AWWA Research Foundation

Commercial Application and Marketing of Water Plant Residuals

Subject Area:
Water Treatment

Commercial Application and Marketing of Water Plant Residuals

The mission of the AWWA Research Foundation is to advance the science of water to improve the quality of life. Funded primarily through annual subscription payments from over 1,000 utilities, consulting firms, and manufacturers in North America and abroad, AWWARF sponsors research on all aspects of drinking water, including supply and resources, treatment, monitoring and analysis, distribution, management, and health effects.

From its headquarters in Denver, Colorado, the AWWARF staff directs and supports the efforts of over 500 volunteers, who are the heart of the research program. These volunteers, serving on various boards and committees, use their expertise to select and monitor research studies to benefit the entire drinking water community.

Research findings are disseminated through a number of technology transfer activities, including research reports, conferences, videotape summaries, and periodicals.

Commercial Application and Marketing of Water Plant Resicuals

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FOREWORD

The AWWA Research Foundation is a nonprofit corporation that is dedicated to the implementation of a research effort to help utilities respond to regulatory requirements and traditional high-priority concerns of the industry. The research agenda is developed through a process of grass-roots consultation with subscribers, members, and working professionals. Under the umbrella of a Strategic Research Plan, the Research Advisory Council prioritizes the suggested projects based upon current and future needs, applicability, and past work; the recommendations are forwarded to the Board of Trustees for final selection. The foundation also sponsors research projects through the unsolicited proposal process; the Collaborative Research, Research Applications, and Tailored Collaboration programs; and various joint research efforts with organizations such as the U.S. Environmental Protection Agency, the U.S. Bureau of Reclamation, and the Association of California Water Agencies.

This publication is a result of one of those sponsored studies, and it is hoped that its findings will be applied in communities throughout the world. The following report serves not only as a means of communicating the results of the water industry's centralized research program but also as a tool to enlist the further support of the nonmember utilities and individuals.

Projects are managed closely from their inception to the final report by the foundation's staff and large cadre of volunteers who willingly contribute their time and expertise. The foundation serves a planning and management function and awards contracts to other institutions such as water utilities, universities, and engineering firms. The funding for this research effort comes primarily from the Subscription Program, through which water utilities subscribe to the research program and make an annual payment proportionate to the volume of water they deliver and consultants subscribe based on their annual billings. The program offers a cost-effective and fair method of funding research in the public interest.

A broad spectrum of water supply issues is addressed by the foundation's research agenda: resources, treatment and operations, distribution and storage, water quality and analysis, toxicology, economics, and management. The ultimate purpose of the coordinated effort is to assist water suppliers to provide the highest possible quality of water economically and reliably. The true benefits are realized when the results are implemented at the utility level. The foundation's trustee are pleased to offer this publication as a contribution toward that end.

In recent years, water utilities have met with increasing pressure to find alternatives for disposal and beneficial uses of water treatment plant (WTP) residuals. Discharge of untreated residuals to surface waters is severely restricted under the National Pollution Discharge Elimination System of the Clean Water Act, and discharge to the sanitary sewer is equally restrictive through wastewater pretreatment, performance, and effluent standards. As a result, beneficial use programs for WTP residuals are increasingly being considered by utilities, not only as a cost-effective alternative, but also as a publicly more acceptable management practice. This report develops a marketing tool that can provide guidance on beneficial and commercial uses of residuals, were to find and how to develop these markets, and presents recommendations about residuals characteristics and handling practices for end users.

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EE&T would also like to thank the other water utilities that provided information on their particular experiences with beneficially using water treatment residuals. The utilities involved included: Erie County Water Authority; Newport News Waterworks; Grand Strand Water and Sewer Authority; Rivanna Water and Sewer Authority; City of Durham, North Carolina; Cobb County-Marietta Water Authority; New Jersey Water Supply Authority; Santa Clara Valley Water District; Hyder Water Utility, Wales, UK; Town of Greenwich, Connecticut; City of Danville, Pennsylvania; City of Fort Collins, Colorado; City of Englewood, Colorado; City of Tulsa, Oklahoma; City of Boynton Beach, Florida; Bradford Water Authority, Pennsylvania; and Cary/Apex, North Carolina.

Many site visits and interviews with manufacturing facilities, compost operations, contractors, etc. were necessary to generate the market descriptions provided in the manual. The assistance of the following individuals was greatly appreciated: Brian Trimble, U.S. Brick Industry Association; Jon Maury, Cherokee-Sanford Brick Company; Bill Parrish, Lawrenceville Brick Company; Frank Post, AMSCO; Leon Millis, Richmond Recycling Company; Ted Cowan and Gary Thomas, Raven Materials; George Bowser, Virginia Peninsulas Public Service Authority; Chuck Cherry, Pioneer Southern; Rob Sutton, ASB Greenworld, Inc.; Patrick Pullen, Glen Gery Brick Company; Wally Klemm, Portland Cement Association; Eric Blankenship, Environmental Waste Recycling; Doug Fender, Turfgrass Producers International; Dr. Nicholas Basta, Oklahoma State University; and Tracey Perron, Scotts-Earthgro, Inc.

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EXECUTIVE SUMMARY

The intent of this manual is to provide U.S. water treatment utilities with a guide for locating and developing alternative methods for the disposal of coagulant residuals. The beneficial uses associated with lime-softening water treatment plant residuals have been well documented in numerous past research studies and therefore are only briefly described in this manual. The primary focus of the manual was to research alternative uses for aluminum- and iron-based coagulant residuals.

State and public acceptance towards recycling water treatment plant residuals has improved due to increased knowledge about the content of coagulant residuals and its successful re-use demonstrated in numerous research studies. The majority of these research efforts have focused on agricultural or nonagricultural land application of the material. Research work has shown that coagulant residuals may or may not provide a benefit to a particular application but studies have consistently demonstrated that residuals do not pose a hazard to the environment or human health. The chemical composition of residuals is primarily inorganic material that is very similar in content to the surrounding natural soils.

Today, research has shifted towards locating uses for residuals as a substitute for other materials commonly used in the production of commercial products. This manual outlines 13 different markets that could potentially benefit by using at least one type of coagulant residuals material. At least some research work on full-scale implementation has been conducted for each of the markets listed. Each market is considered to be a "beneficial use" of coagulant residuals. Beneficial use is defined in this manual as an alternative to disposal by landfilling that does not cause harm to the environment or threaten human health. A market description is provided for each of the 13 markets identified which includes information on some or all of the following issues:

- General description and potential benefits
- Market size and geographical locations
- Manufacturing logistics
- Residuals application process

- Residuals physical and chemical quality requirements
- Case studies of utilities experiences

The manual also provides information concerning the economical and noneconomical considerations that should be evaluated prior to marketing residuals for a particular application. Capital and operation and maintenance (O&M) cost curves are provided for some of the commonly used techniques for handling and dewatering coagulant residuals. Noneconomic factors are also provided along with an example of how to perform an economical analysis for potential alternatives.

The final chapter of the manual provides an outline of the basic procedure required to initiate a successful marketing campaign for finding potential end users. The guidelines provide a general approach that could be tailored by a utility to address their site specific needs and hopefully assist with locating and developing a successful beneficial use program.

CHAPTER 1
PROJECT INTRODUCTION

BACKGROUND NEED

The treatment and disposal of water treatment plant (WTP) residuals is rapidly becoming an integral part of operating water treatment plant facilities due to more stringent local, state, and federal regulations concerning residuals handling and disposal practices. New regulations such as the Interim Enhanced Surface Water Treatment Rule (IESWTR) and the enhanced coagulation rule are requiring the use of higher coagulant dosages to further improve finished water quality. As a result of these practices, more residuals will be generated that will need proper disposal.

The discharge of untreated residuals to most surface waters is being reduced or eliminated under the National Pollutant Discharge Elimination System (NPDES) of the Clean Water Act. Discharge of residuals to the sanitary sewer is also becoming more restrictive due to tougher wastewater pretreatment standards, the limited amount of available wastewater treatment plant (WWTP) capacity, impacts on digester performance, and more stringent WWTP effluent waste disposal standards. Sanitary landfill disposal of dewatered residuals is becoming very costly and the residuals utilize valuable space in a disposal system that is already predicting shortages in the near future. As a result, alternative use programs for the disposal of water treatment residuals are increasingly being investigated by many utilities.

The residuals management goal for most water utilities is to operate an economically efficient as well as environmentally safe residuals management program. In order to accomplish this, a utility needs to develop one or more long-term agreements which provide a safe and reliable outlet for beneficial use disposal of the residuals. Residuals generated from lime softening treatment processes have been successfully beneficially used for many years as a commercial lime substitute for agricultural soils. The beneficial use markets coagulant residuals such as alum, ferric, and PACl have, on the other hand, been more difficult to locate. Potential reasons for the limited beneficial use of the water treatment plant residuals could include:

- Relatively low nutrient value of material
- A perceived concern about aluminum content in alum residuals
- A general lack of information on potential users or markets
- Potential users unfamiliarity with the physical and chemical characteristics of the residuals
- A regulatory frame work that does not clearly address guidelines for beneficial use of WTP residuals

Information concerning the residuals disposal practices currently used by U.S. water treatment plants was obtained by searching WATERSTATS, the Water Industry Database maintained by the American Water Works Association (AWWA). The WATERSTATS program provided the residuals disposal and utilization information presented in Figure 1.1. According to WATERSTATS, 68 percent of the utilities surveyed reported some sort of disposal method including landfills, monofills, sanitary sewer, and stream discharge. The categories showing utilities that are potentially employing a residuals beneficial use program include land application (25 percent) and other (7 percent). The other category could, of course, also mean on-site storage. The data from WATERSTATS, however, does indicate that other than land application, beneficial use is only a very small percentage of the residuals management practices.

Historically, beneficial use markets or applications for residuals have been limited. Land application of residuals to forest land, agricultural fields, or hay fields have been the more traditional methods commonly explored or implemented. More recently, new beneficial use applications and markets have been developed and successfully implemented by a number of water utilities. Some of these new markets include top soil blending, turf farming, cement and concrete manufacturing, soil conditioning, citrus grove application, and composting. Many other commercial and industrial applications remain viable but require further exploration and research.

OBJECTIVES

The objective of this project was to develop a guidance document that will serve the water utility industry as a marketing tool for developing a beneficial use program. This document identifies a number of beneficial use options including land application, commercial and industrial markets, and environmental use alternatives. The key issues presented in this manual include the following:

- Identification of potential markets and associated national organizations
- Identify how residuals would be incorporated in those markets
- Determine residuals chemical and physical requirements for each market
- Outline the required analytical tests and procedures required
- Estimate financial and operational impacts

A description of these topics for each beneficial use application investigated should provide water utilities with the necessary information to select potential beneficial use options and begin marketing their residuals.

The type and quality of residuals generated by a utility significantly impacts the efforts required to find beneficial uses. Water treatment plants generate a wide variety of different solid waste materials which are generally classified as follows:

- Alum
- Polyaluminum chloride (PACl)
- Ferric
- Lime softening
- Polymer
- Coagulant-lime
- Iron/Manganese

Beneficial use markets for disposal of lime softening residuals have historically been relatively easy for utilities to locate due to the lime value of the residuals. A number of research efforts conducted in the past have provided volumes of information on the beneficial use applications available for lime softening residuals. Many of these applications have been used by utilities for years. Some of the existing markets for lime softening residuals include:

- Agricultural soil conditioning
- Land reclamation of strip mines
- Flue gas desulfurization
- Various markets for pelletized lime residuals (i.e., brick mortar, highway filler, pickling baths)

General summaries for some of the lime softening residuals application processes are included in "Slib, Schlamm, Sludge" (Cornwell and Koppers 1990). This manual provides an excellent guide for better understanding water treatment plant handling and disposal practices for both softening and coagulant-based residuals. A series of papers detailing experiences using lime softening residuals for a variety of beneficial uses are included in the 1995 WEF and AWWA Joint Biosolids and Residuals Management Conference Proceedings (WEF and AWWA 1995).

Locating beneficial use markets for alum, ferric, and PACl residuals, on the other hand, has been more difficult. Coagulant residuals typically have low concentrations of valuable nutrients such as nitrogen and phosphorus that are beneficial for crop growth and potentially contain limiting concentrations of certain heavy metals. Due to the difficulties associated with finding end users for coagulant residuals, the focus of this manual was to summarize the potential commercial and agricultural markets available for beneficial use of only coagulant or coagulant-lime residuals. Coagulant residuals are defined as materials generated using alum, iron, or PACl treatment chemicals. Coagulant-lime residuals are alum, iron, or PACl residuals that contain significant concentrations of lime added for non-softening reasons such as pH adjustment and/or to aid in mechanical dewatering.

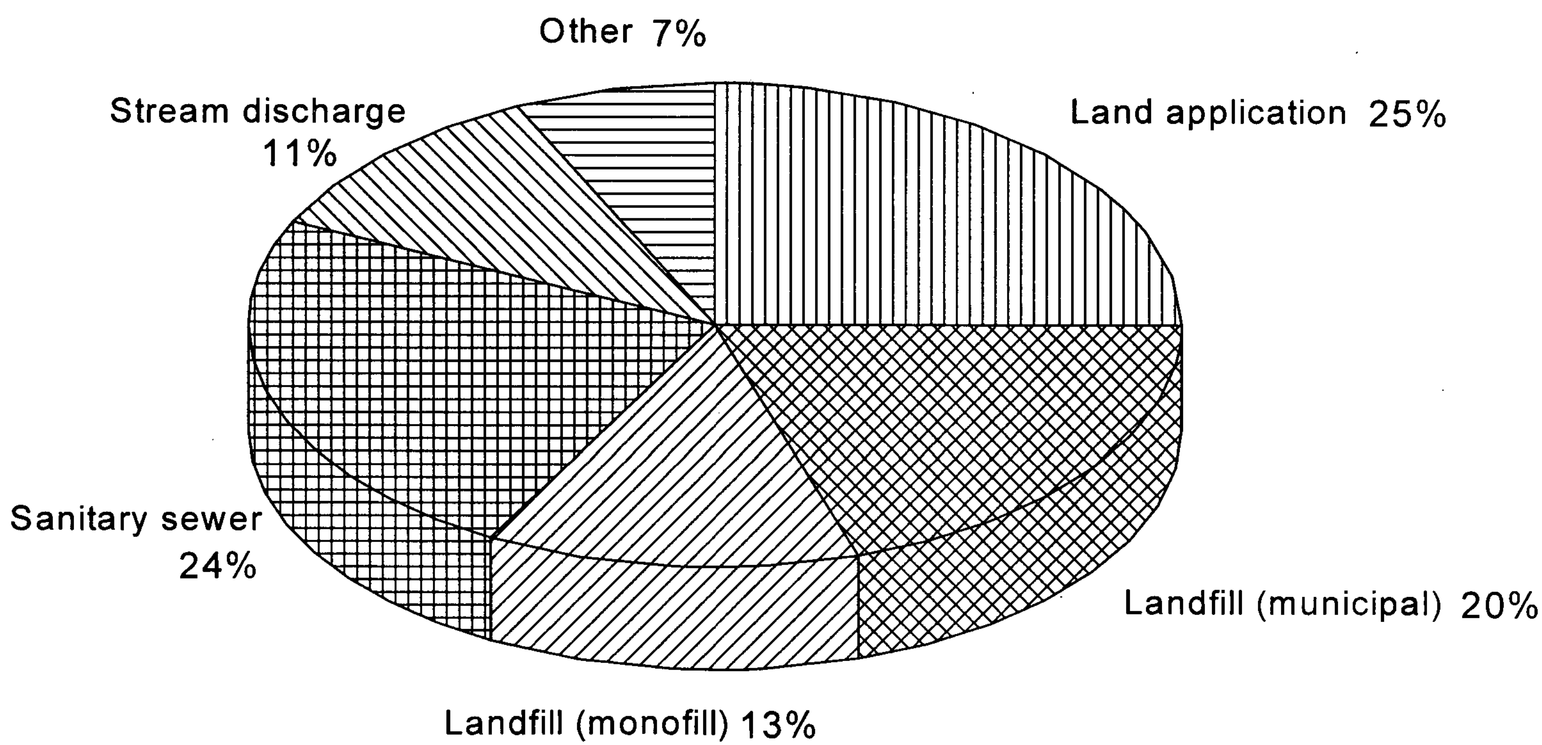


Figure 1.1 Residual disposal (from WATERSTATS)

CHAPTER 2

REGULATORY INVESTIGATIONS

STATE REGULATORY REVIEW

Before embarking on developing a beneficial use program for water treatment residuals, it is very important to determine the regulatory framework. This also provides the opportunity to involve the appropriate regulatory agencies at the beginning of developing a beneficial use plan. This could provide valuable insight into the necessary information that must be collected for obtaining a beneficial use permit. Partnering with the state regulators should be strongly encouraged because there may be very few regulatory guidelines in-place as a basis for the regulators to write an appropriate permit.

Due to the limited beneficial use of residuals in the past, many state regulatory agencies have not developed specific statutes or guidelines for regulating the use of WTP residuals. With the water utilities' desire of making residuals beneficial use more common, there is a greater need for state regulators to define their procedures for classifying and regulating residuals. There is still, however, a wide variability in permitting procedures from state to state. In some states a general permit is available for residuals that meet certain quality criteria, while other states simply define regulations on a case-by-case basis. Some states do not specifically regulate water treatment residuals beneficial use at all.

