached where all of the particles are suspended in the upward flowing air. The pressure drop of the air flowing through the bed is less than it was when the bed was stationary and is essentially equal to the weight of the air and the sand particles in the fluidized column. At this point, the bed is considered to be barely fluidized, minimum fluidization. With increasing airflow the bed will pass from minimum fluidization to smooth fluidization, a bed characterized by violent bubbling and channeling. This is referred to as an aggregated or bubbling fluidized bed. Further increases in airflow may cause slugging. When a bed is slugging, large gas bubbles coalesce and grow as they push upward, much like an airlift pump. Slugging is undesirable because it leads to loss of bedding material. If the airflow is increased beyond the point that slugging occurred, the bed enters lean phased fluidization and excessive amounts of bedding will be lost.

The type of bed that is desired in a biosolids incinerator is midway between smooth fluidization and slugging. This level of fluidization will result in minimum headloss, violent contact between the biosolids particles and the hot bed material and acceptable bed losses in the exhaust gas. Bed material losses in this range are normally 5 percent of the bed volume for every 300 hours of operation.

### **16.4.2 Bed Material and Bed Depth**

Because it is normal to lose five percent of the bed volume for every 300 hours of operating time, the bed depth must be controlled to give the desired residence time this is generally measured using differential pressure devices similar to liquid level measurement. The depth of the static bed is typically 3 to 4 feet and the fluidized depth is 5 to 6 feet.

The operator has to select the appropriate material to replace the lost bedding material. Selection of the proper bedding material has a significant impact on the performance of the FBI.

Fine particles of a wide size distribution remain fluidized over a wide range of airflow rates. Conversely, beds of large uniformly sized grains tend to fluidize poorly with a high degree of slugging. The finer grained bedding tends to be carried out with the exhaust gas at a higher rate than the larger, heavier bedding material. As a result, the quality of fluidization often can be improved by adding finer grained (10 mesh) materials to act as a lubricant. The overall size range of bedding material for a FBI incinerating biosolids should be 10 to 80 mesh at bed velocity of approximately 3 feet per second.

If the grit is added to the incinerator for disposal, the bed will classify the material. It may be necessary to periodically remove the coarser grit particles from the bottom of the bed to assure good fluidization.

### **16.4.3 Bed and Freeboard Temperature**

The biosolids must be introduced to the bed when it is at an operating temperature that

exceeds the ignition temperature of the biosolids. The required temperature may vary depending on the characteristics of the biosolids and the design of the incinerator, but is generally in the range of 1500° to 1600°F. Adjusting the supplemental fuel feed rate controls the temperature of the bed, biosolids feed rate and combustion air feed rate.

The operating temperature of the freeboard area, above the fluidized bed, runs several hundred degrees hotter than the bed temperature. This is a function of many variables, but is due at least in part to the combustion of volatilized organic matter in the area above the bed. The bed temperature typically runs between 1350° and 1400°F while the freeboard temperature may be as hot as 1650°F. This characteristic of FBIs results in thermal oxidation of the exhaust gas within the incinerator, eliminating the need to further thermally treat the exhaust air before discharge.

**16.4.4 Emergency Controls**

The FBI should be equipped with fail-safe electromechanical interlocks ensure that none of the combustion or heat recovery systems can be started or remain operational unless the various cooling elements are on-line. The safety interlocks should be placed not only on the FBI, but also on the emission control systems.

**16.4.5 Troubleshooting**

A troubleshooting guide for a FBI is presented in Table 16.2 (USEPA 1979). The table summarizes problems that have been experienced with FBIs, probable causes and potential solutions.

**Table 16.2 FBI Troubleshooting Guide**

<b>Problem</b>	<b>Probable Cause</b>	<b>Solution</b>
Falling bed temperature	Inadequate fuel supply.	Increase fuel feed rate or repair any fuel system malfunctions.
	Excessive biosolids feed.	Decrease biosolids feed rate.
	Excessive biosolids moisture content.	Coordinate with dewatering system operator to improve performance.
	Excessive air flow	Reduce air flow if exhaust O <sub>2</sub> > 6%
Low O <sub>2</sub> (<4%) in exhaust gas	Low air flow.	Increase combustion air blower speed.
	High fuel rate	Decrease fuel rate
High O <sub>2</sub> (<6%) in exhaust gas	Biosolids feed rate too low	Adjust biosolids feed rate and fuel feed rate to maintain constant bed temperature
Erratic bed depth readings on control panel	Bed pressure taps plugged with solids	If FBI is not in operation, tap a metal rod into the tap pipe. If FBI is operating, apply compressed air to pressure tap after reviewing manufacturer’s safety instructions
Preheat burner fails and alarm sounds	Pilot flame not receiving fuel.	Open appropriate valves and establish fuel supply.

## NATIONAL MANUAL OF GOOD PRACTICE FOR BIOSOLIDS

	Pilot flame not receiving spark.	Remove spark plugs and check for spark. Check transformer, or replace defective pan.
	Pressure regulators defective.	Disassemble and clean regulators.
<b>Problem</b>	<b>Probable Cause</b>	<b>Solution</b>
	Pilot flame ignites but flame scanner malfunctions	Clean sight glass on scanner or replace scanner
Bed temperature too high	Fuel feed rate too high. Increased fuel value in feed biosolids	Decrease fuel rate. Explore reasons for change with WWTF operator
Bed temperature reads off the scale	Faulty thermocouple	Check the entire control system. Repair as necessary
Reactor biosolids feed pump fails	Bed temperature interlock may have shut down pump. Pump is blocked	Check bed temperature. Clear blockage and dilute feed sludge if necessary
Poor bed fluidization	Sand has leaked through support plate	Shut down incinerator and clean wind box
High scrubber temperature	No water flowing. Spray nozzles plugged. Water not recirculating	Open valves. Clean nozzles and strainers. Return pump to service

## Chapter 17 – Incinerator Emissions

---

Properly designed and operated, incineration systems can provide complete combustion of biosolids to produce carbon dioxide, water and sulfur dioxide. Incomplete combustion, however, can result in the formation of hydrocarbons, other volatile organics and carbon monoxide. There is also the potential to discharge particulate matter, metal sulfur dioxide, and nitrous oxides. To be successful, minimization and control of these emissions must be considered during the design and operation of the incinerator system and air pollution control devices (APCD).

### 17.1 Regulatory Summary

USEPA’s 40 CFR Part 503 Rule regulates the emission of seven metals and total hydrocarbons from biosolids incinerators based on the following approaches:

- Risk-specific concentrations for arsenic, cadmium, chromium and nickel
- National Ambient Air Quality Standard (NAAQS) for lead
- Technology-based operational standard for total hydrocarbons
- National Emission Standards for Hazardous Pollutants (NESHAP) for beryllium and mercury

A summary of the Part 503 Rule is presented in Chapter 2.

#### 17.1.1 Risk-Specific Concentrations for Arsenic, Cadmium, Chromium and Nickel

The emission of arsenic, cadmium, chromium and nickel from an incinerator are controlled by limiting the allowable concentration of each metal in the biosolids to be fed to the incinerator. The allowable concentration for each metal is determined for each individual incinerator based on the following equation:

$$C = \text{RSC} \times \frac{86,400}{\text{DFX} (1 - \text{CE}) \text{XSF}}$$

Where:

- C = The pollutant limit expressed as the allowable daily concentration of arsenic, cadmium, chromium or nickel in milligrams per kilogram to total solids, dry weight basis.
- RSC = Risk specific concentration based on the allowable increase in the average daily ground level ambient air concentration for each metal at or beyond the property line of the site in micrograms per cubic meter.
- 86,400 = Conversion factor for seconds per day.
- DF = Dispersion factor based on site specific dispersion characteristics (in micrograms per cubic meter per gram per second).
- CE = Control efficiency for arsenic, cadmium, chromium or nickel based on performance test in hundreds.
- SF = Biosolids feed rate in dry metric tons per day.

The allowable increases in the average daily ground level ambient air concentration for

arsenic, cadmium and nickel are based on the risk-based assessment conducted for the Part 503 Rule. The RSC for these three parameters are 0.023, 0.057 and 2 micrograms per cubic meter, respectively.

The RSC for chromium is determined based on either the type of incinerator used (option 1), or an analysis that involves sampling of the stack gas to determine the ratio of hexavalent chromium to total chromium analytes (option 2).

Option 1

Type of Incinerator	RSC (micrograms/m <sup>3</sup> )
FBF with wet scrubber	0.65
FBF with wet scrubber and wet electrostatic precipitator	0.23
Other types with wet scrubber	0.064
Other types with wet scrubber and wet electrostatic precipitator	0.016

Option 2

$$\frac{0085.0}{r}$$

$$\text{RSC} = r$$

Where:

R = The decimal fraction of the hexavalent chromium concentration in the total chromium concentration measured in the exit gas from the biosolids incinerator stack in hundredths.

**17.1.2 NAAQS for Lead**

The equation used to calculate the allowable concentration of lead in biosolids to be incinerated is similar to the equation used for arsenic, cadmium, chromium and nickel. However, rather than being based on a risk-based calculation developed for the Part Rules, the lead limit is based on a percentage of the NAAQS according to the following formula.

$$\text{Clead} = \frac{0.1 \times \text{NAAQS} \times 86,400}{\text{DF} \times (1 - \text{CE}) \times \text{SF}}$$

Where:

- Clead = The pollutant limit expressed as the allowable daily concentration of lead in milligrams per kilogram to total solids, dry weight basis.
- 0.1 = The allowable ground level concentration of lead from biosolids is ten percent of the NAAQS for lead.
- NAAQS = National Ambient Air Quality Standard for lead in micrograms per cubic meter.
- 86,400 = Conversion factor for seconds per day.
- DF = Dispersion factor based on site specific dispersion characteristics (in micrograms per cubic meter per gram per second).
- CE = Control efficiency for lead based on performance test in hundreds.
- SF = Biosolids feed rate in dry metric tons per day.

### 17.1.3 Beryllium and Mercury

Unlike other metals, beryllium and mercury emissions are regulated as limits to air emissions either by monitoring the exhaust air from the incinerator or the ambient air around the incinerator. In either case, the concentration in the air must meet the National Emission Standards for Hazardous Air Pollutants (NESHAPs, 40 CFR Part 61).

The NESHAP for beryllium requires that the total quantity of beryllium emitted from the incinerator not exceed 10 grams during any 24-hour period. This standard does not apply if written approval has been obtained from the USEPA Regional Administrator for the following:

- (1) when the ambient concentration of beryllium in the proximity of the incinerator does not exceed 0.1 micrograms per cubic meter when averaged over a 30 day period; or
- (2) if the biosolids incinerator operator can prove with historical data that the biosolids fired in the incinerator do not contain beryllium.

The NESHAP for mercury requires that the total quantity of mercury emitted into the atmosphere from all incinerators at a given site does not exceed 3,200 grams during any 24-hour period.

### 17.1.4 Total Hydrocarbons and Carbon Monoxide

Organic compounds such as benzene, phenol and vinyl chloride may be present in the exhaust from an incinerator due to incomplete combustion or the formation of combustion by-products. Total hydrocarbons (THC) or carbon monoxide (CO) are monitored to represent all organic compounds in the exhaust gas that are covered by the Part 503 Rule. In contrast to the limits for metals, which are based on risk-based assessment or the NAAQS, the THC or CO requirement is a technology-based standard. The technology-based approach was used because the methodology for developing a site-specific risk-based approach is not well established.

The Part 503 Rule allows a monthly average concentration of up to 100 parts per million based on volume (ppmv) of THC or CO. The emission limit for THC of 100 PPMV is monitored as propane, corrected to 0 percent moisture and 7 percent oxygen. If the CO in the emission does not exceed 100 ppmv, USEPA allows CO to be used as an alternative to THC. However, a CO limit of 100 PPMV is more stringent than a THC limit of 100 PPM. In either case, the regulation requires the monthly average to be based on the arithmetic mean of 24-hourly averages, with the hourly average based on at least two readings.

### 17.1.5 Proposed Regulatory Changes

After the 503 Rule was promulgated, USEPA indicated that biosolids incinerators also would be regulated under Section 112 of the Clean Air Act (CAA) Amendments of 1990, and that it would promulgate additional biosolids incinerator regulations, if deemed necessary, the Part 503 Rule (referred to as “Round 2”). In addition, in 1997 USEPA proposed to further regulate biosolids incinerators under Section 129 of the CAA.

(Dominak 2001)

The proposed regulations are summarized below:

### *Section 112 of the CAA*

The goal of Section 112 of the CAA is to reduce emission of 188 hazardous air pollutants (HAPs) through the implementation of Maximum Achievable Control Technology (MACT) Standards. (A MACT Standard is defined as “The average emission limitation achieved by the best performing 12 percent of units in this category.”)

Under Section 112 of the CAA, biosolids incinerators and WWTFs are subject to MACT Standards only if they emit:

1. 10 tons or more per year of any single HAP, or
2. 25 tons or more per year of any combination of HAPS.

The Association of Metropolitan Sewerage Agencies (AMSA) polled their members regarding HAPS. The poll indicated that only limited number of the 188 HAPS in the wastewater entering their facilities. In addition, neither AMSA nor USEPA found any WWTF that practices incineration to be major source of HAPS. (Dominak 2001)

### *Section 129 of the CAA*

On January 14, 1997, USEPA published the Federal Register a “Notice of Additional Information” concerning biosolids incinerators, in which it stated its intent to:

1. Delist biosolids incinerators as major sources of HAPs under Section 112 of the CAA and,
2. List biosolids incinerators as “Other Solids Waste Incinerators” under Section 129 of the CAA, along with hazardous waste, medical waste and municipal solid waste.

On April 24, 2000, USEPA announced in the Federal Register, that it has decided not to regulate biosolids incinerators under Section 129 of the CAA. USEPA also indicated that:

1. Biosolids is from a municipal source and,
2. Biosolids incinerators that combust biosolids are not “solids waste incinerator units, therefore Section 129 does not apply to biosolids incinerators.”

In addition, USEPA Published in the Federal Register on August 15, 2000 a statement that it would not be regulating biosolids incinerators under Section 129 of the CAA.

On December 1, 2000 USEPA again announced in the Federal Register that it will not be regulating biosolids incinerators under Section 129 of the CAA and the effective date of this rule would be January 30, 2001.

January 30, 2001 has passed and biosolids incinerators are not being regulated under

Section 112 nor 129 of the CAA. (Dominak 2001)

### *Part 503 Regulation - Round 2*

USEPA previously indicated that it would propose dioxin, dibenzofurans and dioxin-like coplanar PCB (dioxins) emission limits for biosolids incinerators, under Round 2 of the Part 503 Regulation, if deemed necessary, to protect public health and the environment.

In December 1999, USEPA announced in the Federal Register that, based on the results of risk assessment, it is not proposing dioxins emission limits for biosolids incinerators. USEPA based its decision on the fact that the 254 biosolids incinerators emit a combined total of 6 grams TEQ (dioxins)/year out of the 2,745 grams TEQ (dioxins)/year (0.2%) released to the atmosphere in the United States. In addition, USEPA determined that the highest associated risk factor did not exceed  $2.1 \times 10^{-6}$ . (Dominak 2001)

## **17.2 Critical Control Points / Operational Controls**

There are a number of controls associated with incineration emissions. They include:

- Incinerator system selection and design
- Incineration system optimization
- Instrumentation operation and maintenance
- Particulate Emission Controls
- Hydrocarbon Emission Controls
- Dispersion characteristics
- Stack plume elimination
- Record keeping and reporting

## **17.3 Incinerator System Selection and Design**

The type of incinerator used - Multiple Hearth Furnace (MHF) or Fluidized Bed Incinerator (FBI) - will dictate the extent and type of APCD that will be required to comply with emission regulations in general and with regard to products of incomplete combustion. The carbon monoxide (CO) emissions from all FBI are typically below the regulatory limit of 100 ppm at 7 percent oxygen because the temperature of the exhaust gas normally exceeds 14000F. This exhaust temperature allows the FBI to routinely meet the requirement without difficulty.

It has been demonstrated that the Total Hydrocarbon (THC) emissions from MHFs can be kept below the 100-ppm limit by sustaining the top hearth temperatures at about 1000° F. This is possible if the burning hearth is close to the top hearth. This maintains the drying hearth temperatures high enough to oxidize THCs. To keep the burning hearth close to the top hearth, it is necessary to have exceptionally dry biosolids or to use only two hearths for drying. However, when some furnaces are loaded near their design capacity, the fire moves down and the heat required to keep the top hearth temperature at about 1,000° F creates overheating the burning hearth, melts ash and causes slagging.



### 17.4 Air Pollution Control Device System Optimization

Optimization of the operating parameters of any type of incineration system can have a large impact on the quality of the emission and the performance of the subsequent APCDs. Factors such as air entry rate and combustion temperature must be carefully controlled. Optimization of the incinerator system is discussed in greater detail in Chapter 16.

Optimization of key parameters related to the APCDs is of paramount importance to emission control. Table 17.1 lists some of the key parameters of APCD systems that must be carefully controlled.

**Table 17.1 - Operating Parameters for Air Pollution Control Devices**

Operating Parameter	APCD	Example Measuring Instrument
Pressure Drop	Venturi scrubber, impingement scrubber, mist eliminator, fabric filter	Differential pressure gauge/transmitter
Liquid flow rates	Venturi scrubber, impingement scrubber, mist eliminator, wet electrostatic precipitator (ESP)	Orifice plate with differential pressure gauge/transmitter
Gas temperature (inlet and/or outlet)	Venturi scrubber, impingement scrubber, dry scrubber, fabric filter, wet ESP	Thermocouple/transmitter
Liquid/reagent flow rate to atomizer	Dry scrubber (spray dry absorber)	Magnetic flow meter
pH of liquid/reagent to atomizer	Dry scrubber (spray dry absorber)	Wattmeter
Atomized motor power	Dry scrubber (spray dry absorber)	Pressure gauge
Compressed airflow rate	Dry scrubber (spray dry absorber)	Differential pressure gauge/transmitter
Compressed airflow rate	Dry scrubber (spray dry absorber)	Orifice plate with differential pressure gauge/transmitter
Opacity	Fabric Filter	Transmissometer
Secondary voltage (for each transformer/rectifier)	Wet ESP	Kilovolt meters/transmitter
Secondary currents (for each transformer/rectifier)	Wet ESP	Milliammeters/transmitter

The proper range for these parameters may be defined by the performance test and stipulated in the operating permit for the facility. The equipment manufacturer can also provide supporting information.

### 17.5 Instrumentation Operation and Maintenance

The Part 503 Rule requires operators to use instruments to continuously measure and record certain information including:

- THC or CO in the exhaust gas.
- Oxygen in the exhaust gas.
- Information used to calculate moisture content in the exhaust gas.
- Combustion temperatures at multiple points in the incinerator.