To better define how each state presently regulates the beneficial uses of residuals, a cursory review of regulatory statutes in all 50 states was conducted. This involved contacting a representative from each state agency to obtain general information concerning the following topics:

- How are residuals classified?
- What regulatory guidelines exist for beneficial use of residuals?
- What chemical/physical parameters of residuals are regulated?
- Have any utilities within the state been granted a beneficial use permit?

Results from the state-wide cursory review are presented in Table A.1 in Appendix A. As expected, there was a great variety of responses from state to state. Some of the agencies contacted were unable to provide specific answers to some of the topics listed above. Most of the agencies, however, were familiar with residuals and had previous experience in dealing with regulation of residuals for beneficial use applications. Only a third of the states were found to have existing regulatory guidelines that could be used by a utility to assist in program development.

State responses of how residuals are classified for regulatory purposes consisted of several categories as shown in Table 2.1.

Table 2.1

Classification of water treatment residuals

Classification	Number of states	Percent
Solid waste	17	34
Unclassified	13	26
Special waste	11	22
Biosolid	5	10
Industrial waste	3	6
Liquid waste	1	2

Figure 2.1 shows geographically how each state classifies water plant residuals. The term "special waste"is used by many states to denote municipal wastes that are regulated individually on a case-by-case basis. Federal regulations intended for wastewater biosolids or industrial wastes were adopted by some states for regulatory use. Thirteen of the states contacted had no specific classification for WTP residuals.

Regardless of how each state classifies water treatment residuals, it is important to understand which states have specific guidelines for residuals beneficial use applications. This information is shown in Figure 2.2.

The state regulatory review concluded that approximately 50 percent of the states do not have regulatory guidelines specifically intended for residuals applications. About 36 percent of the states have specific regulatory guidelines that must be followed for beneficial use while the remaining 14 percent of the states determine regulations on a case-by-case basis. Finally, Figure 2.2 shows that the majority of the states in the northeast have developed guidelines for use of residuals, while many of the states in the northwest do not have established guidelines for residuals beneficial use.

FEDERAL REGULATIONS

There are no comprehensive federal regulations that exist which specifically apply to WTP residuals. There are certain existing federal regulations that are developed for biosolids and municipal solid waste disposal. The sections of these federal regulations that are currently being used for residuals disposal are as follows:

- 40 CFR 257 and 258: Solid Waste Disposal Facility Criteria and Practices
- 40 CFR 261: Toxicity Characteristic Leaching Procedure (TCLP) Test
- 40 CFR 403: General Pretreatment Regulations for Existing and New Sources of Pollution
- 40 CFR 503: Standards for the Disposal of Sewage Sludge
- CERCLA: Comprehensive Environmental Response Compensation Liability Act
- HMTA: Hazardous Materials Transportation Act

Table 2.2 shows the residuals beneficial use alternatives that could be affected by one or more of these federal regulations.

Table 2.2

Federal regulatory framework for residuals

Federal regulation	Co-disposal	Land application	Turf farming	Co-use with biosolids	Land reclamation
40 CFR 257	✔	✔			✔
40 CFR 258	✔				✔
40 CFR 261	✔	✔	✔	✔	✔
40 CFR 403					
40 CFR 405		✔	✔		
40 CFR 503				✔	
CERCLA	✔	✔	✔	✔	✔
HMTA	✔	✔	✔	✔	✔

The Clean Water Act (CWA), Section 405, established guidelines for the use and disposal of sewage sludge in order to protect leaching into waterways. Leaching of metals into groundwater is the primary issue addressed by CWA Section 405. The framework defined by CWA Section 405 was also adopted for use in land applying residuals. The Resource Conservation and Recovery Act (RCRA) was established primarily to determine toxicity or hazard potential of a solid waste prior to landfilling in order to protect land, water, and air from contamination. The RCRA also provides guidelines concerning the following topics:

- Classification of hazardous wastes
- Standard for treatment, storage, and disposal
- Enforcement of standards
- Authorization for states to implement regulations
- Cradle to grave manifest system

Although developed for biosolids and solid waste, specific sections of RCRA have been adopted by many states for regulating WTP residuals disposal. A summary of the 40 CFR sections that could apply to residuals disposal are listed in the following paragraphs.

40 CFR 257: Criteria for Classification of Solid Waste Disposal Facilities and Practices

This regulation includes provisions that deal with land application of a solid waste, including WTP residuals. In order to comply with Section 405(d) of the Clean Water Act, the owner or generator of a publicly owned treatment facility must comply with the guidelines for residuals disposal and use outlined in 40 CFR 257. The regulation contains specific criteria governing application of residuals to land for production of human food-chain crops and limiting annual and cumulative applications of cadmium and PCBs.

40 CFR 258: Criteria for Municipal Solid Waste Landfills (MSWLF)

The 40 CFR 258 regulation establishes minimum national criteria for all MSWLF units and for MSWLFs that are used to dispose of biosolids. Biosolids, solid wastes, and WTP residuals that are placed in a MSWLF must be nonhazardous as determined by 40 CFR 261, and must not contain free liquids as determined by the Paint Filter Liquid Tests.

40 CFR 261: Identification and Listing of Hazardous Wastes

The 40 CFR 261 identifies the solid waste materials which are subject to regulation as a hazardous waste. A solid is considered a hazardous waste if it exhibits any of the characteristics of ignitability, corrosivity, reactivity, or toxicity as defined in Subpart C of CFR 261 or if it is listed in Subpart D of CFR 261. This regulation is pertinent since the disposal and use options considered for WTP residuals require a nonhazardous designation. Since WTP residuals are not ignitable, corrosive, reactive, or considered hazardous wastes, the toxicity characteristic leaching procedure (TCLP) could be used as the primary indicator that a WTP residual is not a hazardous material.

40 CFR 403: General Pretreatment Regulations for Existing and New Sources of Pollution

Discharges to the sanitary sewer are subject to EPA's National Pretreatment Standards and any additional pretreatment requirements mandated by the state or wastewater treatment facility.

The requirements imposed on a wastewater treatment facility through a permit and/or local ordinance are necessary to enable the facility to achieve compliance with their NPDES permit. Pretreatment standards required prior to discharge of a waste material into the environment are typically site specific.

40 CFR 503: Standards for the Use or Disposal of Sewage Sludge

This regulation describes comprehensive criteria for the management of biosolids. Under 40 CFR 503, biosolids are either land applied in bulk form, sold, or given away. Application can occur on either agricultural land, forests, public contact sites, and reclamation sites or on lawns and home gardens. In order for biosolids to be land applied, criteria for pollutant limits, pathogens, and vector attraction reduction must be met. The Part 503 pollutant limits for land application are given in Table 2.3. All biosolids that are to be land applied must meet the ceiling concentrations in *Table 1 of 503.13*. Bulk biosolids that are applied to agricultural land, forest, public contract sites, or reclamation sites must also either meet the pollutant limits in *Table 3 of 503.13* or be applied at rates so that the cumulative loading rates in *Table 2 of 503.13* are not exceeded. Bulk biosolids that are applied to lawn or home gardens must meet the pollutant limits in *Table 3 of 503.13*. Biosolids that are sold or given away must either meet the pollutant limits in *Table 3 of 503.13* or be applied so as not to exceed the annual pollutant rates in *Table 4 of 503.13* while still meeting the ceiling concentrations in *Table 1 of 503.13*. The addition of WTP residuals to biosolids would most likely reduce the concentration of most of these metals in the final product.

Table 2.3

Part 503 pollutant limits for sewage sludge land application

	Table 1 of 503.13 Ceiling concentrations (mg/kg)	*Table 2 of 503.13* Cumulative pollutant loading rates (kg/ha)	*Table 3 of 503.13* Pollutant concentrations (mg/kg)	*Table 4 of 503.13* Annual pollutant loading rates (kg/ha/yr)
Arsenic	75	41	41	2.0
Cadmium	85	39	39	1.9
Copper	4,300	1,500	1,500	75
Lead	840	300	300	15
Mercury	57	17	17	0.85
Molybdenum	75			
Nickel	420	420	420	21
Selenium	100	100	100	5.0
Zinc	7,500	2,800	2,800	140

The addition of water treatment residuals to biosolids might have a positive impact on subsequent stabilization processes used to meet the Part 503 pathogen and vector attraction reduction requirements. The extent of the impact would depend on the quantity of water treatment residuals added and the stabilization processes used. Therefore, when considering land application of water treatment residuals with biosolids, the impact associated with residuals use first must be determined.

Comprehensive Environmental Response Compensation Liability Act (CERCLA)

The CERCLA, also known as the Superfund Act, was established to deal with the numerous existing abandoned or uncontrolled hazardous waste disposal sites that pose a real threat to public health and safety as well as to the environment. Prior to the act's passage, USEPA was only authorized to regulate hazardous waste management at active and properly closed sites. The Superfund, which is essentially a pool of money derived from special taxes, forms the core of CERCLA. Establishment of this fund fulfilled the primary focus of CERCLA. An expansion of the Superfund pool that serves to continue cleanup efforts begun under CERCLA is provided by the

Superfund Amendments and Reauthorization Act (SARA) of 1986. The funds thereof are used to remediate contaminated sites in accord with RCRA requirements.

The USEPA is authorized under CERCLA to take necessary short-term actions to deal with sites posing some immediate threat to human health or the environment as well as to implement long-term plans to clean up complex sites, which are selected on the basis of risk assessments. The identification of responsible parties is an important part of the remediation process. Possibly the most noteworthy aspect of these regulations, however, is that they employ a volume use basis in assessing cleanup costs, which could potentially place the liability with a utility whose residuals did not cause the problem.

Hazardous Materials Transportation Act (HMTA)

The Hazardous Materials Transportation Act (HMTA) applies to all beneficial uses requiring transportation of residuals. The residuals must be determined to be non-hazardous by RCRA and HMTA in order to transport the material. The HMTA also outlines U.S. Department of Transportation (USDOT) packaging requirements.

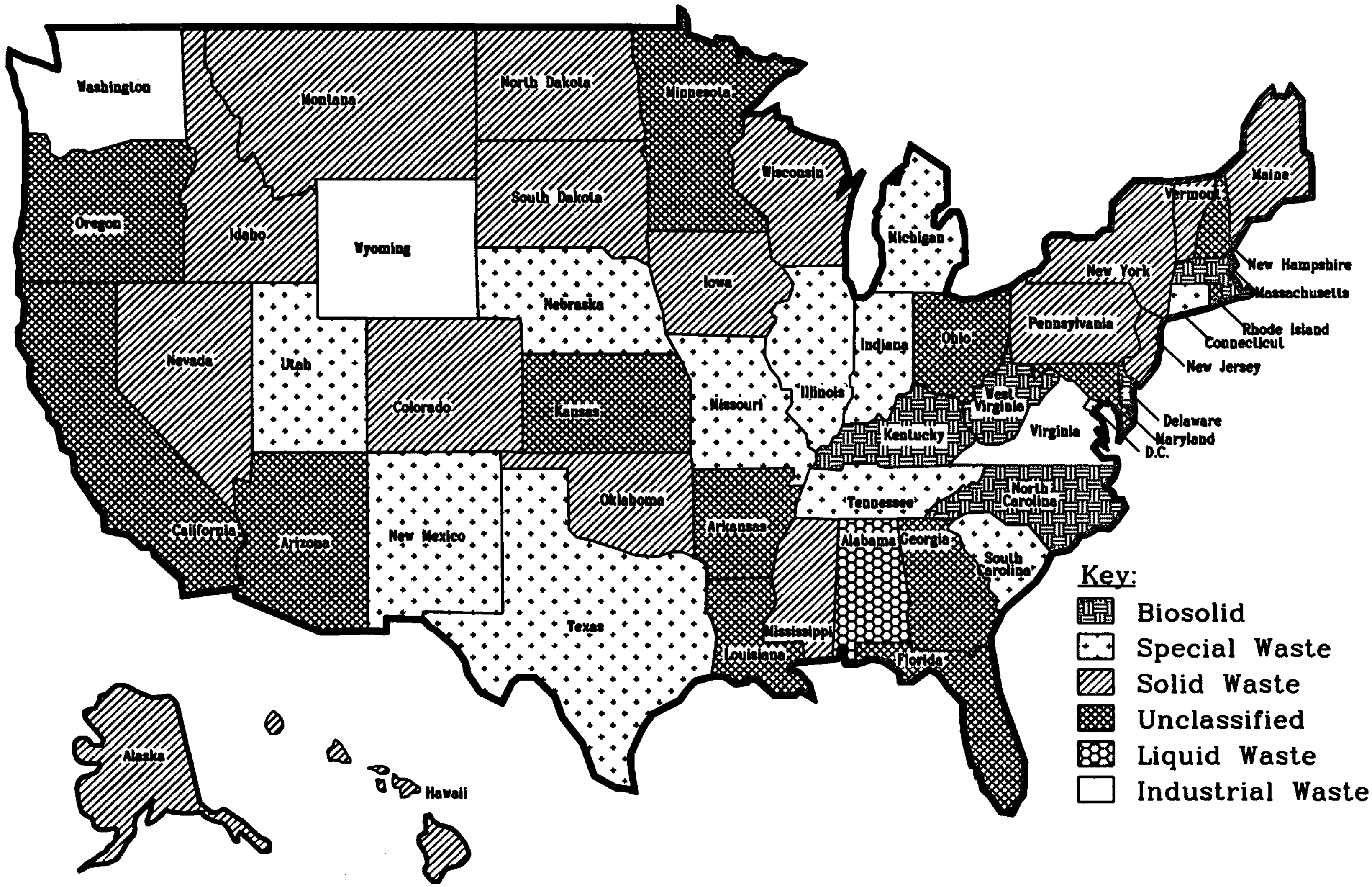


Figure 2.1 State classifications of water treatment plant residuals

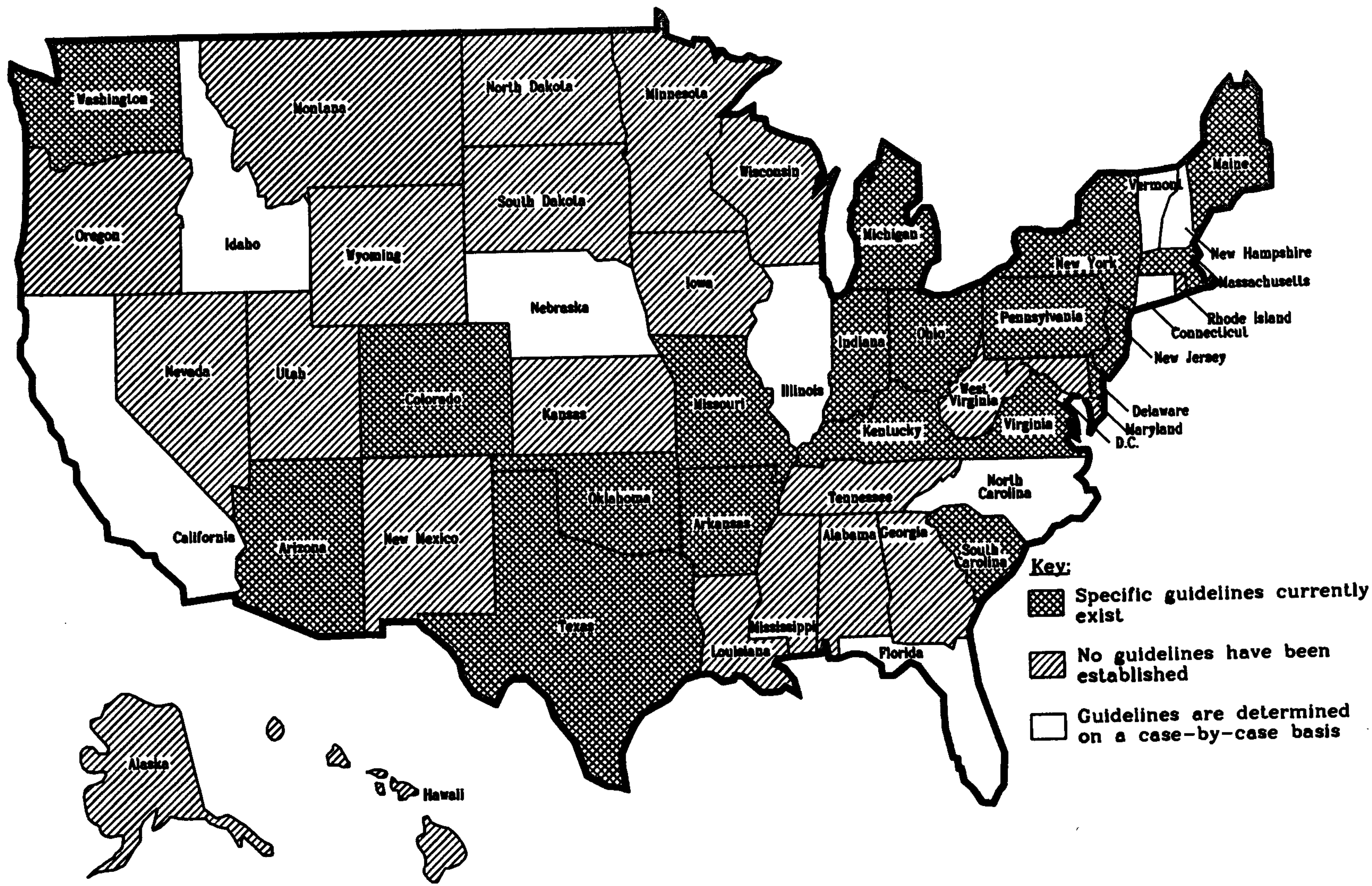


Figure 2.2 State regulatory guideline status for beneficial use of water treatment plant residuals

CHAPTER 3
MARKET INVESTIGATIONS

INTRODUCTION

Many water treatment plants have in the past and/or are currently using a variety of beneficial use methods for managing coagulant and coagulant-lime based residuals. Elimination of surface water discharge, stricter landfilling regulations, higher landfill tipping fees, and restrictions on sewer discharge have forced water utilities to spend more time marketing residuals in order to locate and develop alternatives to disposal for the future. Research and marketing efforts over the years have resulted in the development of many new and innovative techniques for beneficial use of residuals. Many of the beneficial use practices currently used by water treatment plants were adopted from long-standing biosolids programs. An investigation into the current and historical disposal practices used for both water residuals and wastewater biosolids yielded a number of different beneficial use markets, most of which have been used successfully by the water industry. The 13 beneficial use markets that were determined to provide the most potential for WTP residuals beneficial use are as follows:

- Land application
- Cement manufacturing
- Brick making
- Turf farming
- Composting (with yard waste or biosolids)
- Commercial top soil and potting soil production
- Road subgrade
- Forest land application
- Citrus grove application
- Nutrient control
- Landfill cover

- Land reclamation
- Hydrogen sulfide (H_2S) binding

This list contains a broad array of residuals uses that could potentially provide benefit to a number of commercial markets such as agriculture, industrial manufacturing, forestry, solid waste handling, land reuse, and pollution control. For each of the applications listed, residuals could be used to supplement or even replace raw materials normally used. In some cases, coagulant residuals have proven to be equal or even more valuable than the natural or commercial products replaced.

The primary source of information used for investigating the different beneficial use alternatives were water utilities that have in the past or are currently practicing a form of beneficial use. Other sources of information include manufactures, contractors, farmers, and national organizations. There are a number of companies currently in business today that specialize in "turnkey" recycling of water residuals using one or more of the aforementioned beneficial use methods. These companies handle WTP residuals on a daily basis and have developed a variety of beneficial use alternatives and procedures for safe and economical utilization.

A number of water utilities, contractors, national organizations, regulatory agencies, and manufacturers were able to contribute information concerning the logistics involved with each of the beneficial use applications used for their respective fields of knowledge. The market investigations focused on obtaining information relating to the following topics:

- General description and potential benefits
- Market size and geographical locations
- Manufacturing logistics
- Residuals application processes
- Residuals physical and chemical quality requirements

A market description for each beneficial use alternative is summarized in the following sections of Chapter 3. A list of the important residuals chemical and physical parameters was compiled for each application based on information obtained during the market investigations. Table 3.1 provides a list of parameters that could be required for a particular beneficial use application.

Analyses of these parameters should provide a utility with residuals characterization. It is important to note that Table 3.1 contains a list of possible tests that may or may not need to be conducted to characterize residuals properties for each beneficial use market. Each utility should consult with their respective state or local regulatory agency to determine which tests are necessary for characterization of their residuals.

Table 3.1

Potential and useful analytical requirements for beneficial use applications

Parameters	Units
Physical tests*	
Solids concentration	%
Color	-
Texture	-
Soil aggregation	-
Moisture content	%
Grain size analysis (clay/silt/sand)	%
Liquid limit	% solids
Plastic limit	% solids
Mass density	lb/ft^3 (kg/m^3)
Specific gravity	-
Shrinkage	%
Specific weight	lb/ft^3 (kg/m^3)
Shear strength	lb/ft^2 (kg/m^2)
Chemical tests	
Nutrients	
Total Kjeldahl Nitrogen	lb/ton (mg/kg)
Total phosphorus	lb/ton (mg/kg)
Potassium	lb/ton (mg/kg)
Ammonia - Nitrogen	lb/ton (mg/kg)
Nitrate /Nitrite - N	lb/ton (mg/kg)
Calcium	lb/ton (mg/kg)
Calcium Carbonate Equiv. (CCE)	%
Metals	
Total metals †	lb/ton (mg/kg)
TCLP RCRA (8) metals ‡	mg/L
Metal oxides §	lb/ton (mg/kg)

Continued

Table 3.1 (Continued)

Parameters	Units
Radionuclides	
Gross alpha	pCi/g
Gross beta	pCi/g
Radium - 226	pCi/g
Organics	
Total organic carbon (TOC)	lb/ton (mg/kg)
TCLP volatiles / semi-volatiles ‡	mg/L
Loss Of Ignition (LOI)	%
Toxicity	
Phytotoxicity - Microtox test	
Other tests	
Total coliform	no/gram
pH	-

*Physical tests are described in "Landfilling of Water Treatment Plant Coagulant Sludges" (Cornwell *et al.* 1992).

†Total metals analyses includes : Al, As, Ba, Cd, Cr, Cu, Fe, Pb, Mg, Mn, Hg, Ni, Se, Ag, Zn, Mo.

‡TCLP analyses as specified by 40 CFR, Part 261 [Federal Register 1990]. RCRA (8) metals include Ag, Ba, Cd, Cr, Pb, As, Se, and Hg.

§Include major oxides of the following elements: Al, Si, Fe, Ca, Mg, S, Na, K, and Mn.

A number of case studies were developed in order to document actual utility experiences for each form of beneficial use. The location of each utility's case study considered in this project are shown in Figure 3.1. At least one utility case study is included at the end of each market description. A matrix of the utility case studies that are included in the manual are listed in Table 3.2. The case studies presented include beneficial use programs that currently exist or have been abandoned due to specific failures. These experiences are intended to further illustrate the advantages or disadvantages of each beneficial use alternative. The utility case studies include information on some or all of the following subjects:

- Water treatment plant general overview
- Description of beneficial use process
- Marketing process

- Permitting process
- Demonstration/field study experience
- Cost information

MARKET DESCRIPTIONS

Agricultural Land Application

Introduction

Agricultural land application of water treatment residuals is currently the most commonly practiced beneficial use method. It is reported in AWWA's WATERSTAT database that at least 25 percent of the utilities responding perform land application of residuals. The specific type of land application was not reported by WATERSTAT, but it would be reasonable to assume that the majority of the residuals are applied to agronomic soils. Because agricultural land application has been a widely used practice for some time, it is not the intent of this project to extensively investigate land application. Instead, some key issues and references to previous research studies associated with agricultural land application are provided herein.

A detailed description of the processes involved for land application of water residuals are outlined in "Land Application of Water Treatment Plant Sludges" (Elliott, *et al.* 1990). The AWWARF land application manual provides a very good source of technical information concerning the principals and design associated with land applying residuals. Implementation logistics and residuals quality requirements are also summarized in the report. Some of the important land application principals outlined in the AWWARF manual are further defined in this market description.

Table 3.2

Utility beneficial use matrix

Utility	Residuals type	Co-use with biosolids	Com-posting with yard waste	Turf farming	Topsoil blending	Landfill cover	Land applica-tion†	Brick making	Cement manu-facturing	Nutrient control	Road subgrade	Land reclama-tion
Metropolitan Water, LA, CA*	Alum/Ferric		✔						✔			
Tampa, FL*	Ferric						✔					
Elizabethtown, NJ*	Alum				✔		✔					
ECWA, Buffalo, NY	PACl			✔	✔							
Newport News, VA	Alum						✔					
Myrtle Beach, SC	Alum			✔								
Charlottesville, VA	Alum/PACl	✔				✔						
Durham, NC	Alum							✔				
Cobb County-Marietta, GA	Alum/Lime						✔					
NJWSA, NJ	Alum				✔		✔					
Santa Clara, CA	Alum					✔		✔				
Wales, UK	Alum							✔				
Greenwich, CT	Alum	✔	✔									
Danville, PA	Alum									✔		
Englewood, CO	Alum				✔		✔					
Tulsa, OK	Alum								✔	✔		
Boynton Beach, FL	Lime										✔	
Bradford, PA	Alum											✔
Cary/Apex, NC	Alum							✔				
Earthgro, Inc.‡	Alum				✔							
Richmond Recycling‡	Alum				✔							

*Participating utilities

†Land application includes citrus groves, agricultural land, forest land, and hay fields.

‡Commercial user of water treatment plant residuals.

Other valuable land application references include the following:

- "Groundwater and Crop Growth Issues Associated with Water Treatment Residuals (Knocke *et al.* 1991)
- "Agronomic Effects of Land Application of Water Treatment Sludges" (Elliott and Dempsey 1991)
- An Assessment of Cropland Application of Alum Sludge" (Mutter 1994)

General Description and Potential Benefits

A number of land application research studies conducted using coagulant residuals have demonstrated neutral or slightly positive impacts on crop growth (Lin and Green 1990, Geertsema *et al.* 1994). Some of the benefits associated with the addition of coagulant residuals to agronomic soils include:

- Improvement to soil structure
- Soil pH adjustment
- Addition of trace minerals
- Increased moisture holding capacity
- Soil aeration

Some negative effects on soil characteristics have also been documented. Research studies have shown that some coagulant residuals have a tendency to bind plant available phosphorus in soils (Elliott and Dempsey 1991, Knocke *et al.* 1991). Also, aluminum phytotoxicity could also be a problem if the soil pH is not maintained at or above 6.5 (Elliott and Dempsey 1991).

Implementation Logistics

"Land Application of Water Treatment Plant Sludge" (AWWARF 1990) provides a complete instructional guide for a utility interested in pursuing a land application program. The manual provides detailed information on the following topics:

- Description of major components found in coagulant residuals
- Residuals effects on soil phosphorus availability
- Heavy metals and residuals toxicity
- Residuals effects on physical properties and soil pH

Land application implementation logistics outlined by the AWWARF land application manual include:

- Residuals application design
- Site selection
- Agricultural methods
- Storage of residuals
- Application rates
- Monitoring and reporting

Land application of residuals can be performed using either liquid or cake solids residuals. The liquid or solid material could be effectively land applied at any solids concentration found to be economically feasible by a utility and acceptable to the land owner. The amount of dewatering required is based primarily on hauling distances to the application site, storage facilities required, residuals water value, and land owner preference. Solids concentrations for liquid residuals applications range from 0.5 to 10 percent, while cake residuals applications require a solids concentration of greater than 15 percent. A process schematic outlining the typical application procedure used for land applying residuals as a liquid or cake solid is shown in Figure 3.2.

Liquid residuals applications, where feasible, can provide a number of advantages. Liquid applications only require gravity sedimentation and thickening, thereby eliminating the need for costly mechanical dewatering facilities and equipment. Liquid applications to agronomic soils can be applied to soils throughout the growing season depending on the type of crop produced and the application technique used. Applications throughout the growing season, if feasible, may provide an additional water value for crop growth. Residuals applied in a liquid form tend to provide a more even application to agronomic soils, creates less soil clumping, and is incorporated into the natural soil more rapidly. A disadvantage of land applying liquid residuals is the increased volume of residuals, which directly impacts the handling and transportation costs. Liquid applications are only economically attractive when application sites are within close proximity to the water treatment plant, or if relatively small quantities of residuals are generated.

Land application of dewatered residuals requires dewatering to a solids concentration that can be handled by front-end loaders, transported by dump trucks, and spread onto farmland using manure type spreading equipment. Mechanical dewatering requires costly equipment and annual O&M costs. The volume reduction, however, significantly reduces transportation and handling costs. Cake solids are not typically applied during the growing seasons due to the potential for physical crop damage during spreading. Therefore, a residuals storage facility may be required to stockpile residuals until land application is possible. Uneven distribution and soil clumping are also potential problems using cake solids applications.

In order to increase the value of residuals for agricultural use, a number of contractors and utilities have developed processes that combine residuals with other beneficial agricultural products. Residuals amendments include lime addition, fertilizers, biosolids, and finished compost materials. Any of these products could effectively increase the agronomic value of the water treatment residuals. Lime additions are frequently added to coagulant residuals to aid in mechanical dewatering of the material. Fertilizers (N, P, K), compost, or biosolids could be blended with residuals prior to or during the land application process. Blending the residuals with any of these amendment at the proper ratios increases the residuals value and, as a result, makes marketing of residuals to farmers an easier task.

Residuals Quality Requirements

The chemical and physical quality of residuals and effects on agronomic soils are outlined in the AWWARF land application manual (Elliott *et al.* 1990). The manual suggests a number of chemical and physical parameters that should be analyzed for residuals characterization. A list of important residuals quality parameters that should be investigated prior to land applying residuals is presented in Table 3.3. Regulatory agencies responsible for granting land application permits may require a utility to test for some or all of these parameters as part of the permit application process. Subsequent testing may be required on an annual or semiannual basis for permit compliance. As discussed in Chapter 2, each state has their own rules and guidelines for regulating beneficial use programs. Many of the states regulate residuals beneficial use on a case-by-case basis depending on the type of use and quality of the residuals. Therefore, no exact list of parameters will apply to every utility.

Table 3.3

Important residuals quality parameters for land applying residuals

Parameters	Units
Physical tests*	
Solids concentration	%
Color	-
Texture	-
Soil aggregation	-
Moisture content	%
Grain size analysis (clay/silt/sand)	%
Specific weight	lb/ft^3 (kg/m^3)
Chemical tests	
Nutrients	
Total Kjeldahl Nitrogen	lb/ton (mg/kg)
Total phosphorus	lb/ton (mg/kg)
Potassium	lb/ton (mg/kg)
Ammonia - Nitrogen	lb/ton (mg/kg)
Nitrate/Nitrite - N	lb/ton (mg/kg)
Calcium	lb/ton (mg/kg)

Continued

Table 3.3 (Continued)

Parameters	Units
Calcium Carbonate Equiv. (CCE)	%
Metals	
Total metals†	lb/ton (mg/kg)
TCLP metals‡	mg/L
Radionuclides	
Gross alpha	pCi/g
Gross beta	pCi/g
Radium - 226	pCi/g
Organics	
Total organic carbon (TOC)	lb/ton (mg/kg)
Toxicity	
Phytotoxicity - Microtox test	
Other tests	
Total coliform	no/gram
pH	-

*Physical tests are described in "Landfilling of WTP Coagulant Sludges" (Cornwell *et al.* 1992).

†Total metals analyses includes : Al, As, Ba, Cd, Cr, Cu, Fe, Pb, Mg, Mn, Hg, Ni, Se, Ag, Zn, Mo.

‡TCLP analyses as specified by 40 CFR, Part 261 [Federal Register 1990].

Land Application Case Studies

Cobb County-Marietta Water Authority. The Cobb County-Marietta Water Authority (CCMWA), located in the Metropolitan Atlanta area, operates two water treatment facilities with a combined rated capacity of 136 mgd. The James E. Quarles Water Treatment Plant is permitted to treat 64 mgd from the Chattahoochee River. The Hugh A. Wyckoff Water Treatment Plant is permitted to treat 72 mgd of raw water from Lake Allatoona on the Etowah River. Both plants utilize conventional methods of water treatment and use alum as the primary coagulant.

The CCMWA treatment facilities both use the same methods for residuals handling and dewatering. Alum residuals are removed daily from the sedimentation basins and flow into gravity thickening basins. After thickening, residuals are transferred to a conditioning tank where a lime slurry is blended into the residuals at a 10 to 15 percent dry weight basis. Mechanical dewatering using pressure filters provides a final cake solids concentration of approximately 35 percent. After dewatering the cake solids are referred to as "lime byproduct". The dewatered residuals are transported by dump trucks to a residuals storage yard at the Wyckoff plant and stockpiled for two to three months prior to final residuals beneficial use.

The combined volume of residuals generated by both treatment facilities is approximately 10,000 yd^3/yr (7,646 m^3/yr) (wet volume at 35 percent solids). Physical and chemical characteristics of residuals generated from each treatment plant are very similar and the residuals are ultimately combined together for handling and beneficial use.

Overall, the chemical and physical quality of the lime residuals is excellent. Toxicity Characteristic Leaching Procedure (TCLP) analysis have been conducted to determine concentrations of metals, pesticides, herbicides, and volatile organics. The following residuals characteristics have been confirmed by laboratory analyses:

- No toxic contaminants
- Low concentrations of heavy metals
- Very low nutrient content
- Pesticides and herbicides were below detectable limits
- Cyanide and sulfide concentrations were below EPA limits

Until 1990, CCMWA transported dewatered residuals to the county landfill for disposal. Historically, landfill disposal was a cost-effective option, however, it was at times problematic because the County required that the residuals be mixed with construction or yard debris at the landfill prior to disposal. These materials were not always available when the Authority brought its residuals to the landfill. Landfill tipping fees had also steadily increased up to $35.80/ton ($30.00/metric ton). All of these factors forced CCMWA to begin investigating alternative options for future disposal of residuals.

The Authority investigated a number of potential disposal options and eliminated all but the following two alternatives:

- Monofilling
- Land application

CCMWA reviewed each option and ultimately selected land application to crop and pasture land as the best alternative. This selection was based on the availability of farm land in the immediate area, economical capital and operational costs, and a minimal time frame required to initiate the program.

The Authority contacted the Georgia Environmental Protection Division-Department of Natural Resources (GADNR) to discuss the requirements for conducting a land application program. The Authority presented residuals analytical data to GA EPD, discussed research work performed by Pennsylvania State University, and described a similar program that was being conducted in Virginia. The Authority requested permission to perform a full-scale demonstration study to evaluate the use of residuals on cropland. After reviewing the analytical data submitted by CCMWA, the GADNR gave permission to conduct demonstration testing. Data obtained during the one-year demonstration study confirmed that the residuals could be used in a safe and beneficial manner. Based on these results, GADNR classified the residuals as a "recovered material" which did not require a solid waste permit for land application. GADNR also did not require reporting of any monitoring activities from the full-scale application program.