### 17.6 Particulate Emission Controls

Particulates are emitted in the exhaust air from an incinerator system. "Particulate matter" means any airborne finely divided solid or liquid material with an aerodynamic diameter smaller than 100 micron. A micron is one millionth of a meter or about 0.00004 inches. The human eye cannot see particles smaller than about 50 microns or 0.002 inches. The issue is whether particulates are controlled sufficiently to protect human health and the environment.

The Clean Air Act includes a particulate standard, using "PM10" as the control. PM10 means particulate matter with an aerodynamic diameter less than or equal to a nominal 10 microns. The 50 ug/m<sup>3</sup> PM10 standard was determined from long-term epidemiological studies that indicate health effects *likely* when the PM10 concentration is greater than 80-90 ug/m<sup>3</sup>, health effects *possible* at PM10 concentrations between 40-80 ug/m<sup>3</sup> and *no significant effects* at PM10 concentrations less than 40 ug/m<sup>3</sup>.

The USEPA has recently announced plans to modify its air quality standards by the year 2003. USEPA cites new health studies indicating that particulate smaller than 2.5 microns (PM2.5) are the major contributor to serious respiratory health problems. These anticipated standards are expected to apply to ambient air not the air quality leaving the stack.

When the average emissions exceed 6 lb/hr. of "particulate matter" or 4 lb/hr. of "PM10," certain provisions in the Clean Air Act are triggered. These provisions may require a study of ambient air conditions. The use of best available control technology would be required, and there may have to be emission reductions somewhere else in the community to offset the incinerator emissions. The provisions may also require the use of Best Available Control Technology (BACT). Best available control technology devices include:

- as high efficiency scrubbers
- fabric filters
- electrostatic precipitators

All biosolids incinerators that were built or modified after June 11, 1973 are required to meet the particulate emission limit of 1.3 lb/ton dry solids incinerated. This equates to approximately 0.03 grains/dscf at 7 percent oxygen. A survey of incinerators indicated that those units equipped with a combination of venturi and impingement plate scrubbers are meeting this standard, with a range of 0.22 to 1.11 lb/ton. In addition, there are a significant number of biosolids incinerators equipped with air pollution control equipment that are more efficient than the combination of a venturi and impingement scrubbers. (Baturay, A. 1999). Brief descriptions of the following

technologies are provided:

- Cyclone Separator
- Spray Chamber
- Venturi/Impingement Tray Scrubber
- Venturi Scrubbers
- Wet Electrostatic Precipitator

### **17.6.1 Cyclone Separator**

Cyclone separators are generally used as a preliminary treatment step to remove large-size particulate matter, especially from FBI. A cyclone separator, is a vertical cylinder that uses centrifugal force to separate particulate matter from the air stream. Cyclone separators can generally be classified into large and small diameter. Large diameter cyclones have lower collection efficiencies, especially for smaller particles. They usually operate at a pressure drop of 1 to 3 inches of water column.

Small diameter systems are capable of removing more than 90 percent of particles greater than 10 microns and usually operate at a pressure drop of 3 to 5 inches water column.

### **17.6.2 Spray Chamber**

A spray chamber may be a round or rectangular tank, into which water is introduced by a series of spray nozzles. There are three different methods of introducing the scrubbing spray: concurrent with the airflow, counter-current to the airflow and perpendicular to the airflow. Spray chambers are typically used as an initial process with an air pollution control system.

### **17.6.3 Venturi/Impingement Tray Scrubber**

Flue gas enters the precooling section of the Venturi/Impingement Tray scrubber, where spray nozzles provide cooling water. The cooled air then enters the venturi throat where high gas velocity and additional scrubbing water create a high degree of turbulence, which ensures contact between the water droplets and particulate matter.

The more the throat of the venturi is restricted, the greater the headloss through the unit and, up to a point, the greater the removal efficiency. The air then passes up through the base of an impingement scrubber, which consists of trays mounted perpendicularly to the flow in a large vessel. Scrubbing water is introduced from ports along the side of the trays and flows out on the tray surface. As the air passes through each perforation in the tray, it creates a jet that bubbles up through the water and entrains particulate matter. A mist eliminator at the top of the unit reduces water carryover into subsequent APCDs.

### **17.6.4 Venturi Scrubber**

Most venturi scrubbers have a rectangular flange to expose the dirty gases to a multi-rod deck.

Scrubbing liquid is introduced through a series of nozzles ahead of the deck and in the direction of the gas flow. As the liquid and gas pass through the multi-rod deck, the stream effectively forms a series of several venturis between the rods.

The saturated gas, with entrained particles, is forced to change direction and enter the expanded area prior to the pre-demist vanes. Chevron type vanes remove more than 90 percent of the free liquid and serve as a distribution baffle for the final demist section. The final demist section removes the remainder of the liquid droplets with the entrained particulate, and the clean gas passes through to the outlet.

### **17.6.5 Wet Electrostatic Precipitator**

The Wet Electrostatic Precipitator (WESP) is a fine particulate scrubber, and performs best when used as a final polishing device downstream of a primary scrubber. Currently at least thirteen MHFs and two FBIs are equipped with WESPs. The average particulate emission rate from the MHFs equipped with WESPs is 0.19 lb/ton dry solids, ranging from 0.02 to 0.5 lb/ton. However, two of these WESPs were installed without venturitis and one was sized for only 75 percent removal efficiency. If these two scrubbers are not included, the average particulate emission rate for WESPs becomes 0.10 lb/ton, with a range of 0.02 to 0.27 lb/ton. The WESPs installed for FBIs have a similar range of particulate emissions. A properly designed and sized WESP installed upstream of a combination of a venturi/impingement plate scrubber is capable of reducing the particulate emissions from biosolids incinerators to less than 0.1 lb/ton. The materials of construction are very important corrosion problems have been experienced with WESPs. (WEF 1999)

## **17.7 Organics Emission Controls**

As previously discussed, Total Hydrocarbons (THC) or Carbon Monoxide (CO) are monitored to represent all organic compounds in the exhaust gas that are covered by the Part 503 Rule. The discharge limit from the dispersion stack is 100 parts per million based on volume (ppmv) of THC or CO at standardized oxygen and moisture content.

The oxidation of organics requires high ignition energy. The parameters affecting the oxidation rate are temperature, time, turbulence, oxygen availability, size, location, and proximity of the flame relative to the gas flow. The extent of afterburning required to reduce THC and CO levels to 100 ppm at 7 percent oxygen depends on the concentration and oxygen level in flue gas.

A survey was performed that included twenty-two MHFs with an average CO emission rate of less than 100 ppm at 7 percent oxygen. Four of these MHFs are equipped with internal afterburners, five with conventional-external (detached) units, two with side-flue, two with side-exit and nine with post-scrubber devices. (WEF 1999)

### **17.7.1 Internal Afterburner**

As mentioned above, four of the MHFs included in the survey are maintaining CO concentrations below 100 ppm at 7 percent oxygen with internal afterburners. These MHFs have been modified to use upper hearths as internal afterburners, and biosolids incinerated in these furnaces are thermally conditioned. Because thermally conditioned biosolids dewater well and are void of bond-water, they can be ignited easily and burn quickly without predrying. In this case, the MHF functions like a mono-hearth with the

upper hearths being utilized as an internal afterburner while the lower hearths are used to burn char and cool ashes. These furnaces have no drying hearths.

Many MHFs are equipped with top hearth afterburners, which are currently being used for the control organic emissions. In the top hearth afterburner configuration, biosolids are fed into the second hearth and the top hearth is equipped with auxiliary fuel burners. The disadvantages to achieve the required CO reduction with a top hearth afterburner are the reduction of the incineration capacity and the cost of auxiliary fuel. (WEF 1999)

### **17.7.2 Conventional - External Afterburner**

The conventional-external afterburner is a detached refractory lined vessel equipped with auxiliary burners. Although carbon monoxide can be oxidized in a conventional afterburner to the required levels, the cost of auxiliary fuel is prohibitive. The addition of conventional afterburners to existing MHFs also is often difficult due to space restrictions in the buildings where MHFs are housed. (WEF 1999)

### **17.7.3 Side Flue Afterburner**

This is a variation of the top hearth afterburner. In the side-flue afterburner configuration, biosolids are fed into the second hearth and all the drop holes in the top hearth are blocked to force flue gases to go through a side flue equipped with auxiliary fuel burners. As in the top hearth afterburner, the incineration capacity of the furnace is reduced and the requirement for auxiliary fuel is high. (WEF 1999)

### **17.7.4 Side Exit Afterburner**

In the side-exit afterburner configuration, flue gas is exhausted from the burning hearth and retained in an external chamber to oxidize carbon monoxide and other products of incomplete combustion. A portion of combustion products is used for drying biosolids at top hearths, and recycled back to the furnace below the burning hearth. In this configuration, some furnace capacity is lost. In addition, maintaining furnace draft can be difficult. (WEF 1999)

### **17.7.5 Post Scrubber Afterburner**

In the post-scrubber afterburner configuration, flue gases are scrubbed then subcooled in an impingement plate or packed tower followed by an afterburner with heat recovery. The heat recovery may be accomplished with a regenerative thermal oxidizer (RTO) or a recuperative heat exchanger.

### **17.7.6 Regenerative Thermal Oxidizers**

Thermal oxidation is a process where exhaust gas is drawn into equipment and heated to an oxidation temperature of 1500 °F. Any volatile organic compounds in the flue gases are converted in a half of a second or less into water vapor and carbon dioxide before being harmlessly discharged into the atmosphere.

The RTO unit consists of a central combustion chamber and two or more media filled recovery chambers. The incoming process gases are directed up into an "inlet" chamber through the heat recovery media into the combustion chamber to be destroyed then drawn

down through an "outlet" chamber releasing up to 95 percent of its heat for preheating of the next inlet cycle. Chambers regularly cycle from inlet mode to outlet mode regenerating the heat exchange media.

### **17.7.7 Flue Gas Recirculation**

Flue gas recirculation (FGR) is a process where flue gas from the feed hearth of a multiple hearth incinerator is transferred to a hearth below the volatile burning hearth.(CBE)

In this process, 20 to 30 percent of the flue gas (at 350° to 400°C) is recirculated and mixed with the combustion air. The resulting dilution in the flame decreases the temperature and availability of oxygen therefore reducing thermal nitrogen oxide formation. The flue gas is usually recirculated subject to the operational constraints of flame stability, impingement, and boiler vibration.

Retrofitting an existing incinerator with flue gas recirculation involves installation of a system to extract the flue gas from the boiler unit, additional ductwork, fan and a fly ash collecting device. The fly ash control device is necessary to clean the flue gas prior to recirculation. Excessive flue gas recirculation can result in flame instability problems and increased steam temperatures.

## **17.8 Dispersion Characteristics**

As indicated previously, the dispersion characteristics of the site have a significant impact on the discharge limitations for several of the regulated metals. The dispersion factor used in calculating the allowable metals concentration in the biosolids to be incinerated is determined through the use of air dispersion models.

Dispersion models include parameters such as local topography, land uses in the area, nearby buildings, and design characteristics of the exhaust air stack. While there may be little that can be done to improve the dispersion characteristics in terms of topography or land uses, good engineering practices should be applied to design of the exhaust stack. Factors such as location of the stack relative to other structures, exhaust gas velocity and stack height must be carefully considered.

Models were developed by USEPA to provide guidance on determining stack height and to ensure that excessively tall stacks would not be constructed solely for the purpose of achieving dilution (USEPA 1979). The maximum height stack that can be used in modeling to determine maximum metals concentration in biosolids to be incinerated is determined by the following equation.

$$H_g = H + 1.5L$$

Where:

H<sub>g</sub> = Good engineering practice stack height measured from ground level elevation at stack base

H = Height of nearby structure(s) measured from ground level elevation at base of stack.

L = Lesser of height or width of nearby structure.

**17.9 Stack Exhaust Plumes**

Steam plumes from dispersion stacks are not typically a problem with MHF because many of these incinerators have been equipped with RTOs as the last treatment process to reduce organics. As a result, the discharge temperature is too high to allow a visible steam plume to form. With efficient gas cooling systems that are provided for most FBI, the exhaust from Air Pollution Control systems is generally about 200F above the scrubbing water temperature, or approximately 70° to 1000F. Although steam plumes will not be visible under most ambient conditions at these temperatures, there will be conditions under which a stack plume will be obvious. While these occasional plumes may not have any harmful effects, the aesthetic effects may be an issue.

**17.10 Record Keeping and Reporting**

Table 17.2 summarizes the air quality related monitoring requirements for a biosolids incinerator.

**Table 17.2 - Air Quality Monitoring Requirements for Biosolids Incinerators**

<b>Parameters</b>	<b>Amount of Biosolids Incinerated (metric tons per year, dry-weight basis)</b>	<b>Required Monitoring Period</b>
Arsenic, cadmium, chromium, lead and nickel in biosolids	< 290 ≥ 290 but ≤ 1,500 ≥ 1,500 but ≤ 15,000 ≥ 15,000	1x/year 1x/quarter year 1x/60 days 1x/30 days
Beryllium and mercury in biosolids or exhaust gas	Not applicable	As required by permitting authority
THC or CO in exhaust gas	Not applicable	Continuously. Monthly averages reported that equal arithmetic average that include at least two readings per hour.
Oxygen content in exhaust gas	Not applicable	Continuously.
Information needed to determining moisture content in exhaust gas	Not applicable	Continuously.
Combustion temperature in incinerator	Not applicable	Continuously.
Air pollution control device conditions as required by permitting authority.	Not applicable	As require by permitting authority.

The air pollution control device conditions that must be monitored and reported will be based on the results of the performance test. Examples of the types of parameters monitored include the

pressure drop in a venturi scrubber, gas temperature entering various devices, and operating temperature of afterburning devices.



## References

Baturay, A., (1999), *“How Biosolids Incinerators are Meeting More Stringent Air Pollution Regulations”*, WEF/AWWA Joint Residuals and Biosolids Management Conference

Chavond-Barry Engineering Corp., Blawenburg, N.J., (1999), *“Flue Gas Recirculation in Multiple Hearth Sewage Sludge Incinerators”*,

Coalition for Responsible Waste Incineration, *“Particulate Emissions from Hazardous Waste Incinerators”*

Dominak, R.P., (February, 2001), *“Incineration: Current Practices and Future Direction for Biosolids Incinerators”*, Proceedings of the Residuals and Biosolids Management Conference, February, 2001

Eastern Research Group, (November, 1992), *“Technical Support Document for Sewage Sludge Incineration”*, National Technical Information Service

Graham, G., *“Controlling Stack Emissions in the Wood Products Industry”*, PPC Industries 17IEA, *“Flue Gas Recirculation for NO<sub>x</sub> Control”*

Pacific Gas & Electric *“Industrial Heat-Recovery Strategies”*

Saint, W. W., (July, 1996), *“Thermal Dewatering of Biosolids at Bird Island STP, Buffalo, NY”*, ES&E

## Chapter 18 – Ash Management

---

While incineration provides significant volume reduction, there is still a significant quantity of material to be managed. Over a million dry tons of biosolids are incinerated each year. Incineration reduces these biosolids to approximately 400,000 tons of ash, which is either used or disposed (USEPA 1979).

The type of incineration process selected unit will impact the characteristics of ash and, to some extent, the quantity of ash. Combustion of grit, screening, and scum will also affect the characteristics and quantity of ash.

### 18.1 Critical Control Points / Operational Controls

There are a number of controls associated with ash management. They include:

- Quantity of ash
- Ash Characteristics
- Ash Collection

### 18.2 Quantity of Ash

The quantity of ash produced will essentially be equal to the inert fraction of the biosolids being incinerated. Strict air pollution control regulations allow very little particulate material to escape with the exhaust gas. Generally, the quantity of ash produced by a biosolids incinerator will range from 20 to 40 percent of the dry weight of the biosolids fed to the incinerator.

The quantity of ash may vary seasonally as a result of infiltration/inflow in the wastewater collection system or seasonal additions of chemicals to the wastewater treatment process for nutrient removal. Wastewater treatment facilities receiving heavy industrial discharges may also see fluctuations that correlate to production schedules for the given industries.

### 18.3 Ash Collection

The type of incinerator used impacts the physical characteristics of the ash generated. As a result, a basic understanding of the operating principles of Multiple Hearth Furnaces (MHFs) and Fluidized Bed Incinerators (FBIs) and the way each collects ash is essential to defining the physical characteristics of the ash generated by each technology.

#### 18.3.1 Ash Generation and Collection in a MHF

As discussed in Chapter 15 or 16, the MHF can be divided into four zones. The upper zone evaporates water from the biosolids. The second and third zones, proceeding down the incinerator, combust the volatile solids and fixed carbon contained within the biosolids. Ash is collected in the fourth zone of the incinerator, located in the lowest hearth of the MHF, where it accumulates in a layer several inches thick. Air for biosolids combustion is often introduced into the lower hearths of the incinerator. This contact

serves to cool the ash before discharge and warm the combustion air before it reaches the upper hearths.

Ash is discharged from the bottom of the MHF each time a rabble arm on the bottom hearth passes the port at the outer edge of the furnace. Normally this occurs two times per rotation or once every ten to 90 seconds depending on the speed of the center shaft. Because of the intermittent nature of the discharge, a small surge hopper is normally provided beneath the furnace. The three main methods of handling ash from the surge hopper are:

- Slurrying the ash with scrubber drain water and depositing it in a lagoon,
- Lifting the ash with a bucket elevator to a hopper from which it is loaded into a truck for disposal.
- Conveying the ash pneumatically to a hopper for transfer to a truck.

The first method, where the ash is mixed with water to form a slurry, is only appropriate where there is significant land area available. Its principal advantage is that there is little dust. Disadvantages include the heavy wear on slurry pumping systems, the potential for steam at the slurry tank, and the need to at least partially re-dry the ash for ultimate disposal.

Bucket elevators are normally employed at moderate size facilities to lift the ash to the elevation required to load a truck. Lateral movement is normally provided with either flat belt or screw conveyors. The ash is normally wetted to a sufficient degree to control dust. Pneumatic conveyance systems are typically employed at larger facilities. The pneumatic system must be equipped with a bag house or some kind of filter at the discharge point to control dust.

Ash taken from the bottom of the incinerator tends to have a coarse grain and a bulk density of 24 to 40 pounds per cubic foot. If handled with a wet collection system, the bulk density will be in the range of 90 to 120 pounds per cubic foot.

The volatile solids concentration will typically range from 0.5 to 1.5 percent with an average of slightly less than one percent. Studies of ash from numerous MHFs have shown a wide range of volatile solids concentrations, ranging from nearly zero to almost six percent. The average volatile solids content is normally slightly over one percent.

### **18.3.2 Ash Generation and Collection in a FBI**

Unlike a MHF, most if not all of the ash from a FBI is carried out of the top of the furnace and removed from the air stream by the air pollution control system. The exception occurs when large amounts of grit are incinerated. In that case, it may be necessary to periodically remove the coarser portion of the bed from the bottom.