Once the Authority was granted permission to land apply the lime residuals, a consultant was hired to manage the program. The consultant's first task was to locate farmers that were willing to accept the residuals. To do so, the consultant employed a number of marketing strategies, some of which are listed below:

- Discussion at farmer meetings
- Contact county extension agents
- Direct contact with farmers

The Authority was able to generate interest from the farming community due to the fact that they were providing a valuable liming agent at no cost. Initial marketing efforts were able to secure approximately 1,500 acres (607 hectares) of farmland. Approximately 88 percent of this farmland was pasture, the remaining land was cropland.

The consultant is also responsible for land acquisition, monitoring, and program management. A contractor was also hired for hauling the lime byproduct residuals to the application site and land applying the material.

Water treatment residuals are hauled several times per year by dump trucks from the Wyckoff storage facility to the farmland for application. Typically, 3,000 to 5,000 yd^3 (2,300 to 3,800 m^3) of wet residuals (approximately 35 percent solids) are land applied during each of the application periods. Residuals are land applied using a manure spreader, which provides even distribution onto the fields. Application rates are based on the pH of the soil and the liming requirement needed to adjust pH to a good agronomic level. Residuals are typically surface applied at 5 to 15 dry tons/acre (11 to 33 metric tons/hectare). The application frequency for each tract of land varies, but is typically one application every five years. The metal and nutrient concentrations were very low and are not a major factor in determining application rates and frequencies. Overall, the land application program requires approximately 500 acres/yr (200 hectares/yr) in order to land apply all of the residuals generated from the two treatment plants.

Analytical monitoring is not required to be reported to the GADNR, however, the Authority regards their residuals and soil monitoring program as a vital component to the application program. Residuals are sampled quarterly in order to monitor the chemical and physical characteristics. Tests conducted are as follows:

- Percent solids
- Percent calcium carbonate equivalence (CCE)
- pH
- Total metals
- Nutrients

During the first couple of years of land application, TCLP metals, organics, herbicides, and radionuclides tests were also conducted. Concentrations for each of these parameters were found to be very low or below detectable limits and as a result monitoring for these parameters was discontinued. Soil monitoring is routinely conducted on all tracts of land before they are admitted into the program. Soil from approximately ten fields, one field per farm, is then analyzed on a yearly basis. Soil monitoring allows the utility to determine if there are any long term impacts due to residuals application. The analyses conducted included heavy metals and nutrients. Plant tissue analysis is also conducted on crops collected from the same ten fields to determine the associated impacts of residuals application. Chemical analysis of plant tissue includes nitrogen, sulfur, phosphorus, potassium, boron, zinc, manganese, iron, copper, and aluminum.

During the early stages of the program, stream monitoring was conducted both above and below the residuals storage facility at the Wyckoff Water Treatment Plant to determine if stormwater runoff was polluting water quality. Analyses conducted include pH, calcium, aluminum, and turbidity. Data collected to date has shown little variation between upstream and downstream water quality.

The 1992 total cost incurred for both plants for land acquisition, transportation of residuals, spreading, monitoring support, and reporting for land applying 2,275 yd^3 (1,740 m^3) of dry residuals was approximately \$170,000. The cost for laboratory analyses added \$10,000 per plant, bringing the total project cost in the first year to \$190,000. Currently, CCMWA disposes of 3,500 yd^3/yr (267 m^3/yr) of dry residuals at a cost of about \$140,000/yr. The consultant fees average \$25,000/yr. Laboratory analyses costs average about \$10,000 for both water treatment plants. The total program cost is currently \$175,000/yr or \$50/yd^3 (\$65/m^3) of dry residuals.

The current landfill tipping fees are \$35.80/ton (\$35.80/metric ton) making the total cost of landfilling residuals approximately \$260,000/yr. The Authority's total savings resulting from the use of land application is approximately \$85,000/yr. Along with the cost savings, residuals are being beneficially used instead of occupying valuable space in a sanitary landfill. Also, the local farming community benefits from receiving an important agricultural amendment at no cost.

New Jersey Water Supply Authority. The New Jersey Water Supply Authority (NJWSA) operates a 4-mgd (15,100-m^3/day) water treatment plant in Southern Monmouth County, New Jersey. The plant obtains raw water from the Manasquan River and Reservoir System. Raw water pumped from the Manasquan River is delivered to a pre-sedimentation basin and then pumped to the treatment plant or to a storage reservoir. Plant treatment processes include raw water ozonation, addition of alum and polymer, adsorption clarification, multi media filtration, and post-filter GAC contactors.

Alum residuals produced by the treatment plant average 700 dry lb/day (317 kg/day). Residuals are contained in on-site dewatering lagoons for six months for residuals dewatering and air drying. Residuals removed from the lagoons typically have a solids concentration of 25 to 30 percent. The residuals are then stockpiled within a hay baled enclosed site on the water plant property for one year of further air drying. Air dried residuals are approximately 70 percent solids.

NJWSA also accumulates approximately 1,400 yd^3/yr (1,070 m^3/yr) of river sediment that requires incorporation back into the environment. River sediments are obtained through periodic dredging around the plant raw water intake and an area immediately upstream. Sediments are stockpiled on site and allowed to dry to greater than 50 percent solids concentration. Analytical tests show that the river sediments and alum residuals have very similar chemical characteristics. Prior to land application, most of the alum residuals are blended with the river sediments at a rate of less than 50 percent. The remaining residuals are land applied without blending with river sediment.

NJWSA owns 105 acres of land within close proximity to the treatment plant. The designated residuals application areas are located adjacent to the water plant and, therefore, require only minimal road travel. The majority of alum residuals applied at this site are blended with the river sediment.

The NJWSA also developed an annual lease agreement with a local farmer that allows the farmer to use NJWSA's land for hay production. The farmer is responsible for incorporating the dewatered alum residuals into the soil. NJWSA does not charge the farmer a fee for land use but instead receives payment by receiving a percentage of the hay bales produced on the site.

Residuals are land applied once a year. The maximum application rate used for addition of residuals to soils is 20 dry tons/acre (45 metric tons/hectare). Residuals are mechanically incorporated into the soil immediately after application. The agricultural land receives applications of the alum and sediment blend as well as 100 percent alum residuals.

NJWSA applied for and was granted a New Jersey Pollutant Discharge Elimination System (NJPDES) Permit to land apply residuals. The permit application required information from NJWSA on the following topics:

- Description of physical and chemical water treatment processes
- General plant information

- Residuals quantity and moisture content
- Residuals characteristics
- Storage plan
- Land application plan
- Transportation plan

The final NJPDES permit provided guidelines on residuals application procedures and outlined a plan for the sampling and analyses of soil and residuals samples.

NJWSA did not have to actively market their residuals because they owned the property used for land application. NJWSA did, however, have to locate a farmer that was willing to enter into a lease with the Authority and was capable of satisfying the land application requirements outlined by the NJPDES permit. The farm lease contract took approximately one year to finalize from the original draft agreement to a signed final agreement with the farmer.

The NJWSA cost for the land application program is limited to the cost for cleaning residuals from the lagoons and stockpiling on-site. The cost of cleaning is approximately $11,000 for cleaning each of these lagoons. Residuals are typically removed three times per year. NJWSA also pays $2,550/year for the annual NJPDES permit and a minimal yearly fee for laboratory analysis of compliance samples.

Cement Manufacturing

General Description and Potential Benefits

Water treatment residuals have successfully been used as an ingredient for the production of Portland Cement. Cement (commonly referred to as hydraulic cement) is a material that has the property of hardening under water and is the primary bonding agent in concrete and masonry. The name "Portland" was chosen because the inventors thought that cement resembled a building stone quarried from the Isle of Portland off the coast of England. More than 95 percent of the cement produced in the U.S. is Portland cement (USGS 1997). Portland cement is a principal material used for concrete construction and, because of its high rate of use, there is a continuously increasing demand for this material. Uses for cement include ready mix concrete, block, pipe, pre-cast slabs, road construction, and building materials.

The natural materials used for cement production include limestone, shale, and clay. The critical elements supplied by the raw materials for cement production are calcium, silica, aluminum, and iron. Limestone provides approximately 70 to 80 percent of the raw material required for cement production, but only contains low concentrations of aluminum, iron, and silica. In order to supplement the required elements, cement plants add other materials such as clay, shale, iron ore, and bauxite (USGS 1997).

Water treatment residuals generated using lime softening or coagulants commonly contain some or all of the key elements that cement plants add during their manufacturing process. Residuals could potentially increase concentrations of these critical elements which would reduce the total volume of supplemental materials a cement manufacturer would have to purchase and add. A reduction in the volume of raw materials required could provide a cost savings to the manufacturer.

Market Size and Geographical Locations

The U.S. Portland Cement Association (U.S. PCA), located in Skokie, Ill., is a national organization that represents Portland Cement Manufacturing plants in the U.S. and Canada. The U.S. PCA sponsors scientific and economic research to benefit the Portland Cement industry, and provides industry statistics. U.S. PCA reported that during 1997 the total production of Portland cement manufactured in the U.S. was approximately 77 million tons (69.6 million metric tons). A total of 108 cement manufacturing plants were distributed between 37 states. On a regional basis, California had the highest cement manufacturing capacity (13 percent of U.S. capacity) followed by Texas, Pennsylvania, Michigan, Missouri, and Alabama, respectively. These six states accounted for approximate 51 percent of the total U.S. cement production. A total of 14 states and the District of Columbia produce no Portland cement. A typical plant will generate approximately 800,000 tons/yr (726,000 metric tons/yr) (U.S. PCA 1997).

The locations and concentrations of cement manufacturing facilities across the U.S. is highly dependent on regional geology. Cement facilities typically exist in regions that have large natural deposits of limestone that are easily accessible. Figure 3.3 shows where each cement manufacturing plant is located and its approximate capacity (U.S. PCA 1997). The U.S. PCA map clearly demonstrates the regions of the U.S. where most of the Portland cement is produced. Water treatment plants that are located in close proximity to one of the cement manufacturing facilities could investigate the potential for using residuals as an ingredient for cement production.

Manufacturing Logistics

Cement manufacturing processes and raw material ingredients for each cement plant vary, however, the basic manufacturing procedure is common to every facility. A schematic showing in the cement making process is presented in Figure 3.4. The schematic shows each step of the cement making process from the quarry through calcination and finally distribution. The process schematic demonstrates a "dry process" cement manufacturing plant in which all raw materials are ground, conveyed, blended, and fired in a dry form. The combined total number of kilns operating in the U.S. in 1996 was 202 in which 131 (65 percent) used the "dry process" while 71 (35 percent) used the "wet process" (U.S. PCA 1997). The cement process used is based primarily on the moisture content of the raw materials. The "wet process" is typically selected when raw materials are extremely wet and sticky in order to eliminate drying materials prior to crushing and grinding. Because the majority of cement plants utilize the "dry process", the procedure for this type of manufacturing application is presented in the process description. The following summarizes the process used for cement manufacturing (LaFarge 1998):

1. Limestone is the primary raw material mined for use.
2. Crushing and pre-homogenization are processes used to prepare raw materials for burning. Raw materials from the quarry are crushed to a size of 2 in. (5 cm) or less. The crushed limestone is pre-homogenized with other materials such as clay and shale to achieve the correct concentrations of calcium, silica, aluminum, and iron.
3. A raw feed mill or grinding mill is used to pulverize coarse pre-homogenized material into a fine dry powder.

4. The homogenization procedure is used to screen coarse material out of the fine powder after the feed mill. The coarse particulates are returned to the grinding mill for further pulverization.
5. A preheating tower removes moisture from the fine powder material prior to entering the kiln in order to improve overall fuel efficiency in the rotary kiln.
6. The rotary kiln is used to burn raw materials into clinker. Clinker is the fused cement product that is later ground into a fine powder, which is then referred to as cement. The rotary kiln is divided into the following process zones: preheating zone, calcining zone, burning zone, and cooling zone. Kiln temperatures reach as high as 2,600°F (1,425°C).
7. Cement additions such as gypsum ($CaSO_4$) or fly ash are added to clinker prior to final grinding. Final grinding is performed at the finish mill which can be located at the production facility or at an off-site location.
8. The final product is stored in silos and ready for bulk distribution.

Residuals Application Process

The schematic of the cement manufacturing process previously shown in Figure 3.4 indicates the recommended location for residuals addition during crushing and pre-homogenization of raw materials. Incorporation of the residuals at this stage of the process ensures complete grinding and mixing of the residuals along with other raw materials. A storage facility is required for stockpiling residuals at the cement plant prior to use. The residuals are blended into the other raw materials at a desired ratio based on the quality and quantity of the residuals. Demonstration tests are necessary to determine the optimal mix ratio prior to full-scale production. Other application points may also be possible, however, due to the limited use of residuals for cement manufacturing no established procedures exist.

Storage facilities and application equipment required for adding residuals into the cement making process may or may not pre-exist at the cement plant. A covered concrete storage pad, front-end loader, a conveyor system and a feed hopper could be required for residuals incorporation. Most cement plants will most likely require some process modifications but should not require additional equipment. Cement manufacturing is a year-round process which utilizes a large supply of raw materials, therefore, only short term storage of residuals at the cement plant would be necessary.

Residuals Quality Requirements

Physical Requirements. A recommended listing of physical tests that should be evaluated prior to residuals marketing is listed in Table 3.4. Physical requirements for residuals used as an ingredient for the production of Portland cement focus primarily on the moisture content of the material. Cement manufacturing facilities using the "dry process" require materials with low moisture concentrations. Manufacturers prefer a semi-dry or completely dry material so that residuals would not require further dewatering prior to use (McKnitt 1998, Thomas 1998). Residuals with solids concentrations of 50 percent or higher are more attractive to the "dry" manufacturing process. Mechanical dewatering followed by air drying would be required to achieve a dewatered cake acceptable for this process. The optimal solids concentration of wet residuals when used in the "wet" cement process would have to be determined by the cement manufacturer through experimentation.

Table 3.4

Important residuals physical parameters for cement making

Parameters	Units
Solids concentration	%
Moisture content	%
Grain size analysis (clay/silt/sand)	%
Mass density	lb/ft^3 (kg/m^3)
Specific gravity	-
Specific weight	lb/ft^3 (g/m^3)

Chemical Requirements. The chemical parameters that should be analyzed for residuals characterization are listed in Table 3.5. A number of chemical compounds and elements commonly found in residuals are critical ingredients in materials used for cement production. Cement manufacturers require raw materials that contain significant concentrations of calcium, iron, and aluminum for making good quality cement (McKnitt 1998). Most natural limestone deposits contain a high calcium concentration, but low concentrations of these other elements. Shale rock and clay are typically added along with the limestone to increase concentrations of silica, iron, and aluminum. Cement manufacturers that have experimented with water treatment residuals have found that the material contains most or all of these elements at beneficial concentrations (Thomas 1998).

Water treatment residuals are known to contain major oxides of a number of elements most of which are beneficial to cement making. Oxides of the following elements—Ca, Si, Al, Fe, Mg, S, Na, K, and Mn—are commonly found in residuals. The presence of sodium and potassium oxides effectively decreases the alkali concentrations in the finished cement product. High alkali levels in cement can cause expansion and cracking in finished concrete structures. Natural shale rock and clay used to supplement the Al, Si, and Fe concentrations in cement, in many cases have a high alkali concentrations that are detrimental to cement quality. Therefore, the use of water treatment residuals could potentially benefit the cement production industry by providing a source of low alkali material that includes high concentrations of these industry required elements.

Table 3.5

Important residuals chemical parameters for cement making

Parameters	Units
Calcium	lb/ton (mg/kg)
Total metals*	lb/ton (mg/kg)
TCLP metals†	mg/L
Metal oxides‡	lb/ton (mg/kg)
Gross alpha	pCi/g
Gross beta	pCi/g
Radium - 226	pCi/g
Total organic carbon (TOC)	lb/ton (mg/kg)
TCLP volatiles/semi-volatiles†	mg/L
pH	-

*Total metals analyses includes : Al, As, Ba, Cd, Cr, Cu, Fe, Pb, Mg, Mn, Hg, Ni, Se, Ag, Zn, Mo.

†TCLP analyses as specified by 40 CFR, Part 261 [Federal Register 1990].

‡Include major oxides of the following elements: Al, Si, Fe, Ca, Mg, S, Na, K, and Mn.

The chemical parameters selected for analysis that are most important to cement manufacturers are the TCLP metals, TCLP volatiles, metal oxides, and total organic carbon (McKnitt 1998). TCLP analyses along with reactivity, ignitability, and corrosivity tests of the residuals are critical for demonstrating that the residuals are nonhazardous. The residuals total metals and metal oxide concentrations will provide a manufacturer with important data to determine if the residuals have acceptable properties for use as a cement ingredient. This knowledge will help determine if further analytical testing or demonstration testing is feasible.

The chemical properties commonly associated with residuals that are detrimental to cement production include the following parameters:

- High organic concentration
- Anthracite and/or GAC carbon
- Sulfur
- Potassium permanganate
- High concentrations of heavy metals

Most of these parameters could cause increased emissions during the firing process. Air quality monitoring requirements and permit compliance are strictly regulated at cement plants (McKnitt 1998, Thomas 1998).

Cement Manufacturing Case Study

City of Tulsa, Oklahoma. The City of Tulsa, Oklahoma Department of Public Works operates two drinking water treatment facilities that supply water to the City of Tulsa. The facilities are the A.B. Jewell and the Mohawk water treatment plants. Both facilities treat surface water from reservoirs and use alum as the primary coagulant. Other treatment chemicals used at A.B. Jewell include soda ash, chlorine, polymer, PAC, and potassium permanganate.

Residuals generated from the A.B. Jewell facility are either piped to on-site thickening lagoons or are mechanically dewatered to a 20 percent solids concentration. After mechanical dewatering, the residuals are spread out and allowed to further air dry to 50 to 70 percent solids. The plant typically produces 165 dry lbs/MG (20 metric tons/Mm^3) of raw water treated. During 1998, the plant's daily alum residuals production was approximately 6 dry tons (5.4 metric tons). Laboratory analysis of the A.B. Jewell residuals included the following parameters:

- Corrosivity
- Ignitability
- Paint filter test
- PCB's
- TCLP metals
- TCLP volatiles
- TCLP semivolatiles
- TCLP pesticides

Test results demonstrated that the A.B. Jewell residuals contained no free liquid, no TCLP volatiles or semivolatiles, no PCB's, a pH of 7.3, and only trace amounts of TCLP metals. Based on the results the residuals were classified by the State of Oklahoma as a nonhazardous waste.

The City of Tulsa historically disposed of alum residuals in a sanitary landfill. Due to increasing landfill tipping fees the City began to investigate alternative beneficial use options. A residuals disposal specification was drafted by the City and sent out for competitive bid. The City ultimately hired a local materials contractor to handle disposal of all alum residuals generated. The contractor was also responsible for securing beneficial use permits from the state and for periodic monitoring of residuals quality.

The contractor contacted a local cement manufacturing facility located in very close proximity to the A.B. Jewell treatment plant about using residuals as a raw material for cement production. The alum residuals showed good potential for use as an ingredient in cement manufacturing due to its high concentration of silica, iron, and aluminum.

The local cement company agreed to perform a six month demonstration test using alum residuals in their process. The alum residuals were added in place of shale rock normally added to the cement blend. The tests were successful and the cement manufacturers soon after began using residuals in the full-scale process.

Historical landfill disposal costs paid by the City of Tulsa was approximately $9/ton ($9.90/metric ton). This cost included hauling to landfill and landfill tipping fees. Currently the City pays the materials contractor a hauling fee of $2.40/ton ($2.64/metric ton) and a recycle cost of $3.75/ton ($4.13/metric ton), for a total disposal cost of $6.15/ton ($6.77/metric ton). The contractor indicated that the primary reason that this beneficial use option is economically feasible is because of the very close proximity of the A.B. Jewell Water Treatment Plant to the cement manufacturing facility.

Brick Manufacturing

General Description and Potential Benefits

Brick manufacturing is an ancient art that has been practiced for centuries. Improvements in production techniques and the manufacturing equipment used for brick making has resulted in the development of a modern industry. Computer controlled kiln designs and a better knowledge of the raw materials used for brick making have resulted in increased production and better quality bricks. Today's brick manufacturing facilities in the U.S. produce billions of bricks per year. Manufacturers are capable of providing a wide variety of colors, textures, and shapes desired by consumers. Bricks are used for a wide variety of purposes, however, the majority of bricks produced are used for commercial, residential, and industrial construction.

There are a number of striking similarities between the physical and chemical compositions of materials used for brick making and coagulant residuals. Alum, ferric, and PACl residuals have chemical and physical properties similar to the natural clays and shales used for brick production. Coagulant residuals consist of clays, silt, and sand removed from the water during treatment along with organic matter and other chemical compounds formed during chemical coagulation. Those residuals with a high clay content are optimal for brick making. Lime on the other hand is detrimental to brick quality and, therefore, residuals containing significant concentrations of lime are not acceptable for brick making applications (Ceratec 1998).

The raw materials used for brick manufacturing include clay and shale. Clay is the most abundant mineral material on earth, however, not all clays have the same properties. The natural clay used for brick production must have specific properties in order to produce good quality bricks.

A number of water utilities, along with the assistance of brick makers, have performed demonstration testing using residuals as an ingredient for brick making. Utility experience suggest that success or failure of brick making as a beneficial use alternative is dependent on a number of factors including (Rolan 1976, Migneault 1989):

- Proximity of brick plant to the water treatment plant
- Residuals chemical and physical quality
- Coagulants and other chemicals used during treatment process
- Acceptance of the residuals by brick manufacturers
- Impacts on normal operations

The use of water treatment residuals in brick production could benefit the brick industry in a number of ways. Water treatment plants generate tons of residuals on a daily basis that could be used to offset some of the enormous volume of natural materials used for brick production. The added volume of residuals could potentially decrease the volume of natural clay and shale, thereby, increasing the life of the quarry used by the brick manufacturer for their raw material.

Studies conducted by brick manufacturers have demonstrated that good quality bricks can be produced using water plant residuals. No significant impacts on the structural properties of brick were noted, in testes conducted by the City of Durham, when up to 15 percent alum residuals were added to natural clay for brick production (Rolan 1976). Several manufacturers have also found that residuals containing significant concentrations of iron hydroxide or barium produce a desirable red color in finished bricks (Rolan 1976, Migneault 1989, Owen 1998).

Market Size and Geographical Locations

U.S. Brick Industry Association (BIA) is a national organization that was formed to support the brick making industry. BIA members include brick manufacturers, distributors, and builders.

Statistical information compiled by the BIA includes survey responses from over 200 manufacturing facilities and provides a regional analysis of brick production.

Brick manufacturing in the U.S. is a very large industry. There are approximately 203 brick manufacturing plants in the U.S. that produce approximately 9 billion standard brick equivalents (S.B.E.) per year. The S.B.E. is the industry standard for brick measurement. A standard brick measures 3⅝ in. x 2¼ in. x 7⅝ in. (9.2 cm x 5.7 cm x 19.4 cm) and weighs approximately 4.5 lbs (2 kg). The overall total raw material demand for U.S. brick production in 1997 exceeded 20.5 million dry tons/yr (18.6 million metric tons/yr) (BIA 1997).

Brick manufacturing facilities are located in every state except for Alaska, Delaware, Hawaii, Rhode Island, South Dakota, Wisconsin, Wyoming, Florida, Vermont, and New Hampshire. Brick manufacturing is primarily in regions of the U.S. that have an abundance of surface clay and shale deposits. A map, generated with information provided by the U.S. BIA Census shows a breakdown of the U.S. state and regional quantities of bricks produced is included in Figure 3.5. The map shows that the majority of bricks are manufactured in the southeastern region of the U.S. Texas, California, and Ohio also account for a significant percentage of the total U.S. brick production. The State of North Carolina is the largest overall producer of bricks with a total of 25 different manufacturing plants. The Western region of the U.S. generates the lowest brick production accounting for only 2.4 percent of the total volume of bricks manufactured (BIA 1998).

Manufacturing Logistics

The basic principals for brick manufacturing are similar for all U.S. brick plants, however, individual plants may slightly modify their production processes to accommodate the quality of raw materials mined from their quarries. Basically, raw clay materials are mixed with water to form a plastic mass that can be molded into a desired brick shape. The plastic form is then dried and fired to produce a hardened brick. Modern brick making equipment and techniques allow for applications of various colors and textures. Most bricks produced today are machine made, however, some brick companies still produce custom hand molded bricks (Parrish 1998).

The basic manufacturing process used for brick making is shown in Figure 3.6. The manufacturing procedure has six general phases: 1) winning and storage, 2) preparation of raw materials, 3) forming, 4) drying, 5) firing and cooling, and 6) dehacking and transport (BIA 1986).

Winning of raw materials means to obtain raw materials from mining. Surface clays, fire clays, and shale are mined from open quarries. Fire clays are also recovered from deeper underground mines. Clay and shale are either mixed at the mining site or at the brick plant. It is a common practice to stockpile enough raw materials at the mine site to allow for several days of plant production in case severe weather conditions persist and raw materials can not be obtained from the quarry.

During preparation, raw materials are dumped into mullers and crushing equipment to pulverize the materials into a fine powder. The material is then screened to eliminate coarse materials prior to forming into bricks.

The forming and cutting process is used to make desired brick shapes. The screened raw materials are conveyed to a pugmill for tempering. Tempering is accomplished in a pugmill by adding water to the clay at desired feed rate and mixing the material into a plastic mass. The plastic mass is then passed through a de-airing vacuum chamber to remove air holes and bubbles. De-airing increases workability and plasticity. The clay is then extruded through a die onto a conveyor belt shaped into the form of a long continuous brick. Texture and color agents are then added prior to wire cutting into individual bricks.

The wet bricks are air dried for approximately 24 to 48 hrs at temperatures ranging from 100 to 700°F (37 to 370°C). Heat for drying is supplied by exhaust heat from the kiln.

Dried bricks are loaded onto kiln cars and rolled into the kiln for firing. The firing process takes between 40 and 150 hrs. Firing temperatures are closely controlled to produce desired temperature zones. Kiln temperatures range from 400°F to 2,400°F (200 to 1,300°C). At the end of the firing process the bricks may be "flashed" to produce different colors. Cooling of the brick requires 48 to 72 hrs. Rapid cooling could cause cracks and effect brick color (Parrish 1998).

Dehacking is the process of off loading bricks from kiln cars. Bricks are then sorted, graded, and packaged for storage or transport.

Brick manufacturing is performed year round. Most brick plants operate at or near maximum production capacity in order to meet demands. Demand for bricks, however, is affected by seasonal variations. A high brick demand is noticed during warm weather months due to increased building construction. During the off peak winter season bricks are continuously stockpiled to meet springtime demands.

Residuals Application Process

Brick manufacturing plants have experimented with residuals addition at two different stages of the brick making process. The application locations include addition of residuals at the quarry or at the brick plant (Rolan 1976).

Quarry application of the residuals is the easiest method for blending residuals with the natural raw materials. Dewatered residuals are transported from the water plant to the quarry and either stockpiled or dumped directly into the quarry. Residuals that are stockpiled are later blended with other materials prior to delivering to the plant. Residuals dumped directly into the quarry are ripped into the natural clays by mining machinery. The blending process is accomplished using front end loaders, augers, or pugmill equipment. Residuals blending rates are typically less than 10 percent of the total volume of materials used on a daily basis for brick making. Overall, the amount of residuals that could be supplied by most water treatment plants is only a very small percentage of the huge total volume of raw material used for brick manufacturing. For example, a typical brick manufacturing plant uses on average approximately 121,000 dry tons (109,800 metric tons) of raw materials annually. With a typical blend rate of 5 percent, up to 6,000 dry tons/yr (5,450 metric tons/yr) of residuals could be supplied annually. By comparison, a fairly large WTP that treats 50 mgd (190,000 m^3/day) of raw water with an average turbidity of 15 ntu using 30 mg/L of alum would only generate around 3,000 dry tons/yr (2,720 metric tons) of residuals or 2.5 percent of the volume of materials used by a typical brick plant.

Demonstration studies have shown that blending the residuals at the quarry at a low ratio with natural materials cause the residuals to virtually disappear into the large volume of clay and ultimately have very little or no effect on brick quality (Rolan 1976). Quarry blending of the residuals also minimizes the need for additional equipment for residuals handling the residuals. In most cases the existing machinery at the quarry is capable of handling and blending the residuals.

Blending of residuals at the brick plant requires a more technical approach towards introducing the materials into the existing plant processes. Brick plant blending would most likely involve more operator attention and control than quarry applications of residuals (Migneault 1988). Dewatered residuals from the treatment plant are transported directly to the brick manufacturing facility and stockpiled. Additional facilities at the brick plant may be necessary for storage and handling of residuals prior to incorporation into the brick making process. Additional facilities and/or equipment could include a covered concrete storage pad, conveyers, feed hoppers and front-end loaders. The optimal locations for introduction of residuals into the brick making process is during the "preparation" stage of the process (Maury 1998, Parrish 1998). Residuals added to the plant mullers and crushing equipment along with the natural clay and shale rock for materials blending. After addition of residuals into the other raw materials, the remainder of the brick making process remains unchanged.

Residuals Quality Requirements

Physical Requirements. The physical parameters of residuals that should be evaluated for use in brick production are listed in Table 3.6. The physical properties of residuals used for brick production directly effect brick quality and the manufacturing processes used. Significant changes in properties of raw materials could potentially require modifications to the normal manufacturing processes. The fired brick properties that are of most concern to brick manufacturers are as follows (Parrish 1998, Maury 1998):

- Durability
- Color
- Texture
- Size variation
- Compression strength
- Absorption
- Weight

These properties are directly impacted by the quality of the raw materials used for production. Most brick plants routinely conduct tests to characterize the physical quality of their raw materials. These same tests should also be conducted on residuals in order to evaluate its use for this application. Tests routinely conducted include moisture content, shrinkage, fired properties, grain size analysis, and grain strength. Almost all brick manufacturing companies have full-time mining engineers that routinely conduct tests on raw materials used for brick production.

Table 3.6

Important residuals physical parameters for brick making applications

Parameters	Units
Solids concentration	%
Color	-
Moisture content	%
Grain size analysis (clay/silt/sand)	%
Mass density	lb/ft^3 (kg/m^3)
Specific gravity	-
Shrinkage	%
Specific weight	lb/ft^3 (kg/m^3)

The moisture content of residuals is very important in terms of residuals handling and incorporation into the brick making process. Manufactures prefer a dewatered cake solid residuals of greater than 20 percent solids. Solids concentrations greater than 50 percent are optimal for adding residuals directly into the process. Residuals with a high moisture content could potentially plug the screens that are used to separate out coarse materials after crushing and mulling (Migneault 1988).

Shrinkage is the decrease in size of an air dried or fired brick. Natural clays typically have an air shrinkage of 2 to 8 percent and a fired shrinkage of 2.5 to 10 percent. Some residuals tested have demonstrated a shrinkage rate as high as 20 percent (Migneault 1989). Shrinkage as a result of residuals additions must be controlled, otherwise, process modifications must be made to the die size and cutting equipment. The best way to control shrinkage would be to limit how much residuals is blended with natural raw materials.

The fired properties of raw materials that are most important to brick manufacturers are durability, compressive strength, and color. Durability and compressive strength are indicators of the structural integrity of the finished brick. Brick manufacturers routinely perform ASTM required tests to determine if the fired bricks meet regulatory requirements. Color and brick appearance are also critical finished brick qualities. Color is a physical property of brick, however, it is affected by various chemical properties of the raw materials used (BIA 1997).

Grain size analysis hydrometer method (ASTM D421-58 and D422-63) is used to approximate the grain size distribution of residuals or clay. The grain size analysis provides an estimate of the concentration of clay, silt, and sand sized particles. Residuals with high percentages of clay sizes are optimal for brick making. High sand size content, on the other hand, negatively impacts finished brick quality.

Chemical Requirements. The chemical parameters of residuals that should be evaluated in order to market residuals as an ingredient in brick making are listed in Table 3.7. Residuals chemical parameters that should be characterized include TCLP metals, TCLP volatiles, and total organic carbon. TCLP analyses are used to demonstrate that a material is non-hazardous and is safe for use. The most important metals recommended for analysis include aluminum, iron, manganese, and silica. The organic content should be analyzed and discussed with the perspective brick manufacturer. Some manufacturers report that organics in water treatment allow for a reduction of the kiln firing temperature required and as a result decrease fuel costs. Other manufacturers report that high organic concentrations negatively impact the structural quality of bricks (Owen 1998). Ultimately experimental testing should be performed on each individual residuals to determine its value for brick making. Filter media carbons such as anthracite and powdered activated carbon (PAC) are considered detrimental to the brick making process. The firing properties of granular carbon are known to cause expansion and cracking in finished bricks. Due to this factor, water treatment plant residuals with significant concentrations of anthracite or PAC would not be suitable to brick manufacturers (Maury 1998).

Table 3.7

Important residuals chemical parameters for brick making applications

Parameters	Units
Calcium	lb/ton (mg/kg)
Total metals*	lb/ton (mg/kg)
Metal oxides†	lb/ton (mg/kg)
Gross alpha	pCi/g
Gross beta	pCi/g
Radium - 226	pCi/g
Total organic carbon (TOC)	lb/ton (mg/kg)
TCLP volatiles/semi-volatiles‡	mg/L
pH	-

*Total metals analyses includes : Al, As, Ba, Cd, Cr, Cu, Fe, Pb, Mg, Mn, Hg, Ni, Se, Ag, Zn, Mo.

†Include major oxides of the following elements: Al, Si, Fe, Ca, Mg, S, Na, K, and Mn.

‡TCLP analyses as specified by 40 CFR, Part 261 [Federal Register 1990].

Chemical parameters of residuals that effect colors of bricks include iron hydroxides and barium. Both of these parameters cause bricks to develop a unique red color during firing, which is very desirable to brick manufactures (Rolan 1976, Migneault 1989, Owen 1998).

Brick Manufacturing Case Studies

Santa Clara Valley Water District. The Santa Clara Valley Water District (SCVWD) operates two water treatment plants—Penitencia, a 40-mgd (151,000-m^3/day) conventional filtration plant and Rincondada, an 80-mgd (303,000 m^3/day) upflow clarification and filtration plant. Both facilities use aluminum sulfate (alum) as the primary coagulant.

Alum residuals from the clarification basins as well as filter backwash solids are thickened in large decanting ponds. The ponds are used to thicken the residuals to approximately 3 percent solids. The combined volume of residuals (at 3 percent solids) from the two plants is 20 MG/yr (75,700 m^3/yr). Analysis of the residuals revealed that the material consists of 11 percent iron oxide, 2 percent quartz, along with barium and calcium compounds.

In 1986 SCVWD began searching for an alternative to landfilling residuals. The District installed a belt filter press to mechanically dewater residuals to a solids concentration of 20 percent, thereby reducing the total volume of residuals for disposal.