A venturi scrubber is the most common means of removing particulate matter from the exhaust of a FBI. The collection mechanism in a venturi is impaction. As the exhaust air from the FBI is forced through the throat of the venturi at velocities ranging from 12,000 to 24,000 fpm, the particulates come into contact with water injected either into or just

ahead of the venturi throat. The venturi is followed by a centrifugal separator, which removes the ash slurry from the air stream.

The discharge from the venturi/collector system is typically a slurry with a total suspended solids concentration of about 10,000 to 15,000 mg/l and a particle size ranging from 0.2 to 0.25 mm. This slurry must be concentrated and often dewatered before the ash can be disposed or beneficially used.

Ash slurry from FBI can be discharged to lagoons for settling. Lagoon storage requires a relatively large land area requirements, and the need to eventually dewater the ash for disposal or use.

A common ash management system consists of sending the slurry to a gravity thickener where gravity separates the ash from the water. In some cases, a polymer is used to assist settling. The supernatant is recycled to the wastewater treatment facility and the thickened ash slurry is mechanically dewatered.

Ash from a FBI will typically have a bulk density in the range of 90 to 120 pounds per cubic foot. The volatile solids concentration will typically range from 0.5 to 1.5 percent with an average of slightly less than one percent.

### 18.4 Chemical Characteristics of Ash

As might be expected, the chemical properties of ash exhibit a wide range of constituents. Historical data for ash is often a poor indicator of existing characteristics due to improvements in biosolids characteristics as a result of pretreatment.

Essentially, the total quantity of metals in the ash will equal the quantity of metals in the biosolids being incinerated. Because incineration has the effect of reducing the total mass of material, the concentration of metals in the ash is greater.

Some metals will vaporize at the temperatures found in an incinerator and exit with the exhaust gas. Metals that are expected to partially vaporize during incineration are cadmium, lead, mercury and zinc. As discussed in Chapter 17, the emission control equipment available today will recover most metals volatilized during incineration with the exception of mercury. Typical characteristics of ash are summarized in Table 18.1

**Table 18.1 - Typical Characteristics of Biosolids Ash**

Constituent	Range of Composition, %
Silica (SiO <sub>2</sub> )	20-60
Alumina (Al <sub>2</sub> O <sub>3</sub> )	5-20
Iron oxides	2-25
Phosphoric pentoxide (P <sub>2</sub> O <sub>5</sub> )	3-15
Magnesia (MgO)	1-3
Quicklime (CaO)	10-30
Sodium oxide (Na <sub>2</sub> O)	0.1-1
Potassium oxide (K <sub>2</sub> O)	0.1-1
Titanium dioxide (TiO <sub>2</sub> )	1-3
Zinc oxide (ZnO)	0.1-0.5

### 18.5 Ash Disposal

Fusing ash using heat and chemicals or concrete is considered to be the best long-term solution to control the heavy metal content. It is a permanent solution for even the most prohibitive of standards.

A number of means could be engineered to implement the use of cement-stabilized ash. Perhaps the easiest would be to mix the cement and the ash with water at the plant site in a concrete mixer/hauler and transport the liquid mixture to the landfill or other suitable sites. Landfilling is normally the least costly method of disposal.

Interest in slagging combustion processes for municipal biosolids is strong in Europe and Japan, because high temperatures ensure volatile organic compound destruction and glassified ash stabilizes heavy metals so that they can not be leached. This technology is in the developing phase, and the available database is inadequate to define if whether there is metal fuming at elevated temperatures.

The majority of ash generated by biosolids incineration is disposed of in either Municipal Solid Waste (MSW) landfills or ash monofills. Due to the solids concentration within the ash, dust control is a significant issue. The requirements of 40 CFR Part 258 must be met if ash is placed in a MSW landfill. Any ash that meets the definition of a hazardous waste must comply with regulations in 40 CFR Parts 261 and 268.

### 18.6 Beneficial Use of Ash

Beneficial uses have been identified for biosolids ash. Many of these alternatives have been implemented on a full scale, while other alternatives have been used on a trial or pilot basis. As has been used in agricultural land application programs and in the production of building materials.

### **18.6.1 Land Application**

Ash has been described as a good fertilizer because of its phosphorus and lime content. In addition, it may contain valuable micro-nutrients. A study of ten incinerators in the United States (Furr and Parkinson) found the following fertilizer values.

Nitrogen 0.06 to 0.1 % dry weight

Phosphorus 1.0 to 5.2 % dry weight

Potassium 0.23 to 1.05 % dry weight

Limited research on the use of biosolids ash as a fertilizer has been conducted. The manner in which ash land application would be regulated also requires clarification. While not specific, it is anticipated the criteria contained in the Part 503 Rule would apply.

### **18.6.2 Structural Additive to Building Materials**

Biosolids ash has been used in the production of building materials. The ash has gained limited popularity. A barrier to using biosolids ash as an additive to structural materials such as concrete or asphalt is the fact that it is produced in relatively small quantities by most incinerators. As a result, it is not cost effective for many manufacturers to develop standards and quality control procedures to incorporate biosolids ash into their products. Biosolids ash can be used as filler in asphalt road mix. The ash serves as the fine material that fills the small voids among the pieces of gravel and increases the strength of the material. This also leaves a smaller void for water penetration and helps prevent freeze-out in the winter. Another use of ash is in building products. Although the iron will often color a concrete or cinder block a dull red, the ash will act as filler that allows the formation of sharp corners in the cinder blocks and concrete blocks.

## References

Mytelks, A.I., *et al.*, “Heavy metals and wastewater and treatment plant effluents *Pollution Control Fed.*, **45**, 1859 (1973).

Neufeld, R.D., and Hermann, E.R., “Heavy metal removal by acclimated activated sludge.” *J. Water Pollution Control Fed.*, **47**, 310 (1975).

“Interaction of Heavy Metals and Biological Sewage Treatment Processes.” U.S. Dept. Health, Education, and Welfare, Public Health Service Publ. 999-WP-2, Washington, D.C. (1965).

“Standard Methods for the Examination of Water and Wastewater.” 17<sup>th</sup> Ed., Am. Public Health Assoc., Washington, D.C. (1989).

Lue-Hing, C., Zenz, D.R., Kuchenrither, R., “Municipal Sewage Sludge Management: Processing, Utilization and Disposal”. *Water Quality Management – Vol. 4*, 1992

## Chapter 19 – Biosolids Management at Disposal Facilities

---

It is estimated that between 17 and 23 percent of the 7.1 million tons of biosolids generated in the United States in 2000 were managed at municipal solid waste facilities. Of this total it is estimated that at least 14 percent were landfilled, and 3 percent used as a daily or final cover. It is estimated that up to an additional 6 percent was used in yard waste or solid waste based composting programs (USEPA Biosolids Generation, Use, and Disposal in the USEPA 530-R-99-009 September 1999). Using these estimates, just under 1,000,000 dry tons of biosolids were landfilled or surface disposed in 2000. Over 200,000 dry tons were used as cover material.

This chapter addresses primary uses or disposal practices at municipal solid waste landfills. It also discusses dedicated land disposal programs which are practiced by a relatively small number of agencies.

### 19.1 Critical Control Points / Operational Controls

There are a number of controls associated with the management of biosolids at municipal solid waste landfills and dedicated land disposal sites. These include:

- Biosolids management regulations
- Biosolids solids concentration
- Transportation
- Material handling
- On site storage
- Odor control

Each control will be discussed following a description of the management practices available.

### 19.2 Biosolids Management at Municipal Solid Waste Landfill

At this time the majority of the nearly 1,000,000 dry tons of biosolids arriving at a landfill is disposed of with municipal solids waste (MSW). While currently practiced primarily as a disposal option, with careful management, biosolids use at a MSW landfill could benefit the landfill during its operation and following closure.

*Similar to biological wastewater treatment and biosolids stabilization, a landfill operated as a bioreactor is also a process to optimize the natural degradation of waste*

The concept of operating a landfill as a anaerobic bioreactor has been studied at the University level for more than a decade. It has captured the attention of landfill managers, the USEPA and state regulators. Similar to biological wastewater treatment and biosolids stabilization, a landfill operated as a bioreactor is also a process to optimize the natural degradation of waste. If this concept becomes reality, the use of biosolids at a MSW landfill would be considered a benefit.



The bioreactor landfill concept is being considered as a method to increase the extent and rate of decomposition within a landfill. The increased rate of decomposition would increase total volume capacity, maximize landfill gas generation, improve the management of leachate, and reduce post closure activities. Discussions also propose that the capture and management of landfill gas during the operation of bioreactor, will result in the reduction of greenhouse gases over the active and closed life of the landfill. (MSW Management, September/October 1999).

It is estimated that paper and food waste comprise the majority of the waste stream entering a landfill. Food is estimated to be 10 to 20 percent of the waste stream with paper contributing between 40 and 65 percent. Increasing the rate of decomposition of those materials could increase the “effective” volume of a landfill by as much as 50 percent (Waste News November 2000).

The benefits proposed for bioreactors include:

### *Rapid Organic Waste Conversion/Stabilization*

- Rapid settlement: Volume reduced and stabilized within five to 10 years of implementation.
- Increased gas unit yield, total yield, and flow rate: Almost all of the rapid and moderately decomposable organic constituents will be degraded within five to 10 years of closure.
- Improved leachate quality: Stabilizes within three to 10 years after closure.

### *Maximizing of Landfill Gas Capture for Energy Recovery Projects*

- Significant increase in total gas available for energy use.
- Potential increase in gas extraction efficiency.
- Additional greenhouse gas reduction from lessened emissions.
- Significant economy-of-scale advantage from high generation rate over a relatively short time.

### *Increased Landfill Capacity from Rapid Settlement*

- Increase in the amount of waste that can be placed into the permitted landfill airspace.
- Extension of landfill life through additional waste placement.

### *Improved Leachate Treatment and Storage*

- Significant biological and chemical transformation of organic constituents.
- Reintroduction of all leachate over most of the operational and postclosure care period significantly reduces leachate disposal costs.

### *Reduction and Postclosure Care, Maintenance and Risk*

- Rapid waste stabilization (within five to 10 years) minimizes environmental risk and liability as a result of settlement, leachate, and gas.
- In the event of partial liner failure, there should be no risk of increased gas generation, worsening leachate quality, or increased settlement rate or magnitude (MSW Management September/October 1999).

Some researchers feel that the greatest savings will be realized following closure.

Bioreactors require the moisture, organics, and nutrients that biosolids offer. To be successful, leachate must be recirculated within the landfill. This is counter to the “dry-tomb” approach of the USEPA sub-title D regulations.

To evaluate the effectiveness of bioreactors, USEPA has initiated project XL. Project XL represents excellence and leadership to promote new strategies and provide the data necessary to revise regulations. It is anticipated that the data collected between now and 2010 will answer the questions regarding the viability of landfills as bioreactors. If the results are positive, biosolids will be considered a feedstock. In arid areas the moisture provided by biosolids may be a benefit as opposed to a constraint.

### 19.3 Biosolids Use in the Production of Cover Material

*While acceptable for daily cover, these biosolid products are often too valuable for use at a landfill.*

Biosolids can be used in the production of daily and vegetative cover material at MSW landfills. The production of daily cover, due to its frequency of use, requires a much greater volume of biosolids than the production of vegetative cover. Vegetative cover is required for establishing growth over closed portions of a landfill.

To be valuable for use as a daily cover, biosolids should have a total solids concentration of at least 50 percent (Lue-Hing, Zenz and Kuchenritner, *Municipal Sewage Sludge Management: Processing, Utilization and Disposal*, Technomic Publishing, 1992).

Some biosolids products such as compost, alkaline stabilized material and dried material meet this solids requirement. It is also likely that they also meet the class B pathogen reduction and a vector attraction requirement. While acceptable for daily cover, these biosolid products are often too valuable for use at a landfill.

*Even when the biosolids product isn't being used for daily cover, it is recommended that an agency work with the MSW landfill managers to make them aware of the benefits of the product.*

The value of other materials being used as a daily cover should be compared to the value of the biosolids product. Even when the biosolids product isn't being used for daily cover, it is recommended that an agency work with the MSW landfill managers to make them aware of the benefits of the product. This can be a benefit to both. A use for the biosolids product, if storage becomes an issue, and an additional source of cover material, if adequate quantities are not available or affordable.

Biosolids that have been digested and dewatered or lime treated to meet the class B pathogen reduction requirements, can also be used as a daily cover. To meet the total solids requirement of the landfill manager, the biosolids may require blending with soil or another amendment such as wood chips or ash.

This practice can benefit the landfill manager by reducing the cost of cover material. This savings should be compared to the cost and operating requirements associated with manufacturing cover material using biosolids.

The total solids concentration requirement for biosolids and biosolids products being used for final cover is not as high as that for daily cover. It is recommended that the total solids concentration be greater than 20 percent, and that material with the minimal solids content be blended with soil at a 1:1 ratio. (Lue-Hing et al. 1992).

Concerns have been expressed regarding impact of biosolids as a cover material on leachate characteristics. Work conducted by the USEPA Office of Research and Development found that the addition of biosolids to landfill improved leachate characteristics, measured as chemical oxygen demand (COD) (Farrel, J.B., G.K. Dotson, J.W. Stamm and J.J. Walsh, 1988 “The Effects of Sewage Sludge on Leachates and Gas from Sludge Refuse Landfills” Presented at the Residuals Conference of the Water Pollution Control Federation, Atlanta, Georgia).

In addition to a significantly reduced organic strength as measured by COD, the concentration of Cd, Cr, Cu, Pb, Ni, Fe, and Zn were lower in the leachate collected from cells containing biosolids.

### **19.4 Biosolids Disposal at Dedicated Facilities**

A number of agencies have elected to disposal of biosolids at “dedicated” facilities. These include:

- Mono fills
- Land disposal sites
- Disposal Lagoons

Biosolids only landfills are defined as disposal sites that are used exclusively for the disposal of biosolids. The application of the biosolids can either be in the dewatered or liquid state. However, the biosolids are usually applied in the dewatered state.

Dedicated land disposal (DLD) sites are those sites where the biosolids are applied to the surface of the land on a routine basis where the objective is disposal rather than use. At DLD sites no crops are grown. Sites normally employ annual application rates of 50 to 100 dry tons per acre per year. The biosolids are usually applied as a liquid.

Containment of biosolids landfills is of extreme importance. The most cost-effective landfills are those where the natural soils at the site support such a development. (Lue-Hing et al 1992).

Lagoon disposal is a method available which stabilizes biosolids through anaerobic endogenous respiration while controlling odors using an aerobic water seal. Biosolids are typically introduced to the bottom of a 15 to 20 foot deep lagoon. The biosolids and anaerobic liquid are capped by an aerobic zone near the water surface. The aerobic zone is maintained by natural convection and surface aeration, a facility operating a disposal lagoon in central California reports a 45 percent reduction of volatile solids after one year of storage (Lue-Hing et al 1992).

### 19.5 Biosolids Management Regulations Impacting Surface Disposal and Landfilling

The Part 503 Biosolids Rule regulates the surface disposal of biosolids other than landfilling of biosolids with MSW in an MSW landfill, which is required to meet the Part 258 Landfill Rule. According to Design, Operation and Closure of Municipal Solid Waste Landfills (USEPA, 1994b), all biosolids disposed in MSW landfills must pass the paint-filter liquids test (dewatering biosolids to about 20 percent solids or more will generally meet this goal). Furthermore, the biosolids cannot contain more than 50 parts per billion of polychlorinated biphenyls (PCBs) (40 CFR Part 761) and must not meet the definition of hazardous wastes under the Resource Conservation and Recovery Act (RCRA) (that is, they must not meet the definition of hazardous waste as defined by RCRA or the Toxicity Characteristic Leachate Procedure test).

Biosolids used as MSW landfill cover should be dewatered to achieve soil-like characteristics. The Part 258 Landfill Rule requires that the daily MSW landfill cover consist of 6 inches of earthen material (or alternative materials or thickness approved by the state) and that the solid waste be covered at the end of each day or more frequently as needed to control disease vectors, fires, odors, blowing litter, and scavenging. Biosolids can be used as part of a final MSW landfill cover, which must meet the Part 258 Landfill Rule cover criteria for permeability, infiltration, and erosion control.

For surface disposal in biosolids-only facilities, Part 503 Rule requires that the site meet certain locational restrictions similar to the site restrictions in the Part 258 Landfill Rule. Provisions for closure and postclosure care must be made, and a plan for leachate collection (if the unit is lined), methane monitoring, and public access restrictions must be developed. If the surface disposal unit is unlined, the biosolids must meet concentration limits on arsenic, chromium, and nickel. Also, the surface disposal unit must meet management requirements similar to those for MSW landfills. These management practices include requirements for runoff collection, leachate collection and disposal (if the unit is lined), vector control, methane monitoring, and groundwater monitoring or certification, and restrictions on public access, growing of crops, and grazing of animals. See the Part 503 Biosolids Rule described in Chapter 3 and the USEPA Plan English Guide, 1994 for additional information (Biosolids Generation, Use, and Disposal in the United States, EPA 530-R-99-009, 1999).

### 19.6 Biosolids Solids Concentration

The optimum solids concentration is dependent upon the management practice. In most landfill scenarios, well dewatered, greater than 20 percent solids is desired. In some states required. The advent of bioreactor landfill may reduce or eliminate that requirement. If that is the case, transportation cost will play a larger role in the decision making process.

### 19.7 Transportation

Transportation of biosolids is discussed in Chapter 6. It is mentioned as a critical operational control in this chapter to emphasize the importance to tarps and clean vehicles. Well maintained, clean, tarped, vehicles rarely smell.

### 19.8 Material Handling

Material handling represents the single greatest obstacle to managing biosolids at a MSW landfill. Three “C’s” are important:

- Consistent characteristics
- Consideration of the landfill operator’s schedule
- Communication

Biosolids are difficult to manage in a landfill setting. The confidence and cooperation of the landfilling manager is extremely important.

Any mixing equipment used must be capable of processing biosolids. A number of facilities have reported equipment failures (Lue-Hing et al 1992). A number of these failures are the result of misapplication of equipment.

### 19.9 On-Site Storage

On-site storage should be provided. On-site storage allows the staying of biosolids for periods when the landfill operator does not need them. Having a dedicated location provides the capacity necessary and minimizes any confusion. Consider the use of limestone for pad surface. The limestone provides a good base material, raises the pH of soil it is in contact with, and can have a limited effect on odor generation.

### 19.10 Odor Control

Odor associated with biosolids are certain to reduce the appeal of the material. If there is a strong odor, landfill managers will be reluctant to take advantage of the benefits biosolids offer.

Provide well stabilized material. (This will result in reduced odor potential and improved consistency). Both of which will increase the value of your product.

It is recommended that supply of lime or wood ash be available to cover stockpiles and reduce odor potential. While beneficial for odor control, these materials present their own handling problems.

The location of any stockpile should take into account prevailing winds and the location of workers and neighbors.

## References

Farrel, J.B., Dotson, G.K., Stamm, J.W. and Walsh, J.J., (1988), *“The Effects of Sewage Sludge on Leachates and Gas from Sludge Refuse Landfills”*, Presented at the Residuals Conference of the Water Pollution Control Federation, Atlanta, Georgia

Lue-Hing, C., Zenz and Kuchenritner, R., (1992), *“Municipal Sewage Sludge Management: Processing, Utilization and Disposal”*, Water Quality Management – Vol. 4, Technomic Publishing

MSW Management, (September/October, 1999),

United States Environmental Protection Agency, (September, 1999), *“Biosolids Generation, Use, and Disposal in the United States”*, (USEPA 530-R-99-009)

Waste News, (November, 2000)

## Chapter 20 - Economic Considerations

---

### 20.1 Introduction

For the biosolids generator, biosolids management has two principal components: the dollar costs associated with capital and operating expenses, and the more subjective component that deals with the activities and environmental values of the final recycling or disposal method(s) employed by a generator. Ideally, biosolids programs should be managed in a way that minimizes costs, while also considering other important factors. However, in the final analysis, support for a biosolids program will be garnered through economic justifications that can pass review of municipal officials and the sewer system customers.

This chapter provides guidance on establishing biosolids program goals, determining program costs, comparing alternative management methods, and developing secondary management options.

### 20.2 Components of an Effective Biosolids Program

When asked, most biosolids program managers and officials often say that several factors are important in evaluating the effectiveness of their biosolids program. They are:

- Cost
- Reliability
- Flexibility
- Public Acceptance
- Regulatory Compliance

Biosolids program managers may not always agree that “cost” is the factor that most often determines the direction of the biosolids program. However, overall program costs alone often drive the decision-making process. Operating a cost-effective biosolids program, one that considers the “other factors”, will result in a better program than a program that considers costs alone. These other factors should be given equal weight when deciding on program priorities.

Historically, biosolids recycling programs have included a certain degree of risk. The biosolids manager must be prepared to address the risks and factor them into program evaluations.

Changing regulations and low public acceptance are two of the significant risk factors. When working through the challenges of these concerns, and the level of risk is lowered, program costs are generally reduced.

Consider alternative processes that contribute to good performance, reduce risks and offer reasonable costs. Thickening and dewatering equipment can reduce handling costs for final biosolids product. Storage facilities give flexibility to hold biosolids during periods of inclement weather. Good digestion facilities reduce the risk of nuisance odors from land-applied biosolids and thereby reduce the risk of public acceptance issues. Although these processes may have

associated capital costs, making these changes may result in a more reliable and flexible biosolids program.

### **20.3 Setting Program Goals**

Managers and operators are expected to guide their biosolids program management toward cost effective solutions. However, evaluations of management options should combine information about program goals and costs.

To set program goals, begin by listing the factors that are important in operating the program. All of the “factors” listed in Section 20.3 should all be considered. Or there may other important factors that are not listed here. Survey the officials (decision-makers) and have them rank this list of factors in terms of importance. Schedule a meeting with the officials to review the results of the survey, and discuss in detail how all of the factors will effect the overall effectiveness of the program. Once there is a consensus among the officials regarding the factors that are important to the program, the basis for a biosolids program evaluation can be established.

Do not put all your biosolids eggs "in one basket" is an old adage to keep in mind. Even the best of programs can become undone by unforeseen events. The solution is to have several outlets for biosolids. Options typically include land application, landfilling, incineration, and further processing at another treatment facility. Knowing the costs related to each of these options within a region is important. This information is available from colleagues at other facilities or the utility's consulting engineer.

### **20.4 Economic Considerations**

One of the factors to be considered in evaluating the effectiveness of a biosolids program is cost. Cost analyses, or economic evaluations, can be conducted for a variety of reasons such as, determining current day program costs, comparing different program alternatives, or identifying areas for program improvement.

Several steps are required to carry out an evaluation. They are; predicting solids production, calculating operation & maintenance (O&M) costs, and estimating capital costs. Based on the information generated in these first steps, the unit costs for the biosolids program and for other possible program alternatives can be calculated.

The project engineering consultant is trained to conduct economic studies. Don't hesitate to call upon them for assistance in making biosolids program decisions. Or, for additional information regarding estimating costs for land application systems, refer to the EPA Process Design Manual for Land Application of Municipal Solids (EPA-625/K-95/001).

### **20.5 Estimating Solids Production**

To begin an economic evaluation, the current solids production rate at the facility being evaluated must be established. For most evaluations, it is also helpful to estimate current peak and future solids production rates. Generally, historic plant operating data can be used for solids production estimations, such as:



- Waste solids volume (gpd)
- Waste Total Solids (%TS)
- Waste Volatile Solids (%VS)
- Volatile solids reduction through your digestion process (%VS)

Refer to Chapter 2 – Wastewater Treatment Overview, for guidance in estimating solids production.

If the service area for the facility is growing, it is important to estimate future solids production rates as well. Future solids production information can be useful in evaluating the economic benefit of proposed capital projects or considering alternative management practices. The steps needed to estimate the future solids production are summarized as follows.

1. Develop an average production “ratio” using your facility’s current influent BOD loading (lbs/day) and monthly average “total solids production” (lbs/day) from the example above.
2. Predict the future influent BOD loading and apply the average production ratio (from 1 above) in order to estimate future total solids production.
3. Make assumptions regarding future plant performance, such as: total solids (%TS), volatile solids (%VS), and additional VS reduction (%VS). Consider the effect of increased production levels on process detention time. You may want to assume a lower volatile solids reduction efficiency, if process detention times decrease.
4. Using the information in 3 & 4 above, calculate the future net solids production rate.

It may be important to also take other factors into considerations when thinking about the economic impact of the facility’s future needs. For example, future increases in biosolids production and seasonal limitations to access land application sites may cause the storage capacity at the facility to be exceeded at certain times of the year. It may be wise to look at other options in dealing with temporary storage problems, such as making arrangements to transport biosolids to a local landfill, incinerator, or other treatment facility with excess storage capacity. Even though these options may be more expensive on a unit cost basis, biosolids program reliability may be more important in this situation.

### **20.6 Factors Impacting O&M Costs**

The cost of labor and materials consumed in producing a product is classified as operating and maintenance expenses. Biosolids program operation and maintenance (O&M) costs typically include labor, vehicle operating cost (fuel, maintenance, etc), electrical power, chemicals, spare parts, analytical testing, insurance, training, public relations, and permitting fees. Labor, transportation, and/or alternative end use (especially disposal) typically account for the largest portion of the O&M annual cost. Establishing O&M costs can be useful in looking at current program efficiencies or in comparing different management alternatives.

Both operation and maintenance costs are frequently expressed in terms of dollars per unit of product on an annual basis. Section 20.9 describes how to determine unit costs (cost per dry ton). All biosolids programs should have established methods for determining the annual O&M unit costs. All costs associated with the biosolids program, as noted above, should be included. Establishing line items in the annual operating budget for biosolids O&M costs is an easy way to determine annual costs associated with the biosolids program.

When comparing alternative management methods, the O&M costs associated with each individual component (labor, fuel, chemical, etc) need to be compiled. The primary “controlling” cost factor for any alternative management method can be identified by comparing the individual O&M component costs. This can be an interesting exercise, whereby overall program costs may be reduced by concentrating on reducing the controlling cost. Costs common to all alternatives in the same period of time (eg year) may be eliminated for convenience since their difference will be zero. It is important that care be exercised in estimating the dollars that will be spent for O&M under all plans.

### **20.7 Establishing Capital Costs**

The principle that \$1 today is more valuable than \$1 in 5 or 10 years later is called the “time value of money”. The time value of money is just one of the factors to consider when establishing capital (building) costs. The methods used to compute capital costs are “present worth” and “equivalent annual worth”.

Capital costs usually consist of expenses associated with building construction, the purchase of equipment with a life cycle greater than five years and costing more than \$5,000, and purchase of land, along with related professional service expenses (administrative, financial, legal, and engineering) for these components. Capital costs are expressed in an annual budget as debt service or capital improvement expenses. It is important to understand how to work with capital costs if considering a construction project or equipment purchase, or in evaluating several management alternatives that involve capital costs. In order to develop a biosolids program capital cost, you will also need to separate the biosolids treatment portion from other treatment system capital expenses. This separated cost can be called the biosolids capital cost.

Two of the most commonly used methods of computing capital costs are “present worth” and “equivalent annual cost”. In using either method of calculating capital costs, the “life” of the project must be considered. In other words, how long will the equipment last? Present Worth and equivalent annual cost also consider annual disbursements for O & M over the “life” of the project.

Present worth can be defined as the value of a project at time 0, or when a future amount of money is converted into its equivalent present day value. It is preferred for making economic decisions related to setting a price for project alternatives. Equivalent annual cost can be defined as the uniform dollar amounts at the end of a defined period that are equivalent to a project’s cash flow. It is a method of calculating annual capital costs where capital costs remain the same each year until the debt is paid. When comparing process or equipment alternatives, the annual capital cost values will vary with the total cost, interest rate, and loan or bond term.

When correctly applied, all methods used to calculate capital costs should lead to the same conclusion. There are many good texts that provide a detailed explanation of the ways to establish capital costs. Engineering Economy (Ted G. Eschenbach, 1995) is one textbook that may be helpful. Facility engineers and consultants are also an excellent resource to tap when evaluating capital costs. For additional information regarding estimating capital costs for various solids treatment processes, refer to the EPA Process Design Manual for Solids Treatment and Disposal (EPA-625/1-79-011).

### **20.8 Determining Unit Costs (cost per dry ton)**

Evaluating the cost effectiveness of a biosolids program should include calculating the unit cost for the biosolids management alternative being used. This is an important exercise because it:

- allows comparison of the current management alternative to other possible alternatives (such as comparing the cost of landfilling to land application)
- assists in making critical decisions about the future direction of the biosolids program (such as deciding whether to land apply liquid biosolids or land apply dewatered biosolids)
- assists in predicting the cost of adding other end use options (such as adding a drum thickener to reduce the amount of water being transported)
- allows comparison of the biosolids program with other local and regional biosolids programs
- helps in making annual biosolids program budget decisions
- encourages managers to think about all aspects of the current biosolids program and how cost effective improvements can be made

When biosolids production data and total program costs (capital plus O&M) are known, unit costs (in dry tons) can be easily calculated. This is simply the total cost (amortized capital costs plus annual O&M costs) divided by dry solids production annually for a unit cost in dollars per dry ton. The costs for processing (such as digestion or dewatering) and off-site handling (such as can land application) should both be established. These costs can be compared among biosolids program alternatives or to unit costs of biosolids programs at other facilities. It is also interesting to compare program unit costs to those reported in professional magazines or industry reports.

Calculating the unit cost for the current biosolids program is generally the first step in evaluating a program. Once the time is spent to calculate the unit cost, compare that cost to the cost of other management alternatives. It may be surprising to find out that the current operating method is cost effective. Or, maybe with only a few minor changes, the program costs can be reduced.

Historically, agricultural land application of biosolids has been among the more cost-effective programs. Costs for using biosolids for reclamation work and landfill disposal costs tend to be higher. These above comparison costs are for off-site handling alone, and do not include processing costs necessary to prepare a recyclable product.

### 20.9 Consider all Factors Associated with Alternative Management Methods

Generate a list of all the positive factors associated with the management alternative selected. But, don't overlook the value of selecting a secondary management method, as an option. For example, contracting with another local treatment facility to take liquid biosolids when access to land application sites is not possible may be wise. Most options require some sort of pre-qualification. Don't wait until the need for the secondary option becomes apparent before investigating pre-qualification criteria.

Decisions should not be made on the basis of economic considerations alone. The choice of alternatives should be based on considering all of the consequences that are likely to come from each alternative. When a more costly alternative is selected, the assumed economic value of the non-economic consideration(s) is the differential price between alternatives. In other words, non-economic items have an economic value or weighted cost value.

The problem is choosing from among a variety of alternatives in order to best satisfy the decision makers' immediate and longer-term objectives. Section 20.4 discusses setting biosolids program goals where the decision-makers take part. The principles and procedures of the selection process, especially when the economic characteristics of alternatives are of significant concern, require use of a consistent procedure. In general, the process of making decisions consists of a number of well-defined steps. These same steps can be applied to all types of decision-making. They are listed below.

- Define problem – Don't define the problem too broadly or the problem may seem insurmountable; don't define the problem too narrowly or better solutions may be overlooked. The key skill is to ask the right questions.
- Select objective – The correct objective is to consider the time value of money and all costs and benefits.
- Identify alternatives – Choose as many alternatives as possible. Brainstorming is usually a helpful process.
- Evaluate consequences – The first round of consequences should be evaluated broadly. Consequences for the better alternatives should be evaluated in greater detail.
- Selection – Selecting the best alternative is related to selecting the best objective. If the wrong objective is chosen, then the selection will not be the best. Often the process is selection of the best choice from the best alternatives...but the lowest cost alternative may not be the one selected.
- Implementation – The key to implementation is to involve all those who will be affected by the selection.
- Follow-up – The results are monitored and refinements or changes are made according to the data collected.

It is unrealistic and inappropriate to expect estimates of costs and revenues to always determine the best alternative. The selection process will have to account for other factors, such as those in Section 20.3, Components of an effective biosolids program.

### 20.10 Program Costs

There are tradeoffs between processing costs and end use costs. Utilities have an important choice to make between incurring processing costs or end use costs. Biosolids stabilization and dewatering processes cost the utility capital, operations and maintenance expenses. Simpler processes typically have lower treatment costs than more complicated processes. For example, the production of Class A compost, advanced alkaline lime product, or heat dried pellets are significantly more costly than production of digested cake. Class A products, however, may be sold to customers, and thereby have low cost for handling outside the treatment plant. The benchmarking study by the Water Environment Research Foundation (*Benchmarking Wastewater Operations—Collection, Treatment, and Biosolids Management*, Project 96-CTS-5) indicates that, even when the lower utilization costs of Class A products are considered, utilities producing Class B products for beneficial use enjoy lower total costs for biosolids handling.

Comparing the cost of operation at one facility to the costs of utilities elsewhere in the state and nation should be undertaken. While not a lot of information has been published that provides useful comparisons, the Water Environment Research Foundation (WERF) sponsors national conferences and research projects that provide up-to-date information. WERF's benchmarking report provides a good basis for comparison. A paper presented at Water Environment Federation's Residuals and Biosolids Management Conference in 2000 reported a range of costs for biosolids treatment and end use from a low of \$144 to a high of \$948 per dry ton. The average cost was reported to be \$419 (McMillon et al., 2000). This paper can be used as a guide in looking at biosolids program costs and comparing costs from other facilities.

The cost of biosolids management is very much affected by the percent solids in the biosolids material. One dry ton of biosolids is equivalent to 40 tons of liquid biosolids at \_\_\_% TS, five tons of biosolids cake at \_\_\_%TS, two tons of screened compost, or one ton of heat-dried biosolids pellets. The cost of transporting biosolids products may constitute two-thirds of the total biosolids utilization costs, which demonstrates that transportation of water can be a major cost item for the utility.

### 20.11 Economic Benefits of Biosolids Recycling

As a manager of a biosolids program, it may be beneficial to talk about the economic value of biosolids recycling. *BioCycle* magazine published a detailed analysis of the value of biosolids produced by the Hampton Roads Sanitation District. The value of biosolids was calculated to be \$95 per acre. This is about \$20 per dry ton of biosolids. The average dairy farming family, after covering all direct expenses of operations, earns a "profit" of less than \$8,000 annually. Clearly, biosolids use is a better alternative to commercial fertilizers. Another benefit of biosolids is that it helps replace soil organic matter lost from cultivated soils over time.

The equivalent fertilizer value of a facility's biosolids can be calculated by applying the commercial nutrient unit value to it. Table 9.1 provides an example of this exercise. Substitute the facility's biosolids nutrient quality analyses in the table.

**Table 20-1 Determining equivalent fertilizer value of lime-stabilized biosolids**

Nutrient	Quantity lbs/ton of biosolids (1)		Unit Value in \$/lb (2)		Biosolids Equivalent Value, in \$ (3)
	A	X	B	=	C
Total Nitrogen, N	76		0.18		13.68
Phosphorus, as P <sub>2</sub> O <sub>5</sub>	48		0.25		12.00
Potassium, as K <sub>2</sub> O	6		0.15		0.60
Lime, CaCO <sub>3</sub> equivalent	400		0.03		12.00
Total Biosolids Nutrient Value				=	\$38.28/ dry ton

1. Based on biosolids quality analysis, expressed as percent of nutrient content times 2000 pounds per ton.
2. Based on commercial fertilizer values published in the Pa Bulletin, effective 7/1/99.
3. Calculated by multiplying column A and column B
4. Based on a factor of 2.3 times total P in lab analysis, to give P<sub>2</sub>O<sub>5</sub> equivalence.
5. Based on a factor of 1.2 times total K in lab analysis, to give a K<sub>2</sub>O equivalence.

### 20.12 Common Sense Suggestions for Cost Effective Biosolids Programs

Some common sense suggestions to improve a biosolids program’s effectiveness are summarized below. Most of the suggestions noted below were included earlier in this chapter.

- Maximize on-site storage capacity (thicken liquid to reduce storage capacity requirements, construct additional storage facilities, construct dewatering facilities)
- Develop one or several management options to your primary method (land application, land reclamation, landfill, compost, incinerate, or further treatment at another facility)
- Plan to have proper paperwork for all management methods ahead of time (don’t wait until the storage pad or tanks are full)
- Consider program reliability, flexibility, public acceptance as well as cost (use a weighted cost for non-economic variables)
- Satisfy state and federal Part 503 Rule regulations (make sure the facility meet pollutants, pathogen, and VAR with current treatment process – make plans to improve treatment process if the facility doesn’t meet the requirements – be aware of changes in state and federal regulations and respond to changes)

- Develop a plan to satisfy future needs (compare projected storage and handling requirements to existing storage and equipment capacities -Determine how much land is needed for land application and schedule permitting new sites as they are needed)

## References

Eschenbach, T.G., (1995), *Engineering Economy: Applying Theory to Practice*, Richard D. Irwin, Inc.

McMillion, R.T., Rockers, G.F. and Lewis, W.R., (2000), “*Biosolids Treatment and Disposal Practices Survey*”, Proceedings of the 14<sup>th</sup> Annual Residuals and Biosolids Management Conference.

United States Environmental Protection Agency, “*Benchmarking Wastewater Operations—Collection, Treatment and Biosolids Management*”, Water Environment Research Foundation, Project 96-CTS-5

United States Environmental Protection Agency, (September, 1979), “*Process Design Manual for Sludge Treatment and Disposal*”, (USEPA 625/1-79-011)

United States Environmental Protection Agency, (1985), Handbook: “*Estimating Sludge Management Costs*”, (USEPA/ 625/6-85/010)

United States Environmental Protection Agency, (September, 1995), “*Process Design Manual for Land Application of Sewage Sludge and Domestic Septage*”, (USEPA/625/R-95/001)



## Appendix A - Risk Assessment

---

A complete description of the exposure assessment methodology and risk management issues for the proposed Part 503 Rule is found at 54 Federal Register 5764 - 5791. The following section describes the exposure assessment pathways modeled in the final Part 503 Rule and the basis for the decisions made in developing the approach for each use and disposal practice. A detailed discussion of the exposure assessment methodology (i.e., models, pathways, parameter values, assumptions and others) and the risk management decisions used by USEPA to develop the final Part 503 Rule numerical criteria are contained in the Technical Support Documents.