The SCVWD conducted experimentation using alum residuals for brick or tile manufacturing. Tests were conducted using residuals to characterize its firing properties. The residuals/clay mix demonstrated a very high shrinkage (20 percent for residuals/clay mix versus 8 percent for clay only) and higher than normal absorption (20 percent versus 3 percent, respectively). These data suggested that the alum residuals could potentially be used for manufacturing floor tile, roof tile, clay pipe, and brick. The SCVWD contacted a number of local manufacturers and eventually located a brick company that was willing to conduct demonstration testing.

Demonstration production tests conducted by the brick company showed that the raw material composition could potentially include up to 10 percent alum residuals at a 25 percent solids concentration. The alum residuals also caused a very nice red brick color due to the presence of barium in the residuals. During full-scale production tests the brick company discovered that there were significant operational problems due to the high moisture content of the residuals and determined that a drier residuals was necessary. To resolve this problem the SCVWD began using solar drying to increase the solids concentration up to 60 to 80 percent.

In 1987, out of 583 truck loads of residuals 383 truck loads were landfilled while 200 truck loads were used for brick production. While the process worked, there were a number of problems encountered by the brick company, including:

- Only a small percentage (less than 10 percent) of residuals could be used per brick
- The residuals increased shrinkage and made dimensional control difficult.
- Use of residuals required manufacturing process changes
- The process was more labor intensive and involved more operator attention

Unfortunately, the brick company went out of business and, therefore, SCVWD's work with brick production was discontinued. The SCVWD continued their marketing efforts to locate other types of beneficial uses. Residuals were used for a period of time as a surface material for a local auto racetrack and co-used with manure to produce fertilizer. The residuals provided a very slippery surface for the racetrack which was desirable for this type of racing. The problem with this application was that the residuals had to be re-applied prior to each race because over time the properties changed (due to air drying). Use as a mineral amendment for fertilizer production was also effective, however, landfilling the material was determined to be the chosen disposal alternative.

The SCVWD currently uses its residuals as a landfill cover material. This method of disposal was considered to be the easiest means of disposal. After delivery to the landfill, the SCVWD is no longer responsible for the material. The SCVWD has a disposal contract with the landfill, and the landfill authority is responsible for obtaining the required disposal permits.

Cary/Apex, North Carolina. The Cities of Cary and Apex, North Carolina jointly own and manage a 16-mgd (60,560 m^3/day) water treatment plant that treats raw water from Jordan Lake. The lake provides a stable source of raw water with a typical turbidity range of 5 to 15 ntu. The treatment plant uses a conventional treatment process and feeds alum as the primary coagulant along with potassium permanganate, seasonal applications of powdered activated carbon, and coagulant and filter aid polymers.

The plant generates approximately 1.5 dry tons/day (1.36 metric tons/day) of alum residuals. Currently the utility has a contractor that is in charge of residuals handling, dewatering, and disposal. The contractor uses a mobile belt filter press to dewater residuals to 17 percent solids prior to disposal. The utility is in the process of constructing a permanent residual dewatering facility and in the future will dewater residuals without the assistance of a contractor.

Historically, the utility's alum residuals have been disposed of in sanitary landfills. The State of North Carolina classified the residuals as a nonhazardous substance and had previously provided the utility with a permit for performing joint land application of water and wastewater residuals using a 50:50 blend ratio. To date, joint land application of residuals has not been attempted, however, this may provide a valuable beneficial use option for the future.

In an effort to reduce or eliminate landfilling as the method of residuals disposal, the contractor worked out an agreement with a local brick manufacturer that was willing to accept all of the utilities alum residuals. The contractor transported dewatered residuals to the clay quarry used by the brick company. At the quarry the residuals were stockpiled prior to blending with the natural clay and shale used for brick production by the brick company. At this time, the brick company also accepted other industrial byproducts that were also blended into the brick materials.

The utility and contractor both signed an agreement with the brick company that certified that the residuals delivered were actually alum residuals and posed no hazardous potential. After accepting the residuals, the brick company was responsible for obtaining storage and regulatory permits as required for residuals use. The alum residuals were blended into the natural materials at the quarry prior to delivery of the materials to the brick plant using front-end loaders. The brick company preferred quarry applications because it simplified materials handling and incorporation into their existing manufacturing process. After blending, the alum residuals basically disappeared into the enormous volume of raw materials used. Production tests showed that the addition of other residuals had no effect on brick visual or structural quality.

The volume of the alum residuals generated by the utility is an extremely small amount compared to the total volume of raw materials used by the brick plant. The brick company operates four plants that produce approximately 500 million bricks per year which requires over 1 million dry tons (907,800 metric tons) of raw materials per year. The Cary/Apex plant only generates 550 dry tons/yr (500 metric tons/yr) which amounts to only 0.2 percent of the materials used at one of the four plants. Although the amount of extra raw material added was insignificant, both parties involved agreed that this was an environmentally friendly beneficial reuse of the residuals and could help preserve valuable landfill space.

The brick company charged $25/ton ($27.54/metric ton) for residuals delivered to the quarry. The revenues generated by disposal fees and the added volume of raw material provided minimal benefit to the brick company. There was also some concern that the use of industrial byproducts could cause degradation to brick quality. Because of these factors, the brick company stopped accepting industrial waste materials. The contractor was then forced to resume delivery of the alum residuals to a sanitary landfill for disposal.

Hyder Utility-Wales, United Kingdom. The Welsh Utility (part of Hyder Plc) provides water service to approximately three million people and 100,000 businesses in Wales and surrounding areas in England. The utility operates 115 water treatment facilities that produce approximately 218 mgd (825,000 m^3/day). A 50 mgd (189,000 m^3/day) facility is located approximately 17 miles (27 km) from a brick manufacturing plant. Hyder produces alum and ferric residuals. The largest Hyder treatment facility produces 22 percent of the utility's water and uses alum as the primary coagulant. Both alum and ferric residuals can be provided as a liquid (5 percent solids) or can be dewatered or air dried to 15 to 20 percent solids. The residuals are composed of 30 to 40 percent organic matter, primarily due to the raw water and polymers used for settling. The concentration of aluminum hydroxide and/or ferric hydroxide ranges from 10 to 30 percent.

In 1994, new waste management regulations forced Hyder to begin looking at alternative methods for residuals disposal and/or reuse. The utility contacted a local independent brick manufacturing company, to discuss the possibility of using residuals from nearby facilities as a substitute for clay. The brick manufacturer agreed to perform experimental testing using the residuals to determine if brick making was a viable alternative.

Experimentation by Castle Brick using both the alum and ferric residuals for brick production lasted approximately 18 months. The dry clay used for brick production was initially mixed with up to 10 percent liquid residuals (5 percent solids). This was followed by further tests with a 10 to 15 percent mix ratio of residuals at 15 to 20 percent solids. During brick production, it was noted that the high organic concentration in the residuals reduced the firing temperature in the brick kiln and reduced the overall amount of energy required during the firing process. It also appeared that the metal hydroxide content of the residuals helped to generate a low porosity brick (a desirable quality for bricks). The finished bricks were determined to be structurally acceptable. Ferric residuals were demonstrated to add a deep red color that was desirable to the manufacturer. Based on these findings, the use of water residuals for brick production was determined to be a viable alternative. Castle Brick also demonstrated that the residuals could also be used for production of tile and paving slabs.

UK Waste Management Licensing Regulations ensure that "controlled" wastes are disposed of at licensed sites. Taxes are levied to encourage utilities to minimize waste and recycle residuals. Currently the cost of water treatment residuals disposal is $19.30/ton ($21.26/metric ton) and in the near future will increase to $24.80/ton ($27.30/metric ton). Utilities that use the residuals for beneficial applications are exempt from these taxes. Brick making is considered as a beneficial use and, therefore, the residuals are untaxed. Permit requirements, however, do exist for storage and disposal. The permit requires that residuals must be stored without causing pollution to the environment.

Hyder is currently saving approximately $80,000/year in disposal costs (based on 2,313 tons [2,100 metric tons] of solid residuals plus 980 yd^3 [750 m^3] of liquid residuals) and is projected to save approximately $90,000/year after the UK landfill Taxes are increased to $24.80/ton ($27.30/metric ton). The utility currently provides 3,300 tons/year (3,000 metric tons/yr) of residuals to Castle Brick at no charge. This volume amounts to 15 percent of Castle Brick's total yearly clay usage. Castle Brick also saves approximately $1500/month on fuel costs due to the high organic concentration of the Hyder residuals. This effectively saves the manufacturer a total of $23,000/year.

City of Durham. The City of Durham, North Carolina operates two conventional water treatment plants that use alum as the primary coagulant. The City of Durham, in 1976, experimented with using alum residuals as an ingredient for producing building bricks. The State of North Carolina was at the time and still is the largest producer of bricks in the U.S. In 1976, approximately 1.3 million tons (1.18 million metric tons) of dry clay was used per year for brick production by approximately 22 brick manufacturing plants.

The City of Durham contacted a local brick manufacturing company, and the company agreed to evaluate the use of alum residuals to determine its feasibility as a clay substitute for brick production. The brick company was supplied liquid alum residuals at 8 percent solids from the Durham treatment plants. The first tests focused on using liquid residuals to replace the water required for brick production. These bricks only contained 0.05 percent alum residuals and were not distinguishable from bricks made with only clay. Further tests were conducted using a blend of up to 15 percent residuals with clay. No structural problems were found with the residuals amended bricks and it was noted that an increased residuals concentration caused the bricks to have a desirable red color. The addition of water residuals as a water replacement method require significant operator attention during production and was eliminated as a viable option. Use of dry residuals blended with natural clay showed good potential and was further investigated.

The City of Durham experimented with hauling and disposing of the alum residuals directly into the clay quarry. At the quarry the residuals were ripped into the natural clay. The City was in favor of this idea because a greater volume of residuals could be disposed of more frequently. The brick company was also in favor of this because this plan would minimize any necessary operational changes. Using the quarry disposal method, brick properties were found to be unaffected by residuals addition. The residuals basically disappeared into the huge volume of natural raw clay and shale materials.

The use of alum residuals for brick making was determined to be a feasible alternative, and the brick company was willing to accept all of the alum residuals that could be supplied by the City of Durham, but only if the City hauled the residuals to the site and paid a tipping fee. The tipping fee requested by the brick company was only slightly less than the amount the City paid for landfill disposal. The cost savings associated with brick production were determined to be economically unattractive and, therefore, the utility discontinued its marketing effort in 1976 for residuals use in brick production.

Turf Farming

General Description and Potential Benefits

The turf farming industry since the early 1980's has doubled the total number of acres used for turf grass production. The 1992 U.S. Agriculture census listed a total of 218,160 production acres (88,290 hectares) in the U.S. versus 124,600 acres (50,425 hectares) in 1982. The majority of turf grass produced is used for residential landscaping. Other turf grass uses include commercial building landscaping, golf courses, sports fields, parks and cemeteries, and roadside landscaping.

The typical turf grass production farm during 1997 averaged 350 acres (141 hectares) with a total production acreage of 67 percent of the farm (235 acres [95 hectares]). Farming operations require six or more peak season full-time employees. The majority of turf farms are privately owned and operated. Approximately 90 percent of turf farm acreage in the U.S. is owned, while the remaining 10 percent is leased land (TPI 1997).

Turf grass sod production, similar to other agricultural crops, requires a significant investment by the farmer that must be recovered through production and sales in order to maintain a profitable operation. Turf farmers compete with nature, other methods of turf establishment, turf producers, and other forms of ground cover. Intensive management is required to produce quality turf grass. A list of machinery that is typically found at a turf farm is listed below.

- Forklifts
- Mowers

- Tractors and trucks
- Land grading/leveling equipment
- Seeders
- Sod harvesters
- Rototillers
- Aeration equipment
- Fertilizer spreaders
- Irrigation equipment

Major farm operational expenses include salaries, land cost, equipment capital and O&M cost, trucking, fertilizer, pesticides, and seed. Most turf farms today have at least one full-time marketing employee for the turf sales. Most of the turf produced is sold wholesale. Producers transport 80 percent of their product while the remaining 20 percent is picked up by customers (TPI 1997).

During sod harvesting a small percentage of soil is removed from the farm. Over years of operation and sod harvesting soil loss could become significant. To supplement the soil loss, residuals has been identified as a possible material that could be used as a soil replacement. A number of research projects have been conducted in order to determine what effects water residuals have on turf growth and soil quality (Knocke *et al.* 1991, Vandermeyden *et al.* 1996, Wooley 1996). Most studies to date have demonstrated that the use of residuals results in neutral or positive impacts on turf growth without negatively impacting the quality of natural soils. Residuals have also been shown to improve soil aeration, provide some nutrient and trace mineral value, and increase soil moisture retention capacity.

Market Size and Geographical Locations

Turf grass Producers International (TPI) is an international organization that is dedicated to advancement of the turf grass sod industry. The majority of the turf grass producers in the U.S. are members of TPI. TPI provides statistical analysis of the turf grass industry production and sales based on member surveys and U.S. Department of Commerce agriculture census information. The

"Ag census" data is collected every five years. At the time of this report, only data from the 1992 census was available, therefore, market size information included in this report is based on the 1992 information provided by TPI.

Between 1987 and 1992, approximately 187 farms totaling 34,000 acres (13,760 hectares) began turf production in the U.S. The total farm acreage increased almost 19 percent during these five years. Production increases since 1992 are estimated (based on the historical trend) to be almost 25 percent, amounting to almost 55,000 new acres (22,260 hectares) of turf production (TPI 1997).

Turf farms are located in every state except Alaska. The geographical distribution of turf farm acreage, compiled by the TPI, is shown in Figure 3.7. This figure shows that the two major producers of turf grass are Florida and Texas which account for almost 34 percent of total U.S. production. The southeastern region of the U.S. has the optimal climate and soil characteristics for growing turf. These states produce 44 percent of the total U.S. production. The Midwestern and Southwestern regions combined account for 38 percent. The Northeastern region of the U.S. accounts for the smallest production acreage (TPI 1997).

The three states with the highest annual turf sales in 1992 were California, Florida, and Texas. Although California only produced 3.7 percent of the total U.S. production, sales of turf grass amounted to almost 79.4 million dollars. Florida and Texas sales in 1992 were 64.2 and 37.8 million dollars, respectively (TIP 1997).

Manufacturing Logistics

Production of turf grass sod is a complicated and highly labor intensive process. Sod is defined as the combination of turf grass, soil, and microorganisms. Sod is a perishable commodity that is very sensitive to environmental changes. Production of sod usually takes 6 to 24 months depending on the following factors:

- Soil quality
- Moisture
- Temperature

- Grass species produced
- Fertilizer, pesticides, herbicides used

The basic production techniques that are typically used for growing turf grass sod are similar for most farms. The management practices, however, are highly specific and at times unpredictable. The five basic farming tasks necessary for sod production are as follows: 1) land preparation, 2) seed placement and establishment, 3) turf management, 4) harvesting, and 5) transportation (TPI 1997).

Land preparation for turf grass sod production is critical for growing and good quality sod. To produce good quality sod, the land must be leveled, graded, and free of rocks. A highly manicured seed bed is necessary to produce a uniform sod. The soil moisture content must also be acceptable for cultivation or soil clumping could occur and prevent seeding.

Seed establishment depends on a number of factors. Soil and air temperature are the two most important environmental factors. Grass seed germinates at about 50°F (10°C), and root development requires an even warmer soil and air temperature. Soil moisture is also critical such that seedlings are not water starved or drowned.

Proper turf grass management is important for maintaining healthy grass as well as for controlling how fast the grass matures. Management practices include irrigation, fertilization, mowing, weed control, and disease control. Application of herbicides and pesticides are only added when severely needed to combat insects and disease.

Harvesting of the turf is the most critical farming task. The decision process for determining when to harvest turf is highly unpredictable. Cool temperatures are required to ensure that the cut sod will survive transportation and replanting. Harvesting is performed using a mechanical harvester that cuts the sod. Sod is then inspected for quality, rolled, and loaded onto pallets for transportation. Sod that is grown for too long loses market value.

Transportation of sod must occur in a matter of hours or the grass could die or be permanently damaged. Any delays in transportation could effect quality, therefore, this process is usually highly coordinated with customers.

Residuals Application Process

Residuals can be applied to turf fields in a liquid or solid form. Extent of dewatering prior to application is dependent on transportation, dewatering costs, economics, and preference by the turf farmer. A process schematic for application of residuals to turf farms is included as Figure 3.8.

Liquid residuals can be land applied during field preparation or during the turf growth stage. Liquid residuals applied to soil during field preparation should be thickened at up to at least 3 percent solids and sprayed evenly over the application area to prevent excessive wetting of the soil. Caution must be used such that the residuals do not increase the soil moisture concentration to levels unacceptable for cultivation and seeding. Liquid residuals could also be applied to the fields while the turf grass is growing. Residuals applied directly onto turf grass must have a very low solids concentration to prevent residuals from blocking photosynthesis by coating the grass blades (Wooley 1996). Liquid applications to turf grass could provide an even distribution of residuals with minimal clumping, as well as a water value for irrigation.

Cake solids residuals application are only possible during field preparation and should not be applied directly to the turf grass. Residuals should be dewatered to a cake solids concentrations of at least 20 percent. Residuals are typically surface applied using manure spreading equipment and then cultivated into the natural soil. Dewatered residuals application methods decrease hauling costs to the farm but could result in uneven distribution and soil clumping.