### *Pathway 1 - Evaluates human exposure to crops grown with biosolids.*

This pathway is designed to protect consumers who eat produce grown in a soil to which biosolids have been applied. The environmental endpoint is an HEI (highly exposed individual) assumed to live where a relatively high percentage of the available cropland receives biosolids. It is assumed that the HEI eats a mix of crops from land where biosolids were applied and from land where this did not occur. For Pathway 1, 2.5 percent of a consumer's intake of grains, vegetables, potatoes, legumes and garden fruits is assumed to come from biosolids-amended soil. Pathway 1 assumes uptake of biosolids pollutants through plant roots, not through direct adherence to crop surfaces as it assumes crops are washed before consumption. This pathway assumes agricultural use in commercial enterprises where crops for human consumption are grown.

Pathway 1 also includes the exposure of a person in a non-agricultural setting who ingests wild berries and mushrooms grown in biosolids amended soils. Exposure is based on the uptake of a pollutant by each type of berry or mushroom; a daily consumption of wild berries and mushrooms and a fraction of different wild berries and mushrooms grown in biosolids amended soil. The HEI for the non-agricultural Pathway 1 is an individual living where biosolids are applied to a forest, a public contact site or reclamation site. The dose for this pathway is the RfD for an inorganic pollutant; organics were not evaluated for this pathway because they do not concentrate in wild berries and mushrooms.

### *Pathway 2 - Evaluates the situation in which biosolids are added to the soil in a home garden.*

Pathway 2 differs from Pathway 1 primarily in the fraction of food groups produced on biosolids amended soil. For this pathway, as much as 60 percent of the HEI's diet of certain food groups is grown in the home garden where biosolids are used as a fertilizer. Pathway 2's home gardener produces and consumes potatoes, leafy vegetables, legume vegetables, root vegetables and garden fruits.

### *Pathway 3 - Assesses the hazard to a child ingesting undiluted biosolids.*

This HEI is the child who ingests biosolids from storage piles or from the soil surface. Pathway 3 assumes that the biosolids are not diluted with soil when exposure occurs. The ingestion rate of 0.2 grams (dry weight) per day for five years was based on the 1989 USEPA soil ingestion directive suggesting this value for higher risk children. Pathway 3 uses the integrated uptake biokinetic model (IUBK) rather than extrapolating from cattle data as had originally been proposed. The IUBK model used a lead blood level not to exceed 10 micrograms per deciliter, a 30 percent absorption value and a 95<sup>th</sup> percentile population distribution. Using these values in

the IUBK model results in an allowable biosolids concentration of 500 parts per million (ppm). The lead pollutant limit calculated by the peer review committee resulted from the observation that body burdens (absorption) of animals fed up to 10 percent of their diet as biosolids did not change until the lead concentration in the biosolids exceeded 300 ppm. USEPA therefore decided to select the more conservative numerical limit for the final rule to minimize lead exposure to children and set the allowable lead concentration at 300 ppm for Pathway 3.

*Pathway 4 - Evaluates human exposure from the consumption of animal products.*

The HEI for this pathway consumes the tissue of foraging animals that have in turn consumed feed crops or vegetation grown on biosolids amended soils. Pathway 4 depends on plant uptake of a contaminant being proportional to soil concentrations of the contaminant with uptake occurring through the roots to the edible portion or by volatilization from soil to above ground plant parts.

In the non-agricultural setting for Pathway 4, an individual consumes meat or products from wild animals that consume plants grown in biosolids amended soils (meat obtained from hunting herbivorous wild animals). For both agricultural and non-agricultural Pathway 4 HEIs, a background pollutant intake is also assumed.

*Pathway 5 - Evaluates the consumption of animal tissue that has been contaminated by direct ingestion of biosolids by the animal.*

The HEI consumes the tissue of foraging animals that have incidentally ingested biosolids. As with Pathway 4, the HEI is assumed to consume daily quantities of various animal-tissue food groups and is also assumed to be exposed to a background intake of each pollutant.

*Pathway 6 - Establishes level of pollutants in biosolids to protect animals ingesting plants grown on biosolids amended soils.*

This pathway assumes the livestock diet is 100 percent forage grown on biosolids amended soil and that the animal is exposed to a background pollutant intake. For Pathway 6, when a sensitive species has been identified for a specific pollutant, that species is used in the exposure assessment (e.g., livestock, domestic grazing animals, birds and rodents).

*Pathway 7 - Designed to protect the highly sensitive/highly exposed herbivorous livestock animal which incidentally consumes biosolids adhering to forage crops and/or biosolids on the soil surface.*

Pathway 7 assumes a 1.5- percent biosolids in the livestock diet and a background pollutant intake for the animal, as well as the most sensitive species for which data are available for each pollutant.

*Pathway 8 - Evaluates the risk of plant toxicity from pollutants in biosolids.*

USEPA determined an allowable pollutant concentration in the soil that would be associated with a low probability ( $1 \times 10^{-4}$ ) of a 50 percent reduction in young plant growth (not necessarily a mature plant yield reduction). Since phytotoxicity resulting from metals is sensitive to changes in pH, plant species and the degree of binding capacity in the biosolids matrix, USEPA elected to “cap” at the 99<sup>th</sup> percentile pollutant concentration from the NSSS for some metals.

*Pathway 9 - Designed to assist in establishing pollutant loading limits to protect highly exposed/highly sensitive soil biota.*

Since only limited field data exist which indicate levels at which inorganic pollutants become toxic to soil biota, the database available for earthworms which were raised in biosolids were used to set the criteria for this pathway. These criteria are based on a No Observed Adverse Effect Level (NOAEL) for the earthworm *Eisenia foetida*.

*Pathway 10 - Designed to assist in determining pollutant loading limits to protect highly sensitive/highly exposed soil biota predators (i.e., sensitive wildlife that consumes soil biota that have been feeding on biosolids-amended soil).*

A literature review identified what the Agency determined is a pollutant intake level protective of sensitive species in general. Chronic exposure assumes the sensitive species diet to consist of 33 percent of such soil biota.

*Pathway 11 - Evaluates human exposure to biosolids pollutants through inhalation.*

A tractor driver tilling the field is the HEI for Pathway 11, which evaluates the impact of suspended particles of dewatered biosolids. Pathway 11 assumes the incorporation of biosolids to a depth of 15 cm and a distance from the driver to the soil surface of 1 m with no more than 10 mg/cubic meter ( $\text{mg}/\text{m}^3$ ) of total dust.

*Pathway 12 - Designed to protect surface waters for beneficial use in order to protect both human health and aquatic life.*

The runoff of pollutants from soil on which biosolids have been applied is calculated so that the soil pollutant concentrations would not result in exceeding a Water Quality Criterion for a pollutant if the soil enters a relatively small stream. Rate of soil loss was based on the Universal Soil Loss Equation and a sediment delivery ratio. Water Quality Criteria designed to protect human health assume exposure through consumption of drinking water and resident fish and are also designed to protect aquatic life.

*Pathway 13 (Land Application) - Evaluates the exposure of a farm family inhaling vapors of volatile pollutants that may be in biosolids applied to the land.*

Six pollutants were included in this pathway: benzo (a) pyrene, dis (2-ethylhexyl) phthalate, chlordane, DDT, dimethylnitrosamine, polychlorinated biphenyls. These pollutants were selected from USEPA's hazard indices screen because they are semi-volatile. Organic pollutants which are highly volatile were not evaluated for Pathway 13 because such compounds would volatilize in the wastewater treatment processes and were therefore not considered to be of concern. Similarly, non-volatile metals were not evaluated in the vapor pathway. The vapor pathway assumes that the total amount of the pollutant spread each year would vaporize during that year. The allowable annual pollutant loading rate is thus equal to the amount that may be allowed to enter the atmosphere per unit area per unit time without exceeding the allowable pollutant concentration in the air. This concentration corresponds to the RfC, risk specific dose or an acceptable daily dose derived from an MCL. A plume model was used to determine the resultant pollutant concentration in the air with a never changing wind direction so that the HEI always remains in the centerline of the plume.

*Pathway 13 (Surface Disposal) - Evaluates the exposure of an individual inhaling vapors of any volatile pollutants for a 70-year period.*

The HEI is assumed to live at the downwind edge of the site and to inhale air, at 20 cubic meters per day, for 70 years, contaminated with volatile organic compounds from a surface disposal site. Volatilization rates were calculated with equations that consider constituent parameters.

Allowable lifetime exposure (at a risk level of  $10^{-4}$ ) is the basis for back-calculating the allowable loss rate to the vapor pathway. This value, divided by the fraction that vaporizes, provides the allowable pollutant concentration at the site.

*Pathway 13 (Incineration) - Evaluated exposure of an individual inhaling particulates and gases from an incinerator 24 hours per day, 365 days per year for 70 years.*

This HEI is located when the highest annual ground concentration of incinerator emissions occurs. This pathway evaluated five metals (arsenic, cadmium, chromium, lead and nickel) and approximately 70 organic compounds, which are represented by a surrogate measure of total hydrocarbons. Allowable metal concentrations are calculated by determining the removal efficiency across the incinerator and air pollution control device site-specifically and considering the feed rate to the system.

*Pathway 14 (Land Application) - Evaluated exposure of individuals obtaining drinking water from groundwater directly below a field where biosolids were applied.*

The allowable pollutant rate was determined from the MCL that must be met at the groundwater interface with no allowance for dilution, the decay rate of a pollutant and other factors that affect either the time period for decay or the dispersion of the peak concentration.

*Pathway 14 (Surface Disposal) - Evaluated exposure of individuals who obtained their drinking water from wells located 150 meters or less downgradient, using either MCLs or risk level of  $1 \times 10^{-4}$  for an HEI consuming two liters of water per day over a 70 year lifetime.*

Numerical limits were derived for both covered and uncovered surface disposal sites, considering pollutant losses through three processes: volatilization, on-site degradation, and leaching.

## Appendix A References

United States Environmental Protection Agency, (1994), *“Land Application of Sewage Sludge: A Guide for Land Appliers on the Requirements of the Federal Standards for the Use or Disposal of Sewage Sludge”*, 40 CFR Part 503. (USEPA/831-B-93-002b)

United States Environmental Protection Agency, (September, 1995), *“A Guide to the Biosolids Risk Assessment for the USEPA Part 503 Rule”*, (USEPA/832-B-93-005)

United States Environmental Protection Agency, (November, 1993), *“Technical Support Document for Land Application of Sewage Sludge”*, (USEPA 822/R-93-001a)

## **Appendix B – State and Regional Biosolids Contacts**

---

For information on state and regional biosolids contacts, visit the National Biosolids Partnership website at:

[http://www.biosolids.org/contact\\_inyourregion.asp](http://www.biosolids.org/contact_inyourregion.asp)

## Appendix C – Soil Characteristics

---

The primary objective of biosolids recycling is to improve soil productivity and fertility. For that reason, application practices need to take into account the basic characteristics of soil.

Understanding soil characteristics and reactions can help in making wise decisions about recycling practices, even though many believe that biosolids land application presents no greater risk to human health and the environment than most other farming practices. This section includes basic information on soil formation, soil properties, the hydrologic cycle, and soil chemistry.

### C.1 Critical Control Points / Operational Controls

Having a basic understanding of soil characteristics will help to:

- locate suitable sites for biosolids recycling
- understand the characteristics of soils and suitability for biosolids recycling
- gain a level of respect from the farmer
- appreciate local and regional issues related to soil fertility

The controls listed below can be used to improve overall biosolids program management.

- Be familiar with basic soil characteristics. Basic knowledge of soil characteristics is helpful in understanding issues dealing with: seasonally wet soils, erodible soils, soil compaction, ponding, etc.
- Understand how soil characteristics can impact your biosolids program. Properly managing a biosolids land application or reclamation program requires an understanding of the relationship of soil to: crop yields, soil fertility test reports, the fate of metals, biosolids application activities, and many other issues.
- Display a level of knowledge that allows you to communicate with regulators, conservation personnel, and farmers. Understanding basic soil characteristics shows a level of commitment and professionalism on your part.
- Use suggested references as important resources when evaluating potential biosolids application sites. There are several references listed at the end of this appendix that are especially important. The US Department of Agriculture's Soil Survey for the local area where the site is located should be consulted prior to the first application of biosolids. Soil Surveys provide valuable information about soil productivity and soil characteristics, and assist in proper management of the site.

### C.2 What is Soil?

Soil is the dynamic surface layer of the earth, composed of mineral and organic materials and sustaining a wide variety of plant and animal life. Soils develop over time through the physical and chemical influences of climate and biological organisms on geologic materials (the soil's **parent material**). Parent material may be either undisturbed, underlying bedrock, or may be deposits of minerals transported by gravity, wind, water, or ice.

Structurally, soils are a matrix of solid matter and pore spaces. The solid matter is mineral particles of rock fragments and organic matter from decayed plant and animal tissue. Pore spaces are filled either with air or with a solution of water and dissolved salts. Minerals account for approximately 45% of the soil by volume, organic material 1-5%, air 20-30% and water 20-30%. This combination of minerals, air and moisture provides an environment for a host of living organisms.

Many thousands of unique types of soil exist in the world. This is due to differences in the variety of soil formation characteristics.

### C.3 Soil Formation

Things that are a part of the soil formation process include: the type of parent material, climate, organisms, topography, and time. Soil in any one place results from the combined influence of climate and living matter acting upon the parent rock material. Topography, time, and how the soil is used condition this process. **Weathering** is the combined action of processes that physically disintegrate and chemically decompose rock.

Climate plays a dominant theme in the role of shaping the characteristics of the soil. Soils associated with climates with excess soil water are strikingly different in structure, composition, and fertility from those associated with a soil-water shortage. The most fertile soils from the standpoint of plant nutrients are those of the semiarid climates. However, unless they are irrigated, they are of limited agricultural value. Surplus water in warm climates is not conducive to producing rich agricultural soils because, under such conditions, the nutrients are leached from the soil. Soil formation is also shaped by the organisms living in or on the soil. Organic matter supplies humus that profoundly influences the soil by preventing the escape of nutrients from the soil.

The soil classification system used to categorize all soils has 10 basic categories called orders. Of the 10 orders in the system, 9 of those soils can be found in the United States. As a result, this section can not include specific information about each order of soil. Instead, only general soil information will be provided. Anyone involved with biosolids programs should be familiar with the local soil types and the impact of soil on local agricultural practices.

### C.4 Soil Classification System

Soil scientists have created a classification system to organize knowledge about soils. This system identifies relationships among soils and their environments, and it describes characteristics that affect their usefulness for various agricultural and engineering uses. Classification begins with the description of a **soil profile**. This is an exposed vertical cut extending from the soil surface down to the underlying parent material. Soil profiles near the surface show **horizons**, or distinctive layers divided by differences in appearance, physical and chemical composition, organic content, structure, or a combination of those properties.

The principal kinds of horizons, or master horizons, are described in Figure C.1. As shown, the surface A horizon and underlying B horizon are dynamic zones of physical, chemical and



biological activity. By contrast, the C horizon consists of comparatively unweathered parent material.

Soils with similar soil horizon and profile characteristics are grouped and designated as a **soil series**. They are given names, often of places where the characteristics of the series are well expressed, such as *Hagerstown silt loam series*. Soil series are further divided into **soil types** based on variations in texture in the A horizon. The types are further divided into **soil phases**, based on variations in slope, degree of erosion, or some other feature that affects their use. Soil types and phases form the basic mapping units used in county soil survey maps.

### C.5 Using Soil Survey Information

County soil survey reports are a major tool used by biosolids applicators for gaining an understanding of soil characteristics for biosolids applications. Soil surveys are developed by the USDA's Natural Resources Conservation Service (NRCS), formerly known as the Soil Conservation Service. The surveys are the product of extensive field work by soil scientists trained in classification and mapping, and the soil maps show soil series and types drawn on an aerial map of the landscape. The surveys are used primarily to predict the productivity of soils under different farm management systems. However, soil surveys also contain other valuable information relating to engineering properties, soil and water features, and usefulness for purposes other than farming. Most surveys include tables covering the following topics: Prime Farmland Assessment; Yields per Acre of Crops and Pasture; Water Management; Physical and Chemical Properties of the Soils; and Soil and Water Features.

### C.6 Soil Properties

A number of properties and characteristics have a bearing on the suitability of soil for land application of biosolids. Although Part 503 Rule does not explicitly require investigation of soils, most state regulatory programs do have restrictions on the use of soils with certain properties. Therefore, you should become familiar with the soil properties listed in this section. There are many excellent references available that provide more detailed information regarding soil and soil properties. The local (county) Soil Survey Manual and the US Department of Agricultural Soil Survey Manual are two references that may be helpful.

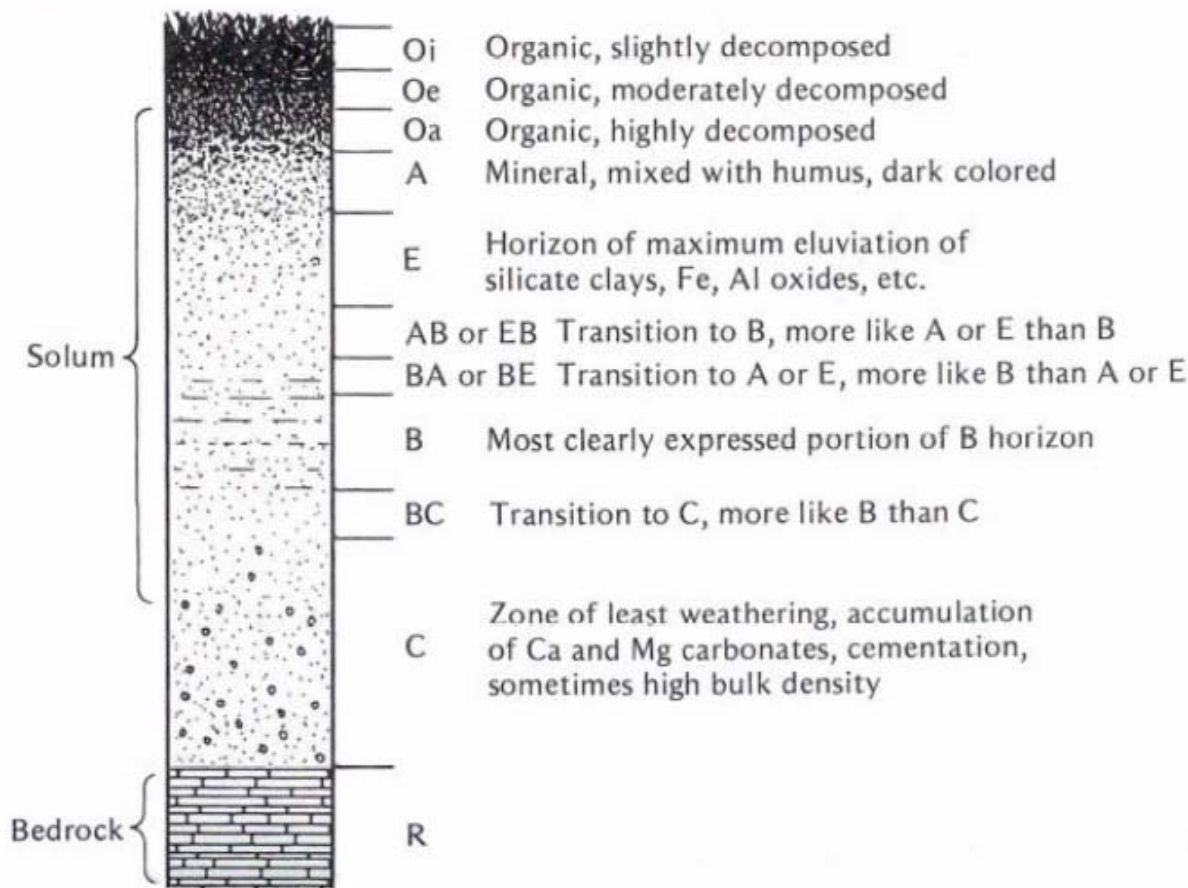
#### *Soil Depth*

Soil depth varies from mere films to layers many feet thick. The depth of soil is dependent on the soil formation processes, both in the present and past. Generally, soil can be expected to be deeper in flat or low lying areas, where soil particles from upslope areas are deposited, and they are often shallower on steep or actively eroded areas. In some cases, shallow soils may need to be avoided during application of biosolids. However, most of the time, shallow soils benefit from the addition of organic matter provided from biosolids.

**Figure C.1 A soil profile showing the principal horizons.**

Source: (Brady, Nyle C. The Nature and Property of Soils. 1990)

**Figure C.1**



*Soil Color*

Soil colors are one of the major features used to identify different soil types. Soils and soil horizons exhibit distinct colors, ranging from dark browns to reds to grays and yellow. Soil color may be inherited from the parent matter. But, more often, soil color is a property generated by physical and chemical soil-forming processes. Dark brown and black colors often indicate an abundance of organic matter; red color usually indicates the presence of oxidized iron compounds and aging. Gray colors usually indicate soil wetness during some part of the year.

**Mottling** (meaning marked with spots of color) is an important feature of soil color. In some cases, mottling occurs in horizons when parent material is not completely weathered. Sometimes the use of green manure (plowing cover crops under to provide organic matter for the soil) can result in soil mottles. More often, mottling is an indication of poorly drained soils that remain saturated with water for significant periods of the year. Mottling occurs in poorly drained soils most of the time, but mottling in itself is not always the result of poorly drained soil. In a case

where mottling is associated with poorly drained soils, the feature is called redoximorphic. Redoximorphic features can be easily confused with mottling. Some mottled colors occur that are associated with poor drainage in the past, even though present conditions do not indicate wet soils. Poorly drained soils are nearly always mottled with various shades of gray, brown and yellow, especially within the zone where the water fluctuates.

In some states, poorly drained soils, as referenced in the soil survey, must be avoided on biosolids application sites. Generally, these soils:

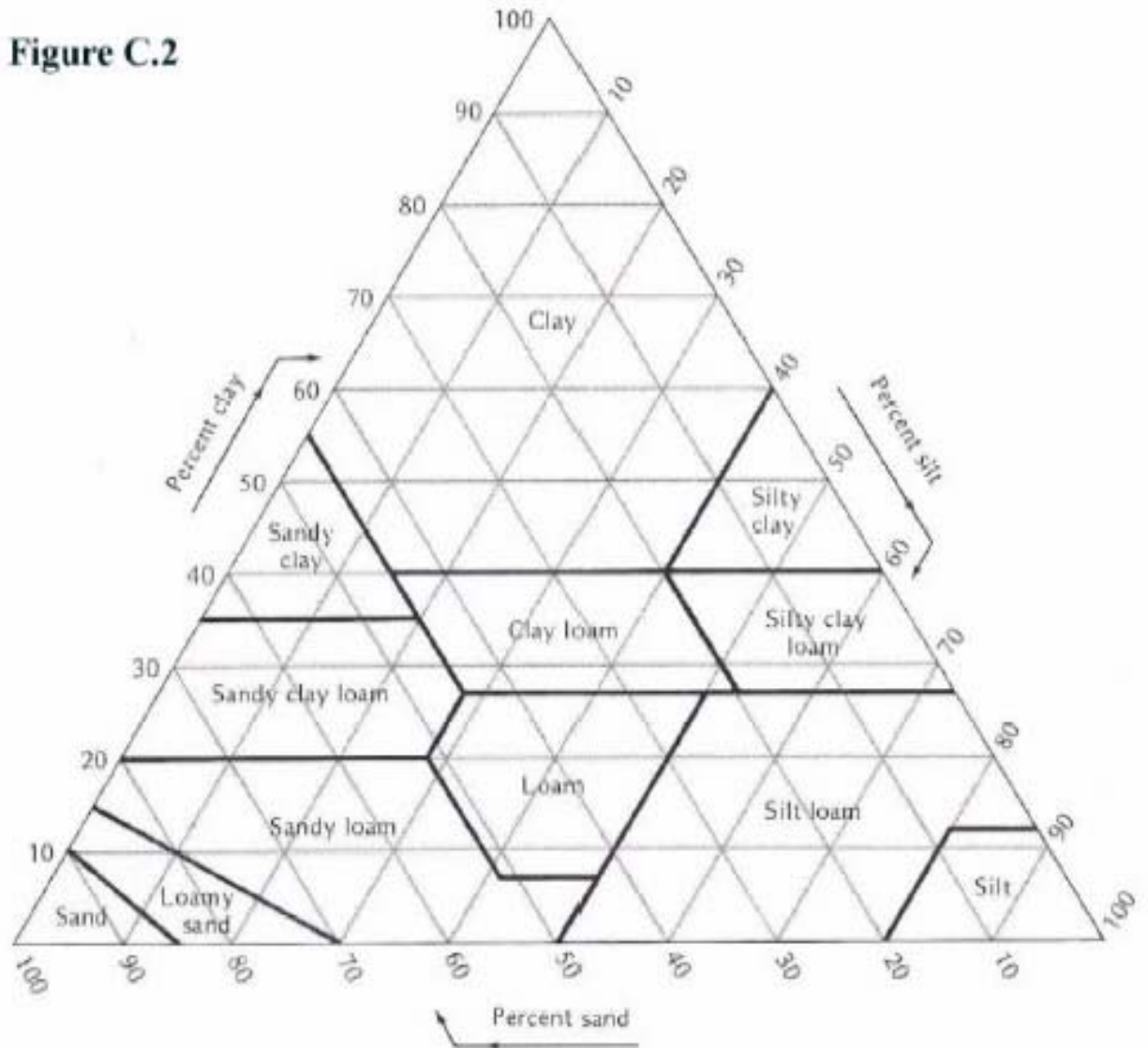
- are difficult to work with when wet
- limit access of application equipment
- have reduced windows for biosolids applications
- have a higher probability of generating runoff

### *Soil Texture*

The texture of a soil horizon is probably its most permanent characteristic. Soil texture refers to the distribution of mineral particles of different sizes, specifically the proportions of clay, silt, and sand in the soil. Figure C.2 shows the soil-texture classes on a triangular graph used by the U.S. Department of Agriculture (USDA). Note that the corners of the triangle represent 100 percent of each of the three grades of particles--sand, silt, or clay. Loam is a mixture in which no grade dominates over the other two.

**Figure C.2 Soil textural classes.**

Chart showing the percentages of clay, silt, and sand in the basic soil textural classes. Source: (Brady, Nyle C. The Nature and Property of Soils. 1990)



Texture largely determines water retention and transmission properties of the soil. Sands hold the least water, while pure clays hold the most. Loams hold an intermediate amount of water. Sand transmits water downward most rapidly, clay most slowly. Sand reaches its full water holding capacity quickly, and added water moves downward to the water table. Clay-rich loams take up water slowly, and additional water becomes surface runoff. As you can see, understanding soil texture is important when planning to apply biosolids. Stones, cobbles, and other coarse fragments are also regarded as a part of the soil mass and are included in the textural soil class. These fragments influence moisture storage, infiltration, and runoff.

### *Soil Structure*

Soil structure is the nature of aggregations (lumps or clusters) of soil particles. Each aggregate is separated from adjoining aggregates by natural surfaces of weakness (cracks). Structure influences water penetration into a dry soil, the susceptibility of the soil surface to erosion, and the ease of cultivation.

Soil structure is of particular concern to biosolids applicators. The application of biosolids adds organic matter that benefits soil by improving structure. On the other hand, repeated traffic of application equipment and trucks over soil can result in a breakdown of the soil structure. The resulting compaction can adversely affect tillage qualities. This is particularly true at times when the soil is wet.

### *Soil Consistency*

Soil consistency refers to the behavior of soil when worked by equipment. Consistency describes resistance to deformation or degree of cohesion in a soil mass. A crumbly (friable) consistency is desirable and is characteristic of a loamy soil. Loamy soil is easy to till, has good water infiltration and permeability, and permits good root penetration. Firm or very firm consistency usually restricts water movement through the soil and can be associated with surface ponding on soils or extended periods of wetness. In some states, biosolids applications may be restricted on such soils.

### *Soil Porosity*

Soil porosity is the amount of pores (voids) of open spaces within the soil matrix capable of holding water and air. Pore spaces account for about 50 percent of the soil by volume. Pore space is not evenly divided between air and water solution and is quite variable. Pore space is related to soil permeability, as discussed below.

### *Soil Drainage*

Soil drainage characterizes the frequency and duration of water saturation. There are seven classes of soil drainage, based on runoff potential, permeability, and internal drainage. Very poorly drained and poorly drained soils may have a high water table that limits their use for biosolids applications, either seasonally or year round. For example, if soils containing excess water are worked with farm or biosolids application equipment they can become compacted, resulting in loss of good structure and permeability qualities.

Drainage on a farm can sometimes be altered through artificial drainage. Artificial drainage through subsurface perforated pipes lowers the water table or removes perched water so that plant roots have a greater vertical zone for growth. Roots will not penetrate into a zone of saturation because of the plant root's need for oxygen. Artificially drained fields offer some opportunity for biosolids applications, though this possibility should be discussed with the local conservation district to insure that the site is managed effectively to protect tile lines and water quality.

### *Soil Permeability*

Soil permeability is the ability of the soil to transmit water or air and is determined by the volume, size, and interconnections of pore spaces. Permeability can be measured in terms of the

rate of water movement through a unit cross section of saturated soil in unit time and is commonly expressed in inches per hour. This rate is called the percolation rate.

Soil permeability may aid in judging a site's usefulness for biosolids applications. Soil types with a rapid percolation rate or a very slow percolation rate may present some limitations for the application of biosolids. Fine textured soils generally exhibit slow to very slow permeability, while values for coarse textured soils range from moderately rapid to very rapid. A medium textured soil such as a loam or silt loam tends to have moderate to moderately slow permeability.

### **C.7 Chemistry and Organic Matter**

The primary function of soil is to serve as a media for plant growth. Soil chemistry and fertility are dimensions of the soil that deliver nutrients to plant roots. Seventeen elements are considered essential for plant growth, and they are placed into two categories that reflect the relative amounts used by growing plants: macro nutrients and micro nutrients. Soil organisms and organic matter also influence plant growth by affecting both physical and chemical conditions in the soil. Additional information on soil chemistry can be found in Chapter 13: Environmental Considerations.

#### *Soil Nutrients*

The three key soil nutrients: nitrogen (N), phosphorus (P), and potassium (K). Crops require large amounts of N, P and K, and their deficiency in soil leads to poor crop yields. Therefore, these nutrients are generally added to the soil in the form of commercial fertilizer, animal manures or biosolids.

Biosolids can be a significant source of nitrogen and phosphorus. Potassium is generally not found in biosolids in significant quantities, but many soils do have adequate natural potassium levels. Typically, when biosolids application rates are based on nitrogen, the amount of phosphorus supplied is greater than what is needed by the crop. However, much of the phosphorus is bound up in the organic matter and soil minerals and is not immediately available for direct plant uptake. If soil potassium is low, it will have to be supplied from another source.

Certain nutrients are required in small quantities, but are nevertheless essential for healthy plant development. These are "trace elements" and are also termed "micro nutrients." Principal micronutrients include sulfur (S), calcium (Ca), magnesium (Mg), boron (B), chloride (Cl), copper (Cu), iron (Fe), molybdenum (Mo), selenium (Se), zinc (Zn), and possibly nickel (Ni). Poor yields and crop failures can sometimes result from the lack of any one of these micronutrients. As a result, they are sometimes recommended for application to certain soils. Biosolids contain all of these micronutrients for plant growth and, when applied to lands, biosolids serve to amend soils with these elements. However, the supply of these elements in biosolids is generally quite variable, depending on the characteristics of the wastewater and the biosolids treatment processes. For example, alkaline (lime) treatment processes add a significant amount of calcium to biosolids. For this reason, it is useful to have your biosolids analyzed by an agricultural laboratory, for micro nutrient status.

For more information about soil nutrients, refer to Chapter 13: Environmental Considerations. The application rate for biosolids, based on the nitrogen need of the crop, is discussed in Chapter 14: Biosolids Nutrient Management.

*Cation Exchange Capacity*

The soil solution contains dissolved elements and compounds with an electric charge, also called ions. Many of these ions are nutrients required by plants for good growth. Soil has the capacity to influence the movement of ions through electrical charges present on the surface of soil particles and organic matter. These charges can attract ions, much in the same way as a magnet attracts iron. The very fine textured particles, specifically the clay and organic fraction of the soil, are primarily responsible for the electrical charge and hence the retention of ions. The overall charge on most soil particles is negative. Positively charged ions, known as cations, include such nutrients as ammonium, calcium, magnesium, potassium, and sodium. These are attracted to negatively charged soil particles. The measure of the soil's ability to hold cations is the cation exchange capacity (CEC). The greater the CEC of a particular soil, the greater the soil's ability to retain nutrients. The addition of biosolids can improve a soil's CEC value because biosolids are high in organic matter. Organic matter contributes to high CEC values.

*Soil pH and Acidity*

Soil pH is a measure of acidity or alkalinity of the soil. On a scale of 1 to 14, a pH of 7 is considered neutral. Lower values indicate acidity, and higher values indicate alkalinity. Soil pH generally ranges from approximately 5.6 to 8.4. Table C.1 has corresponding terms to use for ranges in soil pH. Some soils are naturally acidic, while others are not. Soil forming processes play a significant role in soil acidity and alkalinity. Farming practices can also impact soil pH. Soils that tend to be acidic must be adjusted to a neutral pH through the addition of a liming agent for optimal productivity.

**Table C.1 Ranges of soil pH**

pH Class	pH Range	pH Class	pH Range
Extremely Acid	Below 4.5	Neutral	6.6 to 7.3
Very Strongly Acid	4.5 to 5.0	Mildly Alkaline	7.4 to 7.8
Strongly Acid	5.1 to 5.5	Moderately Alkaline	7.9 to 8.4
Medium Acid	5.6 to 6.0	Strongly Alkaline	8.5 to 9.0
Slightly Acid	6.1 to 6.5	Very Strongly Alkaline	9.1 or higher

---

A decision to add lime to soil is based on: the crop to be grown and the acidity of the soil. Soil test results generally provide a recommendation for lime application in tons per acre specific to the crop to be grown. When required, lime should be added to soil to avoid potential problems with soil leaching or reduced availability of certain cations. In addition, nitrification and microbial activity can be suppressed at a lower than optimum soil pH.

The importance of soil pH in the application of biosolids is related to potential availability of nutrients and mobility of metals present in biosolids. In very acidic soils (pH of 5.5 or less), metals are relatively mobile and can move to the groundwater, and plant growth may be

adversely affected by nutrient deficiencies. Recent research on biosolids has shown that at concentrations of metals typically found in today's biosolids, and at normal soil pH, soil pH management is not a significant concern for metal mobility. Soil pH management, however, is essential for crop growth, as plant nutrients are most soluble at a neutral pH. Chapter 13: Environmental Considerations contains a more detailed discussion relating to the mobility of metals in soils and in biosolids, and the importance of managing soil pH in a biosolids recycling program.

### *Organic Matter*

The amount of organic matter found in soil is an important soil characteristic and cannot be overlooked. The benefits of high levels of organic matter include: improved soil texture, better water holding capacity, increased soil CEC, and increased nutrient availability, especially nitrogen.

The total amount of organic matter in soils varies widely. But, it is generally low, at about 1 to 5 percent by weight. Commonly, soils have the greatest amount of organic matter in the surface layer (A horizon), with significantly less in the layers beneath (B horizon). Soil organic matter is formed by the decomposition of plant and animal residues. The well-decomposed mixture of organic matter in soil is referred to as humus.

Crop yields improve dramatically with the addition of organic matter to the soil. Biosolids are one useful source of organic matter for soil and crop enhancement. Many farmers seek organic amendments for the purpose of feeding the soil to stimulate microorganism activity. Organic matter tends to promote soil aggregation, thereby improving soil texture and water infiltration and reducing erosion potential.

### *Soil Organisms*

Soil organisms play a vital role in the decomposition of organic matter in the soil. Plant and animal residues are consumed by the earthworms and by soil microorganisms such as bacteria and fungi. The decomposition process is strongly influenced by; the number and type of organisms present in the soil, soil temperatures, soil moisture, amount of organic matter, and competition from other organisms.

Bacteria are essential for the processes that make nitrogen available for root uptake. These processes include the conversion of organic nitrogen to ammonia and to nitrate. Chapter 14: Biosolids Nutrient Management provides additional information about the nitrogen cycle.

### *Metals*

Metals are found in trace quantities in soils in varying concentrations. Biosolids also contain trace elements. Some of these elements are essential plant and animal nutrients, while others, like cadmium and lead, are not. To ensure metal levels remain within safe ranges for crops, livestock and humans, state and federal regulations limit the concentrations of some of these elements. Limits are applied to arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium and zinc contained in the biosolids when applied to land. These limits were designed to maintain the long-term productivity of the soil and to ensure its safe use.

Prior to the first use of a site for the application of biosolids, you should consider collecting soil



samples and having the soils analyzed for the metals noted above. Knowledge of the concentration of metals that occur naturally in soils is helpful in establishing base soil metal levels. Unless the soil is naturally high in one of these metals, or unless past activities have contributed to a higher than expected level of metals, most soils should be suitable for the application of biosolids. Part 503 Rule does not require that base line soil samples be collected and analyzed for metal concentrations. However, many state regulations require that soil metal concentrations be established before biosolids are applied.