Liquid or solid residuals application rates to soils similar to other land application practices are usually based on cumulative nutrient and/or heavy metals loading rates. Demonstration studies could be performed to determine the optimal loading rates for good turf growth while minimizing metals accumulation in the soils. Absorption of plant available nutrients and heavy metals loading rates should be assessed prior to full-scale applications.

Residuals Quality Requirements

Physical Requirements. The physical parameters of residuals that are important for turf farm applications are listed in Table 3.8. The residuals solids concentration is critical for handling, storage, and incorporation into the soil. Either liquid or solid residuals can be used for turf farm applications. Grain size analysis is important for characterization of the clay, silt, and sand content of residuals. Texture of residuals is very important for turf field application. Fine textured residuals that do not cause soil clumping are more desirable. Moisture retention and soil aggregation should be evaluated for soil/residuals blends to determine the physical impacts on the natural soil.

Table 3.8

Important residuals physical parameters for turf farming

Parameters	Units
Solids concentration	%
Texture	-
Soil aggregation	-
Moisture content	%
Grain size analysis (clay/silt/sand)	%
Mass density	lb/ft^3 (kg/m^3)
Specific gravity	-
Specific weight	lb/ft^3 (kg/m^3)
Shear strength	lb/ft^2 (kg/m^2)

Chemical Requirements. A list of the recommended residuals chemical parameters that should be evaluated prior to turf farm application are provided in Table 3.9. The chemical parameters important for turf farm applications are very similar to other beneficial use alternatives that involve applying residuals to agricultural land. Analyses for TCLP metals and volatiles are required to determine the hazard potential from leaching. Total metals concentrations, particularly for aluminum, lead, and copper, will most likely dictate soil loading rates and total volume of residuals that can safely be added to a field. Nutrient analysis for nitrogen, phosphorus, potassium, and calcium will provide information on the potential benefits to soil fertility. Other chemical characteristics that may need characterization include total organic carbon, toxicity, pH, total coliforms, and radionuclides. Results from residuals analyses for each of these parameters will provide a farmer and regulatory agency with the required information for determining if the material is acceptable for use in turf farming.

Table 3.9

Important residuals chemical parameters for turf farming

Parameters	Units
Total Kjeldahl Nitrogen	lb/ton (mg/kg)
Total phosphorus	lb/ton (mg/kg)
Potassium	lb/ton (mg/kg)
Ammonia - Nitrogen	lb/ton (mg/kg)
Nitrate/Nitrite - N	lb/ton (mg/kg)
Calcium	lb/ton (mg/kg)
Calcium Carbonate Equiv. (CCE)	%
Total metals*	lb/ton (mg/kg)
TCLP metals†	mg/L
Gross alpha	pCi/g
Gross beta	pCi/g
Radium - 226	pCi/g
Total organic carbon (TOC)	lb/ton (mg/kg)
Loss Of Ignition (LOI)	%
Phytotoxicity - Microtox test	
Total coliform	no/gram
pH	-

*Total metals analyses includes : Al, As, Ba, Cd, Cr, Cu, Fe, Pb, Mg, Mn, Hg, Ni, Se, Ag, Zn, Mo.

†TCLP analyses as specified by 40 CFR, Part 261 [Federal Register 1990].

Turf Farming Case Studies

Erie County Water Authority. The Erie County Water Authority (ECWA) near Buffalo, N.Y. operates two water treatment plants that treat municipal drinking water using conventional methods. The Sturgeon Point Water Treatment Plant (90 mgd [341,000 m^3/day]) treats water from Lake Erie while the Van de Water Water Treatment Plant (50 mgd [189,000 m^3/day]) treats water from the Niagara River. Raw water quality is generally very good, with turbidity typically less than 10 ntu. Both plants use polyaluminum chloride (PACl) as the primary coagulant. Powdered activated carbon (PAC) is fed seasonally for removal of taste and odor.

Combined PACl residuals generated by both plants average 5,500 to 9,100 lb/day (2,500 to 4,100 kg/day) of dry solids. Residuals chemical characteristics are very similar to the native soil, however, the residuals contain higher concentrations of aluminum, manganese, total kjeldahl nitrogen (TKN), and copper.

Residuals handling at the Sturgeon Point Water Treatment Plant consists of a 1.7 acre (0.7 hectares) storage lagoon. The lagoons are cleaned out every five years and freeze-thawed dewatered followed by air drying. The final residuals cake is approximately 60 percent solids. The Van de Water Water Treatment Plant uses a residuals holding tank, a residuals thickener, a retention tank with lime addition, and a plate and frame filter press for residuals dewatering. The final residuals cake concentration is approximately 35 percent solids.

The ECWA conducted a residuals management study to determine the feasibility of residuals disposal by landfilling or by using a beneficial use alternative. A long list of potential beneficial use alternatives were reviewed by the Authority. The following three alternatives were considered to be the most favorable:

- Turf farm application
- Top soil blending
- Light weight concrete blending

The ECWA's criteria for selecting a beneficial use program focused on locating a user(s) that would buy or accept residuals at no cost, develop a number of different beneficial use options, and establish long term contracts that would ensure project success. Beneficial use disposal was determined to be the most economical alternative when compared with disposal to sanitary landfills or monofills. ECWA concluded that turf farming and top soil blending were the most promising options for residuals reuse.

The Authority located a turf farm within close proximity to the Buffalo area that was interested in testing residuals for use as a soil substitute. The turf farm owner agreed to let ECWA perform a demonstration study at the turf farm. The one-year demonstration project involved adding residuals to nine plots each for both Sturgeon Point and Van de Water residuals along with two control (no residual addition) plots. Application rates used were 1.5, 3, and 6 percent, which amounts to 13.7, 27.4, and 54.8 dry tons/acre (30.63, 61.3, and 122.8 metric tons/hectare), respectively. Monitoring during the demonstration study included:

- Residuals analysis
- Soil analysis (prior to water treatment residuals application)
- Soil analysis (one year after water treatment residuals application)
- Soil-water analysis (before and after water treatment residuals application)
- Grass clipping analysis and weight to determine yield

Statistical analysis of the soil and soil-water data revealed that the test plots demonstrated no significant differences compared with the control plots. The readily available phosphorus concentration was not shown to have decreased by the addition of residuals. Visual observations also revealed no significant differences in turf appearance using a residuals loading rate up to 3 percent. The 6 percent loading rate (which would be an unusually high application rate) did cause a noticeable strain on turf growth, however, it was inconclusive whether or not this was a result of residuals addition to the test plot.

Overall, 10 to 20 percent yield increase was achieved using residuals application rates of 1.5 and 3 percent. Data collected from the demonstration study suggested that turf farming was a viable option. Based on the successful findings from the demonstration study, ECWA received a Beneficial Use Development Permit from the New York State Department of Environmental Conservation (NYSDEC). This permit allowed the Authority to begin marketing residuals to turf farmers and top soil producers.

An extensive search was undertaken by ECWA to find markets that would likely be accepted by the NYSDEC. The user search focused on a 30-mile (48.3 km) radius around both plants. Marketing efforts included:

- Discussion with neighboring towns and villages
- Calling businesses in yellow pages
- Discussion with the NYSDEC staff in Buffalo and Albany

A list of potential residuals users were interviewed by the Authority to further explain the residuals chemical and physical characteristics and to discuss the impending plan for developing a beneficial use program. Potential users were screened based on the rationale listed below:

- Cost to the Authority
- Future income to the Authority
- Regulatory compliance
- Regulatory acceptance
- Willingness of user to enter into a long-term contract

Converting from landfill disposal to beneficial use was projected to save the Authority approximately $344,000/yr. It took approximately four years to develop the beneficial use program and included a residuals management study, a turf farming demonstration study, regulatory permitting process, and marketing to locate end users.

Grand Strand Water and Sewer Authority. The Grand Strand Water and Sewer Authority (GSWSA) located in Conway, South Carolina operates a 21-mgd (79,500 m^3/day) surface water treatment plant. The plant uses an Infilco Degremont Superpulsator Clarifier for chemical mixing and solids clarification. Alum is the primary coagulant used in the treatment process. A 60-ft (18.3-m) diameter clarifier is used to thicken residuals removed by the clarifier. Filter backwash water solids are stored and thickened in an on-site equalization lagoon.

GSWSA owns and operates a 400-acre (161-hectares) turf farm located immediately next to the water treatment plant. The Authority is well established in the turf farming industry. Wastewater treatment plant biosolids have successfully been land applied to the turf farm for a number of years. Historically, revenue produced by turf sales have been sufficient enough to offset the costs for the wastewater residuals transportation and application. Based on past success and the fact that the Authority already owns the equipment necessary for land applying residuals, it was determined that turf farm application of alum residuals was the Authority's best available reuse option.

Before GSWSA began applying alum residuals to their turf fields, a greenhouse study was conducted by the Clemson University School of Agriculture. Turf growth was studied using alum residuals loading rates of 1 in./wk (2.5 cm/wk) at a concentration of 1 percent solids. The study concluded that alum residuals had no detrimental impacts on turf growth. No indications of soil phosphate binding or aluminum phytotoxicity were noted. The study did reveal that Total Kjeldahl Nitrogen (TKN) concentration increased as a result of alum residuals applications.

Based on the greenhouse study findings, a 40-acre (16-hectare) section of the turf farm was designated for use in a full-scale demonstration study. The alum residuals were pumped directly from the thickening basin through a 4-in. (10-cm) diameter irrigation hose and sprayed evenly on the 40-acre (16-hectare) plot.

The residuals were only thickened to approximately 1 percent solids prior to land application which caused the soils to be wet. High soil moisture was a problem because application of the residuals involved pulling an irrigation hose through the turf fields using a tractor. The tractor tended to cause ruts in the fields due to the soft wet soil. To eliminate damage to the field, the Authority installed an irrigation system which included an underground plastic pipe distribution system. The irrigation system eliminated the use of the tractor and, therefore, resolved the problem.

The demonstration study revealed that turf growth and quality in the areas where alum residuals were applied was not significantly different than turf grown in the natural soil. Soil sample analyses indicated that the soil aluminum concentration, as well as other metals, increased with each residuals application. To slow down the accumulation of metals in the soil, an additional 40-acre (16-hectare) application site was added to the study. The increased acreage significantly reduced the aluminum loading rate, and all other metals concentrations were comparable to the natural soil. Soil pH was maintained above pH 5.0 (to minimize aluminum solubility) using occasional applications of agricultural lime. Soil nutrients concentrations in the residuals amended soils slightly increased as a result of residuals addition. Groundwater monitoring revealed that no negative impacts to water quality were caused as a result of residuals application.

Composting

General Description and Potential Benefits

Composting is a natural biological process that accelerates the decomposition of organic solid waste into a soil like material. Composting operations used for recycling solid waste, yard waste, bark fines, and sawdust are becoming an increasingly popular alternative to landfilling. Some communities recycle as much as 60 percent of their solid waste by composting.

Composting operations have successfully used wastewater biosolids for years as an additive to compost piles. During organic decomposition heat is generated which destroys pathogens and effectively sanitizes biosolids into a material safe for reuse. The use of biosolids in composting generates a valuable recycled fertilizer material.

Recently work has been conducted using residuals as an ingredient in compost piles along with yard waste, solid waste, bark, and biosolids. Addition of residuals has been shown to benefit the composting process by providing moisture, trace minerals, pH adjustment, and by serving as a bulking agent. Co-composting using blends of residuals and biosolids has been demonstrated to benefit the composting process and final product by diluting heavy metals concentrations which are regulated by many states for land application reuse.

Finished compost material can provide a valuable and environmentally safe soil amendment for agricultural or commercial soil applications. Many municipal composting facilities supply finished compost materials to end users at little or no cost, while commercial composting operations use their finished compost to produce top soil and potting soil blends which are bagged and sold commercially.

Market Size and Geographical Locations

Composting operations are located in every state. Hundreds of composting facilities are currently in operation for recycling of solid waste, yard wastes, biosolids, and residuals. Some of these facilities are owned by public utilities mainly for biosolids composting. Many solid waste landfills have composting facilities which handle yard wastes and organic wastes that are screened out of municipal solid waste.

The U.S. EPA has recognized composting as a vital component to addressing the U.S. solid waste problem. EPA's goal is for 50 percent of all solid waste generated to be recycled. To meet the EPA recycling demands, many communities are planning for or are currently constructing new composting facilities. To locate a composting facility in your immediate area it is best to contact a local landfill agency or the U.S. Composting Council. The Composting Council is an organization that was formed to promote composting, develop standards, and provide a voice for the industry.

Manufacturing Logistics

This section summarizes a typical compost pile design and operational parameters for composting materials such as leaves, bark, wood chips, grass, manures, food wastes, or other organic materials. The specific compost pile design and operation should be based on the materials used in the process and should be determined through experimentation. The basic principals of composting listed below would, however, apply to most composting processes.

The composting process used for recycling organic waste materials requires four ingredients to sustain microorganisms necessary for decomposition of waste materials into a soil like material. The key ingredients are air, water, food, and temperature. Proper amounts of each of these elements will result in a successful composting operation.

Composting materials usually requires grinding and blending of raw materials prior to windrow construction. Proper ratios of waste materials need to be mixed to obtain an optimal carbon to nitrogen ratio and a proper moisture distribution. A good ratio of C:N was determined to be approximately 30:1. Typical compost materials that contain high nitrogen levels include grass, biosolids, food wastes, cow manure, and horse manure. High carbon materials include leaves, bark, paper, and wood chips (Cornell Composting 1998).

After blending raw materials, windrows are constructed for storage and aeration of the compost materials. A typical windrow has a trapezoidal shape with a 12- to 20-ft (3.6- to 6.0-m) base and a 6- to 10-ft (1.8- to 3.0-m) height. The exact windrow size is based on the pile ingredients. The smaller pile sizes are better for increased air circulation, larger piles are used to obtain higher temperatures (Bowser 1998).

Compost microorganisms (bacteria, fungi, others) require specific environmental conditions to effectively multiply and decompose organics. Moisture, temperature, and aeration need to be maintained at specific levels for efficient composting. The temperature range that is optimal for composting is 90 to 140°F (32 to 60°C). Pile temperatures below 90°F (32°C) will result in a slow decomposition process while temperatures exceeding 140°F (60°C) will destroy microorganisms. The pile temperature is the best method for monitoring the status of a compost pile. Temperature readings are obtained by placing a temperature probe into the center of the compost pile. For the first 30 days a compost pile should reach temperatures between 100 to 140°F (37 to 60°C). Over time the temperature gradually decreases as the available organic matter is consumed. The entire process takes approximately 120 days (Cornell Composting 1998).

Pile moisture is required by microorganisms for organics decomposition. A moisture concentration of 40 to 60 percent is optimal. When moisture is too low decomposition rates are slowed, and if the moisture content is too high the pile could become anaerobic. Rainfall events and pile watering provide additional moisture to the piles (U.S. Composting Council 1998).

Pile aeration is required to supply oxygen to microorganisms. Oxygen content should be greater than 10 percent for optimal organic decomposition. Turning the compost piles allows for the material to remain oxygenated. Front-end loading or windrow machines are used to turn piles. If oxygen is not circulated, anaerobic bacteria could grow and cause odor problems. Oxygen is supplied by natural circulation or pumped aeration. Air blowers are frequently used when biosolids or other materials that generate significant amounts of odor are composted. Using air blowers eliminates the need to turn the piles, thereby, reducing odor that could potentially be released during pile turnover.

Residuals Application Process

Water treatment residuals have been used successfully as a bulking agent for composting. Fine compost materials such as grasses or ground leaves require a bulking agent to increase pore space for aeration and moisture distribution. For compost operations that receive very dry materials, residuals can also effectively provide moisture to the pile that is critical for organic decomposition.

The blending ratios of residuals mixed into a compost pile is dependent on the type of materials being composted. Demonstration studies would be necessary to determine the optimal residuals to compost mix. Residuals could be blended into the compost blend prior to or during windrow formation. Pugmills, blending augers, windrow machines, and front-end loaders are frequently used for blending the various compost materials. A process schematic which outlines the residuals application process for composting is presented in Figure 3.9.

Residuals delivered from the water plant should be dewatered to at least 15-percent solids for use in composting. Most compost facilities have existing equipment that is capable of handling a semi-dry or dry material. The amount of dewatering required is dependent on the other compost materials used and should be determined on a case-by-case basis. Extremely wet residuals are not recommended for composting applications due to handling and storage problems.

Residuals may require stockpiling at the WTP or compost facility prior to blending and windrow formation. Composting can be performed year round, however, short term storage will be required for periods of inclement weather or for periods when other compost ingredients are not available (i.e., grass, leaves). If residuals are to be stored at the composting site, additional storage facilities may be required. A concrete storage pad with stormwater drainage collection should be used to contain residuals and residuals leachate.

Residuals Quality Requirements

Physical Requirements. The physical parameters of residuals that are recommended for analysis are listed in Table 3.10. The physical characteristics of residuals that are important for composting are the solids concentration, texture, soil aggregation, grain size analysis, and moisture retention capacity. Mechanical or nonmechanical dewatering of residuals would typically be required when using residuals as a compost ingredient.