Many publications are available that provide an average and a range of soil metal levels. If there is a concern that the soil metal levels at a potential site are higher than expected, refer the soil test results to your state land grant university for review.

### *Interpreting Soil Test*

Most land grant universities offer a comprehensive testing service for soils. You can request analyses of soils for parameters of special interest for biosolids application sites. These include measures of nutrients (fertility) and metals (chemistry) in the soils, as well as pH and cation exchange capacity. The accuracy of soil sample analytical results are important. Make certain that the soil testing laboratory is providing accurate results and the information you need is included in the results.

Several features of most soil tests are notable and deserve the attention of biosolids appliers. Most test results include all regulated compounds and also several non-regulated micronutrients. Concentrations of these elements can be expressed in many ways. The first is total metals, reported in pounds per acre (roughly one-half the concentration that would be expressed in a milligram per kilogram of dry soil basis). The second is "Available" metals, expressed as pounds per acre, indicating the amount available for plant uptake. The third is "Activity Level," a measure, similar to the pH scale, that indicates the abundance of the ion in soil solution. Some soil test results are also expressed as a graphic scale, on which concentrations are expressed in a "low to excessive" range, to indicate how they compare to typical values for soils in the region. Soil tests for biosolids application sites provide several useful functions. First, they provide documentation of existing soil nutrient levels so proper crop fertility recommendations and biosolids applications can be determined. Second, testing establishes a baseline and provides a screening mechanism to identify a site that might have concentrations of metal or nutrients above those typical for soils of that type. Because of the expense of soil testing for micro nutrients, many farmers do not have a comprehensive picture of soil quality at their farm, and they may place significant value on having test results, supplied by the biosolids generator or applier, in hand for their own use.

The biosolids applier may benefit from periodic testing of application fields. Over time, the levels of nutrients and metals in the soil may be expected to increase. Obtaining analytical results periodically during the course of the biosolids recycling program can be used to demonstrate that soil constituents remain within acceptable levels. Part 503 Rule does not require the periodic testing of soils for nutrients and metals. In fact, many states no longer require this type of regular comprehensive soil testing. However, consideration should be given to the benefit of periodic soil nutrient and metals testing for the farmer and for demonstrating the safety of biosolids programs.

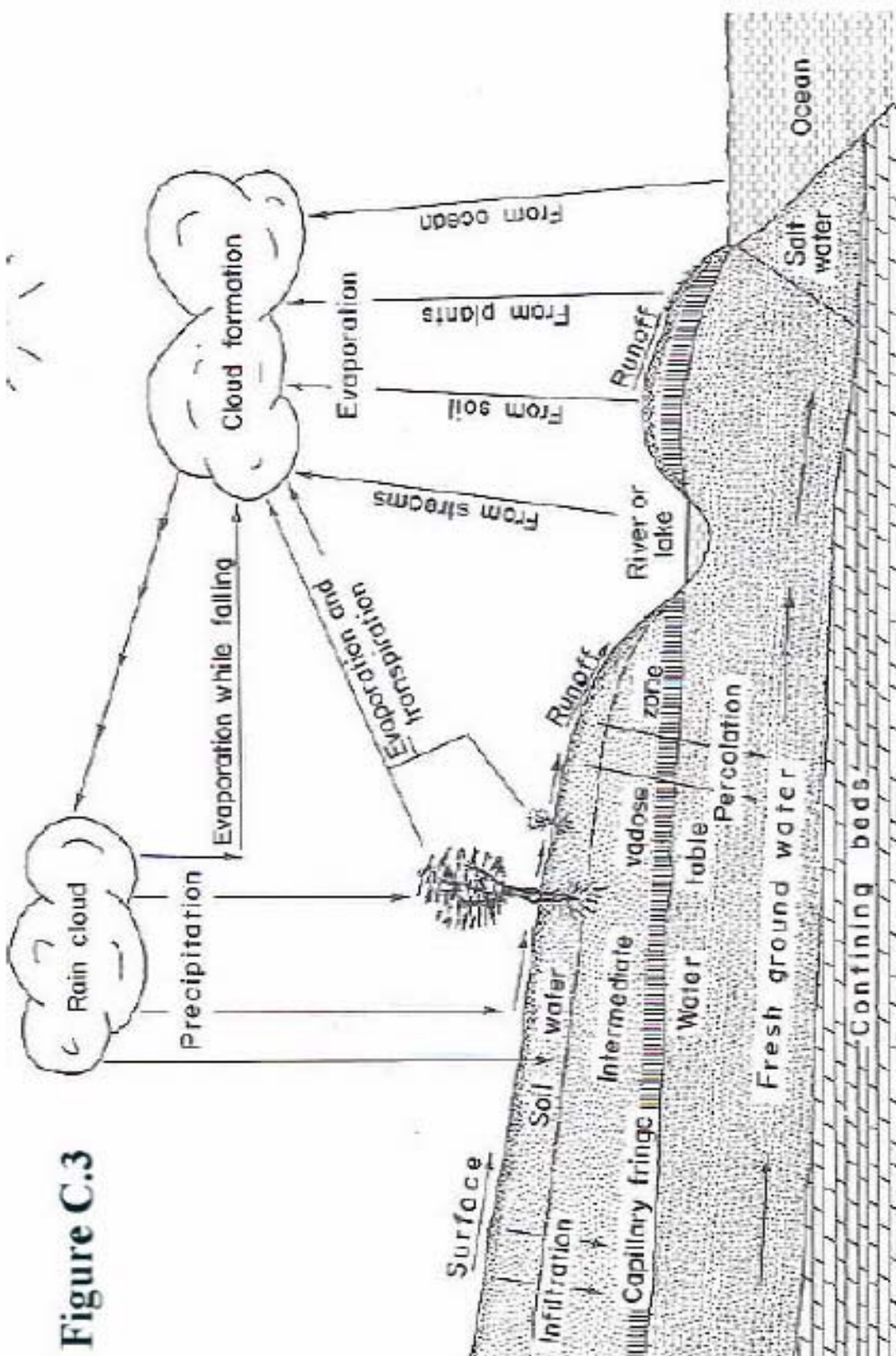
Most soil test kits provide instructions on methods of sampling. EPA and most state regulatory agencies also provide guidance on field soil sampling. All samples must be prepared in a deliberate fashion to ensure they are representative of a field. Sampling techniques include taking multiple grabs at random locations across the field (at least one for every acre), blending the grabs in a thorough fashion, and then partitioning the sample in a way that draws a mixed sample for submission to the soil testing laboratory.

### **C.8 Soil and the Hydrologic Cycle**

Earth's water cycle, or hydrologic cycle, is the continuous circulation of water on our planet. Radiation from the sun evaporates water from the oceans into the atmosphere. The water vapor rises, then collects to form clouds, and falls back to earth as precipitation. Precipitation that falls upon land areas is the source of essentially all fresh water. Some of this precipitation runs over the surface of the earth to streams. Another part soaks into the soil. Much of the water that enters the soil during the growing season is detained in the plant root zone and is taken to the surface by plants or held in the soil pore spaces. During the late fall and winter, some rainfall soaks below the plant root zone and continues moving downward until it enters the groundwater. Groundwater also sustains the flow of streams during periods of dry weather. Streams carry both the surface runoff and natural groundwater back to the oceans. Figure C.3 is a schematic diagram of the hydrologic cycle.

**Figure C.3 The Hydrologic Cycle**

Source: (Edward E. Johnson, Inc. Ground Water and Wells. 1975)



**Figure C.3**

Schematic diagram of the earth's water cycle—the hydrologic cycle.

### **The Fate of Water in Soil**

Water that infiltrates the soil may go in several directions. Some of this water is evaporated from the soil surface. Another portion of the water is absorbed by plant roots and re-enters the atmosphere through transpiration from plant leaves. The water that infiltrates the soil deeply enough may be pulled downward by gravity until it reaches the zone of saturation. The water table refers to the first zone below the soil surface where pore space in the geologic material is filled with water. The thickness of this zone of saturation varies from a few feet to many hundreds of feet, depending on the local geology, and is called an aquifer. In many areas, the land surface is underlain by several aquifers stacked up like a sandwich and separated by dense layers of impermeable materials. The depth to the ground water table should not be confused with the depth of drinking water wells. Drinking water wells are normally placed in aquifers that are isolated from the soil surface and much deeper than the first zone of saturation.

The rate at which water enters the soil surface is called infiltration. Infiltration is expressed in “inches per hour” and is influenced by soil texture, soil structure, soil moisture, and slope of the soil surface. Sandy soils on a level slope would have a high infiltration rate, whereas fine-textured soils on a steep slope would have a low infiltration rate. Soils with low water infiltration rate may pose constraints for liquid biosolids or septage application because of their higher runoff potential. You may not exceed the soil's ability to absorb liquids and cause ponding or surface runoff of materials.

Water holding capacity is a soil characteristic related to pore space. It is the quantity of water held in small soil pore spaces (micropores) against the force of gravity and available for plant use. This soil characteristic is expressed in terms of inches per unit of depth. The greater the organic matter or clay content of soil, the greater its water holding capacity. One important benefit of biosolids is that the organic matter it provides increases the soil's water holding capacity.

Surface runoff refers to water flow over the soil surface as a result of the inability of water to infiltrate. This can be caused either by precipitation falling at an intensity greater than the infiltration rate, or by saturated soil conditions near the surface. Soils with the potential for rapid and very rapid surface runoff may need increased conservation practices, or might instead be avoided for biosolids applications.

### **Seasonal Water Table**

The water table is not a stationary surface, but moves up and down in response to weather conditions. The table rises in rainy seasons, and it drops during droughty periods. The fluctuation of the water table occurs seasonally, as well as over longer periods of time. The variation of the seasonal water table on potential sites is important because the presence of seasonal water can limit biosolids applications. Some state regulations restrict biosolids applications on soils where seasonal water tables are within a certain distance from the soil surface. This information can often be found in the county soil survey. The term “high water level” refers to the seasonal water table and is the highest level of a saturated zone in the soil in most years. The estimates are based on the occurrence of grayish colors or redoximorphic features in the soil. A field check may be warranted for any soil series listed in the Soil Survey with a potential for high seasonal water table.

## References

Brady, N.C., (1990), *The Nature and Properties of Soils*, Macmillan Publishing Company, New York

Lindsay, W.L., *Chemical Equilibria in Soils*

United States Department of Agriculture, (various dates), "County Soil Survey" (for county of interest). Natural Resources and Conservation Service

United States Department of Agriculture, (1962), *Soil Survey Manual*

United States Environmental Protection Agency, (September, 1995), "*Process Design Manual for Land Application of Sewage Sludge and Domestic Septage*", (USEPA/625/R-95/001)

## Appendix D – Nitrogen Balance Check

---

A quick nitrogen balance check compares the amount of nitrogen available at the site (animal manure estimate) to the nitrogen need of the crop (average crop nitrogen need). To complete the quick nitrogen balance check, ask the farm operator to help by providing the following information.

The type of animals The current number and size of the animals The average number of animals on site annually, The number of days the animals are confined versus out on pasture The manure management practices (e.g. daily spreading, storage) A nitrogen analysis of the animal manure, if available The County Soil Survey or extension information on crop yields The method of land application (surface vs. soil incorporated)

Use Worksheet 1, Nitrogen Balance -- Animal Manure Estimate to quickly estimate the number of pounds of nitrogen supplied from animal manure. If there are more than one type of animal at the site producing manure, complete an additional worksheet for each type of livestock. Part 1 of the worksheet establishes the average number of animal units (AU) at the site (an AU is equivalent to 1,000 pounds of animal weight). Part 2 identifies the number of days the animals are confined. Only manure that is stored and later spread on fields should be considered. (Manure generated while animals are out to pasture is not included.) In Part 3, the number of AUs and the days confined are used to estimate the annual amount of manure produced and stored. Daily manure production per AU can be obtained from your county extension office or state land grant university. In Part 4, you will estimate the available nitrogen from manure. If the farmer has a manure analysis, use this to identify how much nitrogen is available per pound of manure. If not, the county extension office or state land grant university can provide an average value for nitrogen per pound of various manures. If the manure will be surface applied and not immediately worked into the soil, you must allow for loss of nitrogen that will volatilize as ammonia. Use information from the county extension office or state land grant university to make this adjustment.

Once the annual amount of manure nitrogen is estimated, it must be compared to the amount of nitrogen needed by the crops to be grown at the site. To estimate the nitrogen needs of the site, ask the farm operator to help by providing the following information.

The typical crops grown The number of acres of each crop typically planted The predominant soil type on each field The average crop yields from the farmer or from the county Soil Survey Land Grant College informational guidance, if available.

Worksheet 2, Balance of Crop Nitrogen, provides a rough estimate of the annual fertilizer needs at the site. In column 1, enter the type of crop. In column 2, enter the predominant soil type. In column 3, enter the expected crop yield (this can be based on the farmer's records, the county Soil Survey, or extension office). In column 4, enter the nitrogen removed by the crop per unit yield. Next multiply column 3 by column 4 to get the nitrogen removal per acre for the crop and write it in column 5. In column 6, enter the number of acres that will be planted with this crop. Multiply Column 5 by column 6 to get the total nitrogen requirement per field and enter it in column 7. Repeat this process for each crop to be grown. Add up the figures in column 7 to get

an estimate of the total nitrogen needed at the site.

The information needed to compare the pounds of nitrogen available from manure (Worksheet 1) to the total pounds of crop nitrogen removed (Worksheet 2) is now complete. With this information, decide whether sufficient quantities of additional nutrients are needed to make biosolids land application at this site worthwhile.

The biosolids capacity of the site (in dry tons of biosolids) can be determined by dividing the additional nitrogen needed by the crop (over what is supplied by the manure) by the pounds of nitrogen available per dry ton of your biosolids. If the biosolids capacity at this agricultural site meets your needs, this site should be considered for inclusion in your program.

**Worksheet 1  
Nitrogen Balance  
Animal Manure Estimate**

1. Number of animal units
  - a. Total animal weight = average # animals X weight of animals \_\_\_\_\_ lbs.
  - b. Animal units (AU) = total animal weight/1000 lbs. \_\_\_\_\_ AU
  
2. Animal manure stored
  - a. full days animals confined \_\_\_\_\_ days
  - b. partial days animals conf'd (hours confined x 24 hrs. x days) \_\_\_\_\_ days
  - c. total equivalent days stored = (2a) + (2b) \_\_\_\_\_ days
  
3. Tons of manure produced and stored
  - a. daily production = AU lb x manure prod. Lb/AU/Day <sup>1</sup> \_\_\_\_\_ lbs/day
  - b. total production = (3a) x (2c) \_\_\_\_\_ lbs
  - c. manure produced and stored = (3b)/2000 lbs/ton \_\_\_\_\_ tons
  
4. Nitrogen available from manure
  - a. tons manure (3c) x nitrogen content of manure \_\_\_\_\_ lbs N
  - b. available manure nitrogen = (4a) x N availability factor <sup>2</sup> \_\_\_\_\_ lbs N
  
- Total nitrogen available from manure \_\_\_\_\_ lbs. N

1. See Table 2-12 "Average daily production and total nutrient content of manure" from the *Penn State Agronomy Guide*
2. See Table 2-13 "Percentage of total manure nitrogen remaining available to crops after storage and handling, as affected by application method and field history" from the *Penn State Agronomy Guide*





## Appendix E - Biosolids Recycling and Soil Conservation

---

Land recycling of biosolids should go hand-in-hand with sound soil conservation practices. All areas used for biosolids applications should be managed within the context of an effective erosion and sediment (E&S) pollution control plan. This chapter provides a brief overview of soil conservation concepts and planning considerations related to biosolids applications to the land.

### Critical Control Points / Operational Controls

Biosolids recycling and soil conservation controls are related to operation of the site where land application activities take place. They include:

- inspection of fields to assure that practices have been implemented
- periodic review of site to assure practices and structures are being maintained
- identification of areas where erosion is occurring
- crop rotation and tillage methods

### Soil Conservation

Accelerated soil erosion can dramatically reduce land quality and productivity. Sediment deposition of eroded soil (sedimentation) in water bodies diminishes aquatic habitats. Soil erosion also reduces the water carrying capacity of streams and the storage volume in lakes, ponds, and reservoirs. Agricultural field rilling and gullying from accelerated erosion reduces soil productivity and can eventually render a field unusable for farming. Another unwelcome result is the transport of pesticides and nutrients into surface waters. For example, phosphorus washed from agricultural fields exposed to accelerated soil erosion can lead to enrichment (eutrophication) of local water bodies.

Accelerated soil erosion is principally caused by man's activities disturbing the soil's natural vegetative protective cover. Farm managers apply soil conservation practices to provide for high level, sustained, agricultural production while at the same time conserving vital soil resources. The guiding principle of soil conservation is to manage the soil resource base to maintain productivity indefinitely.

### Farm Conservation Plan and Biosolids Recycling

A number of states have regulations governing erosion control. In the case of agricultural plowing and tilling, the landowner is responsible for managing the soil resource base. In doing so, the landowner may develop and implement an Erosion and Sedimentation (E&S) control plan, commonly called a *soil conservation* or *farm conservation* plan. In most states, areas receiving biosolids must have an *implemented* farm conservation plan.

Farm conservation plans prepared for biosolids recycling activities generally address areas of the site used directly for processing, storage, and land application of biosolids, as a minimum.

However, it is reasonable to manage all land at a site within the context of an effective conservation plan.

Structural practices such as diversions, terraces, and waterways are common components of a conservation plan. After initial installation, these conservation practices must be monitored to assure continued satisfactory performance. They tend to gradually fill-in, reducing their effectiveness over time. Consequently, maintenance of conservation practices is essential. Conservation practices used for field application of livestock manure are generally suitable for biosolids recycling. The exception to this is isolation distances from certain site features and some public access limitations required by local, state or federal ordinances or regulations. These requirements are discussed in Chapter 8. Imposition of more stringent conservation practices or increased isolation distances for biosolids recycling areas are not appropriate or necessary.

### **The Soil Erosion Process**

Both wind and water can cause accelerated soil erosion. This chapter focuses on water erosion, which is the predominant soil loss mechanism in the U.S.

#### ***Factors Influencing Water Erosion***

The four major factors affecting water erosion are:

- climate
- soil
- vegetation
- topography

Climate factors include precipitation, temperature, wind, humidity, and solar radiation, with precipitation energy being the most important. Soil properties such as structure, texture, organic matter content, moisture content, density, and chemical and physical characteristics all affect erosion. Appendix C provides additional information about these soil properties. Silts are generally considered to be the most erosive soil texture. Vegetation reduces soil erosion by: intercepting rainfall, slowing of surface water flows, binding soil aggregates with roots, and improving soil structure and infiltration capacity. Topographic factors that influence erosion include slope, slope length, and the size and shape of the contributing watershed.

#### ***Types Of Water Erosion***

Soil erosion involves two basic processes:

- soil particle detachment
- transport

Five categories of soil erosion are recognized: *raindrop erosion*, *sheet erosion*, *rill erosion*, *gully erosion*, and *stream channel erosion*. Raindrop erosion occurs as a result of raindrop impact directly on soil particles. Splash displaces the soil and begins the erosion process. Sheet erosion is the uniform removal of soil in a very thin layer. Studies have shown that this type of erosion is very rare. In most cases, what is commonly perceived as sheet erosion is actually rill erosion on a microscopic level. Rill erosion detaches and moves soil by water running in small, well-defined flow paths. Loosened or displaced soil particles from raindrop impact also add to rill water

flows, increasing the impact of this form of erosion. Rill erosion can be particularly severe in areas containing soils with a low infiltration rate. By definition, rill erosion is readily seen and easily traversed or removed by normal tillage equipment. Gully erosion is similar to rilling, but the resulting flow channels can not be traversed or repaired by standard tillage equipment. It is therefore an advanced form of rill erosion. Stream channel erosion detaches soil particles from stream banks.

## Soil Loss Prediction

Soil erosion loss is usually associated with sheet and rill erosion. For many years soil scientists have estimated soil loss (erosion) with the Universal Soil Loss Equation (USLE). The current form of this method, the Revised Universal Soil Loss Equation (RUSLE), is based on a version originally developed in the 1960s. This method was developed after 40 years of field observations. The procedure is called “Universal” because it accommodates geographic differences. Earlier prediction approaches were not readily applied to different geographic regions. Today, the equation is widely accepted and has proven to be a valuable tool for soil conservation planning. The RUSLE method is now used by most of the Natural Resource Conservation Service (NRCS) offices throughout the nation.

Once soil loss predictions are computed, they are compared with acceptable levels of soil loss. Acceptable levels of soil loss, or tolerance levels (T), are based on a variety of factors. In general, T represents the rate at which soil can be replaced by natural soil forming processes. If erosion is limited to levels at or below T, the soil base will be sustained indefinitely, the goal of soil conservation. Soils in different settings, derived from various parent materials, have different T values. The T values of soils across the United State range from 2 to 5 tons per acre per year. Most soils have T values of 3 to 4 tons per acre per year. Thinner soils have a T value of 2 while thicker soils have a T value of 5 (Jarrett, 2000). Standardized T values have been developed for each soil series, which are available from the local NRCS office.

## Revised Universal Soil Loss Equation (RUSLE)

Equation E.1 presents the RUSLE in its most commonly recognized form. The factors involved in the soil erosion process are readily apparent in the equation.

### Equation E.1

$$A = R \times K \times LS \times C \times P$$

Where:

A = Average annual soil loss, expressed in tons per acre

- R = Rainfall and runoff erosivity index by geographic location
- K = Soil-erodibility factor
- LS = Topographic factor
- C = Cropping-management factor
- P = Conservation practice factor

## Preparation of Conservation Plans

Farm conservation plans are typically prepared by the local NRCS office, in cooperation with the Local Conservation District (LCD). A request for preparation of a conservation plan is normally directed through the LCD. Depending on workload and priorities set by the LCD, preparation may take as little as one month or up to 12 months (or longer). An alternative to going through the LCD is to hire a private consultant, who may be able to prepare a plan more quickly, but for a fee. No fee is charged for plans prepared by the NRCS.

The content of a farm conservation plan, as formalized by the NRCS in practice, generally includes the following components:

- Identification of the farm owner(s) and operator(s)
- Local municipality and State location
- NRCS Soil Survey Map showing the location of the farm and its property limits
- Identification of the Land Capability Class of soils contained on the farm property
- A non-technical soils description for soils contained on the farm property
- A conservation plan map of sufficient scale to show cropland areas and various existing and proposed conservation plan practices
- A conservation plan map legend
- A record of decisions and application of conservation practices including: cropland area identification, and; planned and applied conservation practice amounts, dates, and narrative record for each cropland area
- Certification of compliance with the federal programs, such as the Food Security Act (signed by the land owner, NRCS district conservationist, and LCD)
- Soil loss calculation/documentation worksheets demonstrating that T will be met when the selected conservation practices are applied

The Part 503 Rule does not require that biosolids recycling conservation plans be approved by the LCD, but it is a good practice for private consultants to interact with LCD and/or NRCS personnel to obtain concurrence when possible. Plans prepared by private consultants may not include every component listed above. However, at a minimum, all conservation plans for biosolids recycling fields should demonstrate that soil losses from land application fields will not exceed T.

Some conservation plans prepared by the NRCS and approved by LCDs in the last 10 years have not been designed to meet T. As such, these plans may not satisfy the local requirements of an effective E&S plan. It is the responsibility of the land applier to confirm that farm conservation planning has been designed to meet the local conservation planning requirements and that the planned practices have in fact been installed and maintained.

## Soil Conservation System Options

Table E.1 provides a list and brief description of conservation practices commonly employed on, or in conjunction with, cropland used for biosolids recycling.

Table E.1. Common Conservation Practices\*

Conservation Practice	Brief Description
Crop Rotations	Alternating crops grown in a field according to a planned sequence. Rotations may include annual and perennial crops as well as grasses and legumes.
Cross Slope Farming	Farming across the slope, nearly on the contour. This practice is not as effective as contour farming and may result in the need for more waterways.
Contour Farming	Conduct tillage, planting and harvesting operations around the hill, not up and down. Increasing the height of ridges after planting creates miniature terraces increasing the effectiveness of this practice.
Contour Stripcropping	Planting alternate bands of permanent vegetation across the slopes on the contour. Use this practice to minimize the potential for erosion.
Residue Management	Protecting the soil from erosion by limiting tillage of the prior year's crop residue on the soil surface. Includes no till, mulch till, and ridge till.
Pasture and Hay Plantings	Grasses and/or legumes are planted for use as pasture and/or to be harvested as forage. Species are selected based on soil properties and specific use.
Contour Buffer Strips	Planting bands of permanent vegetation across the slopes on the contour. Use this practice to minimize the potential for erosion.
Field Borders	A band of grass or legume at the edge of a field used in place of end rows.
Filter Strips	Bands of grass or legumes that filter runoff and other contaminants before they reach water bodies or sources.
Cover Crops	Close-growing crops that temporarily protect the soil where major crops don't provide cover.
Diversions	Cross-slope constructed channel seeded to permanent vegetation used to intercept and safely dispose of surface runoff. Concentrated flows and sheet flow may be intercepted. Hay may be harvested. Diversions also provide habitat for wildlife when managed for that purpose.
Terraces	Cross-slope constructed channels that are cropped similarly to adjoining fields. Terraces intercept sheet and concentrated flows. Collected water is held to allow for maximum infiltration or is carried to a suitable outlet away from the

\* After NRCS, 1996

Prior to field application of biosolids, land appliers should conduct a field tour to ensure that conservation practices have been installed and maintained in accordance with the farm conservation plan. If planned practices or acceptable substitutions have not been installed, the field should not be used for biosolids application until effective erosion control measures have been planned and installed as necessary. When land appliers are uncertain as to whether the planned conservation practices have been installed, the LCD should be contacted for their opinion. Alternatively a qualified private consultant may be used to make the determination.

## References

Jarrett, A.R., (2000), *Water management*, Second Edition, Kendall/Hurst Publishing Co. Dubuque, Iowa.

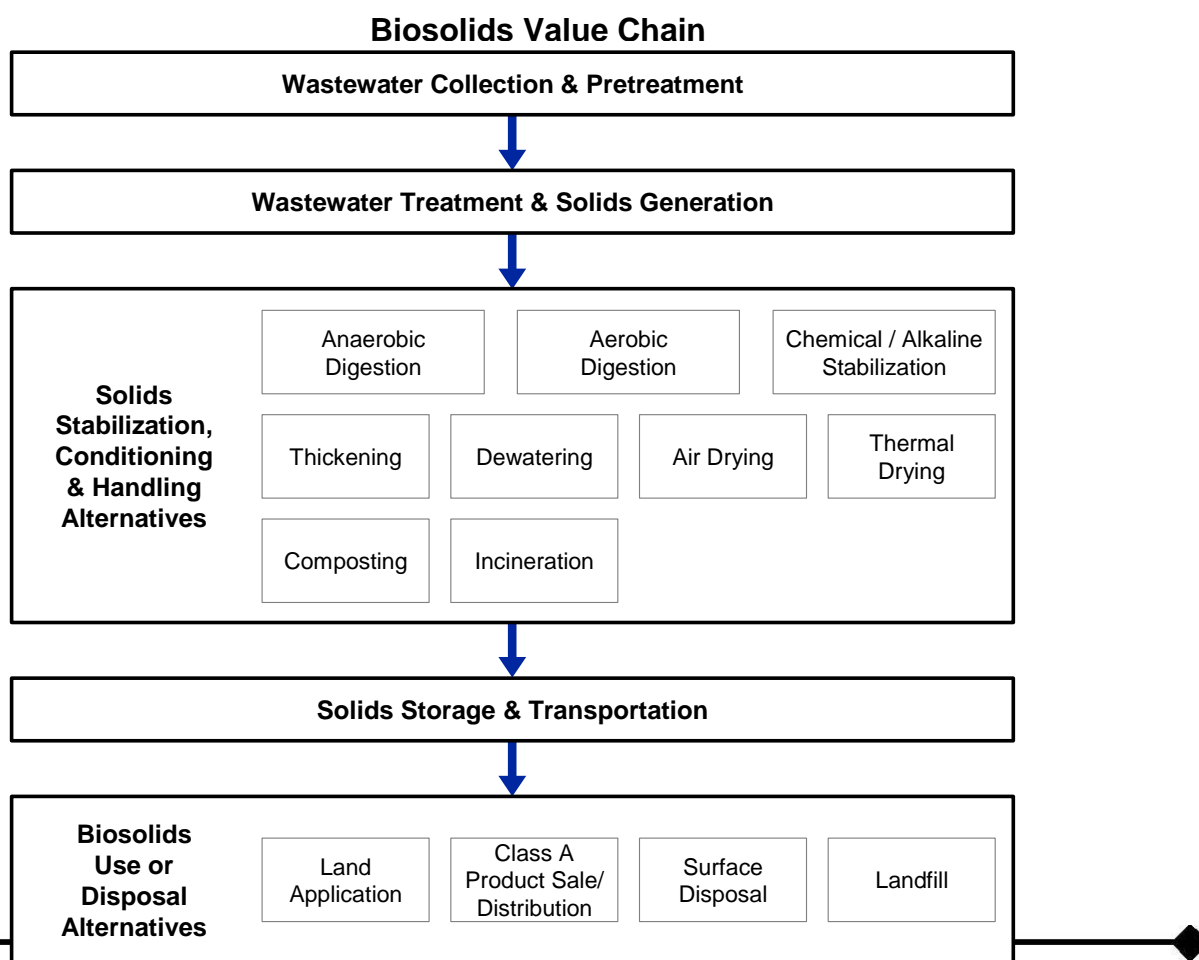
NRCS, (1996), *A conservation catalog for Pennsylvania*, Cooperative effort of the NRCS, Pennsylvania Department of Environmental Protection and Somerset and Westmoreland CCD's

United States Department of Agriculture, (various dates), "County Soil Survey" (for county of interest). Natural Resources and Conservation Service

## Appendix F – Critical Control Points throughout the Biosolids Value Chain

The purpose of this appendix is to clarify identification of critical control points throughout the biosolids value chain. Critical control points are locations, unit processes, events, and activities throughout the biosolids value chain, from pretreatment through final use or disposal of biosolids. Effective management of critical control points assures that biosolids management activities meet legal, quality, and public acceptance requirements and do not have undesirable environmental impacts. This effective management of critical control points is accomplished with operational controls. Each critical control point has one or more associated operational controls. Operational controls include standard operating procedures, work practices, process controls, and monitoring and other management methods such as ordinances, permits, periodic reports and inspections.

At each major step in the value chain (e.g., solids stabilization, conditioning and handling), wastewater treatment facilities have a variety of alternative processes to choose from. For example, solids stabilization methods might include aerobic digestion, anaerobic digestion, chemical stabilization, composting, thermal drying and/or air drying. In identifying critical control points, organizations participating in the NBP Biosolids Management Program must include all methods that apply to local operations. Some alternatives may not apply to some operations.



Organizations participating in the NBP Biosolids Management Program are required to identify critical control points that are consistent (e.g., similar in scope and scale) to those in the *National Manual of Good Practice for Biosolids*. The table below can help organizations confirm that their critical control points meet NBP requirements. For example, if an organization were to identify “Wastewater Treatment” as a critical control point, this would be too broad in scale and scope to allow for effective mapping and management of environmental impacts and operational controls. Wastewater Treatment refers to an entire link in the biosolids value chain or a broad category of critical control points. To be consistent with NBP expectations, an organization would need to dig deeper within Wastewater Treatment to identify specific locations or activities – such as anaerobic digestion, air drying systems, or solids dewatering.

The NBP encourages organizations to go even one level deeper when identifying critical control points, as indicated in the table below. For example, under anaerobic digestion, organizations could identify digester temperature and detention time as critical control points needing effective management to assure that biosolids activities meet legal, quality, and public acceptance requirements and do not have undesirable environmental impacts.

As discussed, earlier, the guidance contained in this manual is not intended to be interpreted as requirements that third party auditors will use. Auditors should ask if the manual was consulted during the identification of critical control points and operational controls. However, auditors should recognize that each facility and biosolids management program is unique. Consequently operating procedures will be unique as will the selection of critical control points and operational controls. Auditors should recognize and allow for the possibility that a critical control point for one organization may be listed as an operational control (or monitoring/measurement) by another organization.



Biosolids Value Chain	Examples of Critical Control Points
Wastewater Collection and Pretreatment	Industrial – Significant Industrial User discharges
	Commercial user discharges
Wastewater Treatment and Solids Generation	Solids screening / grit collection
	Scum blanket
	Primary treatment
	Secondary treatment
Solids Stabilization, Conditioning, and Handling	Anaerobic digestion <ul style="list-style-type: none"> <li>- Temperature</li> <li>- Digester mixing</li> <li>- Detention time</li> <li>- “End product” meets regulatory requirements</li> <li>- Any regulatory/permit requirements that identify specific locations/activities that need to be managed</li> </ul>
	Aerobic digestion <ul style="list-style-type: none"> <li>- Temperature</li> <li>- Digester mixing</li> <li>- Aeration requirements</li> <li>- “End product” meets regulatory requirements</li> <li>- Any regulatory/permit requirements that identify specific locations/activities that need to be managed</li> </ul>
	Chemical stabilization – Class B product <ul style="list-style-type: none"> <li>- Quality of add mix of chemicals / lime</li> <li>- Mixture consistency</li> <li>- Mixture pH and temperature</li> <li>- Mixture detention time</li> <li>- Any regulatory/permit requirements that identify specific locations/activities that need to be managed</li> </ul>
	Chemical stabilization – Class A product <ul style="list-style-type: none"> <li>- Quality of add mix of chemicals / lime</li> <li>- Mixture consistency</li> <li>- Mixture pH and temperature</li> <li>- Mixture detention time</li> <li>- “End product” meets regulatory requirements</li> <li>- Location of facility – air emissions management</li> <li>- Any regulatory/permit requirements that identify specific locations/activities that need to be managed</li> </ul>
	Composting <ul style="list-style-type: none"> <li>- Quality of add mix of bulking agent</li> <li>- Mixture consistency</li> <li>- Mixture temperature</li> <li>- Mixture turning</li> <li>- Mixture detention time</li> <li>- “End product” meets regulatory requirements</li> <li>- Any regulatory/permit requirements that identify specific locations/activities that need to be managed</li> </ul>

Biosolids Value Chain	Examples of Critical Control Points
<b>Solids Stabilization, Conditioning and Handling (continued)</b>	Air drying system <ul style="list-style-type: none"> <li>- Location of facility</li> <li>- Mixture turning</li> <li>- Mixture temperature</li> <li>- Mixture detention time</li> <li>- “End product” meets regulatory requirements</li> <li>- Any regulatory/permit requirements that identify specific locations/activities that need to be managed</li> </ul>
	Thermal drying systems <ul style="list-style-type: none"> <li>- Location of facility – air emission management</li> <li>- Temperature</li> <li>- Detention time</li> <li>- Stack emissions</li> <li>- “End product” meets regulatory requirements</li> <li>- Storage bin / silo</li> <li>- Any regulatory/permit requirements that identify specific locations/activities that need to be managed</li> </ul>
	Bioenergy / Incineration <ul style="list-style-type: none"> <li>- Thickening</li> <li>- Dewatering</li> <li>- Scum conditioning</li> <li>- Thickened solids holding tank</li> <li>- Burn zone</li> <li>- Scrubber</li> <li>- Stack emissions</li> <li>- Any regulatory/permit requirements that identify specific locations/activities that need to be managed</li> </ul>
	Dewatering <ul style="list-style-type: none"> <li>- Location of facility</li> <li>- “End product” meets specifications / percent solids</li> </ul>
	Thickening <ul style="list-style-type: none"> <li>- Location of facility</li> <li>- “End product” meets specifications / percent solids</li> </ul>
<b>Solids Storage and Transportation</b>	Solids storage <ul style="list-style-type: none"> <li>- Site location</li> <li>- Distance to neighbors</li> <li>- Road access</li> <li>- Set back from surface water</li> <li>- Depth to groundwater</li> <li>- Any regulatory/ permit requirements that identify specific locations/activities that need to be managed</li> </ul>
	Solids transportation <ul style="list-style-type: none"> <li>- Truck (e.g., maintenance, appearance)</li> <li>- Truck cover</li> <li>- Transportation route</li> <li>- Truck cleaning facilities</li> <li>- Any regulatory/permit requirements that identify specific locations/activities that need to be managed</li> </ul>

Biosolids Value Chain	Examples of Critical Control Points
<p><b>Biosolids End Use or Disposal</b></p>	<p>Land application</p> <ul style="list-style-type: none"> <li>- Application site location</li> <li>- Location of off loading from trucks</li> <li>- Interim storage/staging area</li> <li>- Perimeter of biosolids application site-setback distances from surface water/neighbors/wells</li> <li>- Depth to groundwater</li> <li>- Agronomic rate</li> <li>- Truck cleaning on site</li> <li>- Any regulatory/permit requirements that identify specific locations/activities that need to be managed</li> </ul>
	<p>Class A/EQ product sale and distribution</p> <ul style="list-style-type: none"> <li>- Product and packaging specifications</li> <li>- Product application rates</li> <li>- Product transportation</li> <li>- Any regulatory/permit requirements that identify specific locations/activities that need to be managed</li> </ul>
	<p>Landfill</p> <ul style="list-style-type: none"> <li>- Landfill</li> <li>- Any regulatory/permit requirements that identify specific locations/activities that need to be managed</li> </ul>
	<p>Surface disposal</p> <ul style="list-style-type: none"> <li>- Site location</li> <li>- Perimeter of application site – setback from surface water/neighbors/wells</li> <li>- Depth to groundwater</li> <li>- Truck cleaning site</li> <li>- Access road</li> <li>- Any regulatory/permit requirements that identify specific locations/activities that need to be managed</li> </ul>