Table 3.10

Important residuals physical parameters for composting applications

Parameters	Units
Solids concentration	%
Texture	-
Soil aggregation	-
Grain size analysis	-
Moisture content	%
Mass density	lb/ft^3 (kg/m^3)
Specific gravity	-
Specific weight	lb/ft^3 (kg/m^3)
Moisture retention	cm water/cm soil depth

Chemical Requirements. The chemical parameters of residuals that are recommended for analysis are listed in Table 3.11. Residuals used in composting should be tested for TCLP metals and volatiles to determine hazard potential. A total metals analysis should also be conducted on the residuals and residuals/compost blend. Total metals concentrations are typically required for obtaining a regulatory permit to apply or distribute the finished compost product. Residuals typically contains low concentration of carbon, nitrogen, and phosphorus, however, the other compost products effectively provide nutrients that increase the fertilizer value of the finished product. Typical compost materials such as food wastes, manure, and grasses all contain significant amounts of nitrogen and phosphorus. For compost materials that have extremely high nutrient concentrations, residuals could potentially bind soluble nutrients thereby reducing the concentrations to non-polluting levels. Residuals could also benefit the compost piles by buffering pH to reduce the impact caused by acid-forming bacteria in compost.

Table 3.11

Important residuals chemical parameters for composting applications

Parameters	Units
Total Kjeldahl Nitrogen	lb/ton (mg/kg)
Total phosphorus	lb/ton (mg/kg)
Potassium	lb/ton (mg/kg)
Ammonia - Nitrogen	lb/ton (mg/kg)
Nitrate/Nitrite - N	lb/ton (mg/kg)
Calcium	lb/ton (mg/kg)
Calcium Carbonate Equiv. (CCE)	%
Total metals*	lb/ton (mg/kg)
TCLP metals†	mg/L
Gross alpha	pCi/g
Gross beta	pCi/g
Radium - 226	pCi/g
Total organic carbon (TOC)	lb/ton (mg/kg)
Loss Of Ignition (LOI)	%
Phytotoxicity - Microtox test	
Total coliform	no/gram
pH	-

*Total metals analyses includes : Al, As, Ba, Cd, Cr, Cu, Fe, Pb, Mg, Mn, Hg, Ni, Se, Ag, Zn, Mo.

†TCLP analyses as specified by 40 CFR, Part 261 [Federal Register 1990].

Metropolitan Water District of Southern California. In February 1993, Metropolitan Water District of Southern California (MWD) initiated a water treatment residuals marketing program. The initial goal of the program was to decrease the cost of residuals disposal from one plant by 50 percent. Traditionally, residuals from the plant were sent to local landfills. The program was initiated based on the high and increasing cost for residuals disposal, increasing environmental regulations and restrictions, long term liability concerns and the fact that landfilling is a non-beneficial use. The program began as a demonstration project for one of MWDs water treatment plants, and due to its success, the program now includes three of MWD's facilities.

MWD has been able to identify and utilize four reliable vendors to recycle residuals. These vendors include a cement company and soil composting firms. Presently, over $700,000 in direct cost savings have been realized from the recycling program. In addition, a $5,000,000 cost to expand a MWD monofill has been canceled due to the success of the residuals marketing program.

Water treatment facilities owned and operated by MWD are designed conventionally for incorporating coagulation, flocculation, sedimentation, and dual- and tri-media filtration. Most design capacities range between 350 to 750 mgd (1.3 to 2.8 million m^3/day). Equipment capacities, nonetheless, must exceed the average generation rate to account for seasonal fluctuations in water flow and water quality standards. The quality of residuals generated at each treatment plant depends on the raw water blend used (State Water Project and Colorado River Aqueduct water), season, and water treatment chemicals used. Due to the high variability in residuals quality, a commercial user may want to perform several demonstration tests before acceptance of MWD's residuals.

Three different composting firms have used MWD's residuals as ingredients for composting. The finished compost product has been used at nurseries, farms, and sold commercially. The residuals nutrient concentrations are very low, however, the material is a valuable bulking agent. The residuals also increases the compost moisture content. Plant life such as weeds, tules, and small willows growing in the lagoon have not presented problems for the composters.

MWD's residuals were attractive to composters due to its high mineral content, good color, lack of rocks, lack of debris, and pH buffering capacity. The residuals chloride concentration was a concern due to the increased use of ferric chloride by MWD facilities. The heavy metal concentrations measured in the finished compost product were found to be acceptable for final disposal of the material. The analyses used to characterize MWDs residuals for use in composting are presented Table 3.12

Table 3.12

MWD's residual quality requirements for composting

Beneficial use	
Solid concentration	60 percent
pH	6.5 to 8.0
Silica content	40 percent
Aluminum content	20 percent
Water content	40 to 60 percent
Nutrient content	Very low
Liquid limit	<50 percent
Specific gravity	2.1
Density	60 to 65 lb/ft^3 (292 to 317 kg/m^2)
Organic content	Low
Chloride concentration	2.5 lb/ton (1,250 mg/kg)
Specific conductivity	1,520 μs/cm

Rivanna Water and Sewer Authority. The Rivanna Water and Sewer Authority (RWSA) provides water and wastewater treatment services to the City of Charlottesville and Albemarle County located in Central Virginia. The Authority operates five surface water treatment plants and four wastewater treatment plants. Daily water production averages 11 mgd (41,360 m^3/day). Aluminum sulfate (alum) historically has been used as the primary coagulant for water treatment, however, the Authority switched to polyaluminum chloride (PACl) to lower residuals production.

Composting of wastewater sludge or "biosolids" is practiced at the Authority's Moores Creek Wastewater Treatment Plant. The facility has a 26,100 ft^2 (2,424 m^2) covered compost area. Mechanical blowers rated at 1,000 ft^3/min (28.3 m^3/min) are used for aerating the compost piles. The wastewater treatment plant finished compost has very good chemical characteristics, and routinely meets the Virginia Department of Health and State Water Control Board regulatory guidelines.

Residuals production at the South Rivanna Water Treatment Plant (RWSA's largest plant) averages 177 dry lb/MG (21,200 kg/Mm^3)of water treated. This facility dewaters the residuals using a belt filter press to 20 percent solids.

The objective of the Authority's beneficial use plan program was to incorporate residuals into the current practice of composting wastewater biosolids. The objectives of joint composting the two municipal wastes were as follows:

- Assess impact of alum sludge on compost pile temperature
- Evaluate impacts on chemical characteristics of compost
- Combine residuals into one common method of disposal

Water treatment residuals were blended with other compost materials at a 25 and 12.5 percent mixing ratio. Mixing of the compost materials was accomplished using a mixing augur. A 70-ft (21.3-m) long by 13-ft (3.9-m) wide by 10-ft (3.0-m) high compost pile was set up with a blend of alum residuals, wastewater biosolids, and wood chips on the ends of the pile and a biosolids and wood chip blend in the center section of the pile. The piles were aerated for a period of two weeks. Pile temperatures were measured daily to determine if adequate temperatures were being obtained for pathogen destruction. A standard practice is that the pile temperature must be at least 131°F (55°C) for three days to effectively achieve pathogen destruction. For the first 14 days the blowers were operated intermittently to aerate the piles. After this period the blowers were operated continuously for a period of time to cool and dry the piles. After composting was completed the finished products were analyzed for chemical composition.

Results from joint composting WTP residuals and biosolids showed that the process was viable and could provide a viable alternative method for residuals disposal. The following conclusions were determined based on the demonstration study results:

- A 25 percent blend of residuals was the maximum allowed in order to obtain desired pile temperatures.
- Alum sludge slightly increased the concentration of heavy metals (Cu, Ni, Pb, and Zn) in the finished compost product.

- Joint composting was found to be a cost effective alternative.
- The compost contains significant levels of phosphorus, therefore phosphorus binding was not a concern.
- Research suggests that using residuals/biosolids compost at a loading rate of 20 tons/acre (44.8 metric tons/hectare) for 20 years, soil metals concentrations would not be significantly increased.

A side benefit of joint composting is that both municipal wastes could be combined into one common material for disposal and as a result decrease labor and facilities cost.

Although RWSA demonstrated that joint composting of residuals and biosolids was a viable alternative, the Authority determined that the more economical disposal option was to use the water residuals as daily cover at a local landfill. Currently the Authority delivers all of the residuals produced to the landfill at a cost of $9/wet ton ($9.90/metric ton) and there is no landfill tipping fee. The Authority still practices biosolids composting at Moore's Creek facility but does not add WTP residuals into the compost blend.

Town of Greenwich, Connecticut. The Town of Greenwich, Connecticut combines biosolids and various yard wastes as ingredients for composting. Composting provides stabilization of the wastewater biosolids and generates a valuable organic soil conditioner. In 1987 the Connecticut-American Water Company requested that the Town consider incorporating alum residuals into their current composting operation. The goal was to blend the alum residuals into the compost piles without disturbing the current chemical and biological activity. Some issues the Town needed to address were as follows:

- What effect will alum residuals have on compost quality?
- Is use of alum residuals compatible with existing equipment ?
- Will increased aluminum concentration impact plant growth?
- Determine if alum residuals could be composted with just wood chips?

To provide answers to these questions the Connecticut-American Water Company and the Town formed a partnership to conduct a demonstration study using alum residuals as an ingredient in the composting process and to study impacts on plant growth using the newly formed compost product.

The study conducted by E and A Consultants (E and A Environmental 1988) consisted of two different compost blends. The first compost pile was constructed using alum residuals and ground leaves. A second compost pile was constructed using wastewater biosolids mixed with ground leaves. Both compost piles were continuously aerated and the pile temperatures were measured periodically according to standard composting procedures. A comparison of the Greenwich wastewater compost and the Connecticut-American alum residuals compost is listed below:

- Alum compost had a higher pH (7.15 versus 6.41) than wastewater compost. (Alum residuals were mixed with lime during dewatering.)
- Wastewater compost had higher nutrient concentrations (higher ammonia and phosphorus).
- Alum compost had a higher conductivity.
- Wastewater compost had higher metals concentrations for Zn, Cu, Hg, Ni, and Cd.

The appearance of the two compost piles was similar and there were no objectionable odors or undesired characteristics noted during the field study.

The finished compost product from both the residuals and biosolids compost piles was used to perform pot studies using beans and cucumbers. Top soil with no compost addition was used as the control soil. The growth study demonstrated that beans had a slow germination rate in the residuals compost and did not produce a very good yield, compared with the biosolids and control pots. Cucumber growth, however, benefitted from the residuals compost. The cucumbers grown in the alum compost germinated faster and at a higher percentage and ultimately produced a higher yield than the biosolids compost and control pots. No visual signs of phytoxicity were noted in the residuals compost pots.

Based on these findings, it was determined that the alum compost could potentially be used as a plant growth media depending on the plant species used. Overall, the demonstration indicated that composting alum residuals along with yard wastes is a viable option that should be further investigated.

Top Soil and Potting Soil Production

General Description and Potential Benefits

Manufacturing of commercially sold soil products is a very large industry. Artificial or screened soil products such as mulch, potting soil, top soil, and manure are available at commercial lawn and garden centers. There is a high seasonal demand for these products for residential and commercial landscaping and horticultural applications.

In order to manufacture commercial soil products, various raw materials are required. Typical ingredients used for potting soils and top soils include perlite (aeration), crushed limestone (pH conditioning), sand (weight), bentonite clay (bulking agent), peat mosses, bark fines, and fertilizer (N and P). These ingredients are transported to a manufacturing facility where ingredients are blended and bagged for sale. Raw materials costs and transportation costs are both major economic consideration for manufacturers.

Use of water treatment residuals as an ingredient for production of various commercial soil products has become an increasingly popular option for utilities. Residuals have been demonstrated to be an effective substitute for a number of raw materials commonly used for soil production including perlite, limestone, sand, and bentonite clay. Residuals are valuable to soil manufacturers primarily for use as a bulking agent or weight additive in their products. Most of the ingredients used in soil production are very light weight. To increase product weight, manufacturers add heavier materials such as sand or clay. Without the added weight, a 40 lb (18 kg) bag of potting soil would be extremely large and bulky and difficult to handle by consumers. Use of residuals could effectively reduce the amount of other materials normally used and as a result decrease materials and transportation costs.

Manufacturers also realize the value of using recycled materials for product sales and marketing. Products advertised as a "recycled material" could provide a manufacturer with a significant marketing advantage over competitors.

Market Size and Geographical Locations

Commercial soil production is a very large and widespread industry. There is a high demand for low cost ingredients that could benefit commercial soil products. Production facilities that blend commercial soil products typically include composting operations, bark recycling facilities, and soil blending and bagging facilities. These facilities require large quantities of raw materials and could potentially use large volumes of residuals.

In order to determine if a soil manufacturing facility is within close proximity to a water plant a utility could search the yellow pages or simply visit a lawn and garden center and look at the different products. Transportation distance and cost, as with many other alternative use plans, is a critical factor for determining if residuals use is an economically attractive option for this application.

Manufacturing Logistics

Manufacturing of commercial soil products is a year-round process, however, the products are sold mostly in the spring and summer seasons. Products are stockpiled during the fall and winter months to meet the spring time demands. The manufacturing process used depends on the type of product being produced. Process descriptions are provided in the following paragraphs for manufacturing potting soils, top soils, and manure fertilizers.

Potting Soils. Potting soils are a combination of various raw ingredients and are used primarily for horticultural applications. Raw materials that are frequently used to produce non-professional grade potting soils include peat moss, bark fines, sand, clay, compost materials, and fertilizers. Professional grade potting soils contain only peat moss, bark fines, and a few other non-soil like materials. The raw materials for making potting soil are transported to a site used for storage, blending, and bagging. The ingredient are loaded into a feed hopper by a front-end loader for blending, and mixed at desired blend ratios. The blended ingredients are then completely mixed and conveyed to a storage bin prior to bagging. When there is a demand for the product, the material from the storage bin is conveyed to a machine for bagging or is loaded to a truck for direct customer pickups.

Top Soil. Top soil production involves a slightly different manufacturing process than potting soil. Most commercial top soil products are manufactured primarily using only non-soil like materials including hardwood and pine bark fines, along with wood ash and lime for pH adjustment. Fertilizers are also added to boost the nutrient value. Bark fines are a byproduct from mulch manufacturing facilities. Mulching facilities screen bark to produce different size mulch and the remaining fine material that passes through the screens is collected and used to make top soil. The blending and bagging process used is the same as used for potting soil (Cherry 1998).

Manure Fertilizer. Manure from both cattle and horses is dried and transported to the production facility for bagging. The manure product is very light, so sand or clay has to be added to increase weight. Blending and bagging equipment used are identical to equipment used for potting soil and top soil.

Residuals Application Process

Water treatment residuals used as an ingredient for manufacturing commercial soil products is handled and blended using the same equipment, machinery, and techniques as used for the other ingredients. Additional storage space and conveyors may be necessary for addition of residuals. The amount of residuals added to a soil blend is typically only a small percentage of the entire mix. Blend ratios are a function of the consistency, quality, and availability of the residuals. Ratios must be determined by the manufacturer through demonstration testing.

Many commercial soil production facilities include a composting operation which generates finished compost products for use as ingredients in potting soils and top soils. Residuals could be incorporated with other raw materials during the composting process instead of direct addition to soil products. A general process schematic showing typical production processes for top soil, potting soil, and manure is shown in Figure 3.10.

Residuals Quality Requirements

Physical Requirements. The physical parameters that are most important for soil production are listed in Table 3.13. Physical qualities of a residuals are very important for use in commercial soil production. The color and texture of a residuals must be a very consistent dark brown or black appearance similar to a rich organic soil. Consumers will not purchase products that do not resemble good quality soil. The texture of the residuals is also important. A fine texture is more desirable to manufacturers to minimize soil clumping.

Table 3.13

Important residuals physical parameters for top soil/potting soil applications

Parameters	Units
Solids concentration	%
Color	-
Texture	-
Soil aggregation	-
Moisture content	%
Grain size analysis (clay/silt/sand)	%
Mass density	lb/ft^3 (kg/m^3)
Specific gravity	-
Shrinkage	%
Specific weight	lb/ft^3 (kg/m^3)

Mechanical dewatering is required to generate a cake solid residual of greater than 20 percent solids concentration for residuals use as a soil ingredient. Additional air drying may also be required prior to use for soil production. Manufacturers prefer a semi-dry or dry residuals that is approximately 40 to 60 percent solids concentration. Grain size analysis, moisture retention capacity, density, and specific weight are also important physical characteristics for use as a soil ingredient.

Chemical Requirements. The chemical requirements of residuals used for ingredients in commercial soils are similar to other alternative uses involving crop growth. The recommended residuals chemical parameters for analysis are listed in Table 3.14. TCLP analysis for metals and volatiles will demonstrate the hazard potential due to leaching of metals or volatiles. The total metals analyses of residuals will provide a manufacturer with the information required for determining if the material is suitable for use. A complete nutrient analysis should also be conducted to determine concentrations of N, P, and K.

Table 3.14

Important residuals chemical parameters for top soil/potting soil applications

Parameters	Units
Total Kjeldahl Nitrogen	lb/ton (mg/kg)
Total phosphorus	lb/ton (mg/kg)
Potassium	lb/ton (mg/kg)
Ammonia - Nitrogen	lb/ton (mg/kg)
Nitrate/Nitrite - N	lb/ton (mg/kg)
Calcium	lb/ton (mg/kg)
Calcium Carbonate Equiv. (CCE)	%
Total metals*	lb/ton (mg/kg)
TCLP metals†	mg/L
Gross alpha	pCi/g
Gross beta	pCi/g
Radium - 226	pCi/g
Total organic carbon (TOC)	lb/ton (mg/kg)
Phytotoxicity - Microtox test	
Total coliform	no/gram
pH	-

*Total metals analyses includes : Al, As, Ba, Cd, Cr, Cu, Fe, Pb, Mg, Mn, Hg, Ni, Se, Ag, Zn, Mo.
†TCLP analyses as specified by 40 CFR, Part 261 [Federal Register 1990].

Most soil manufacturers have the capability of conducting their own soil tests to determine content. Most likely the manufacturer would request a residuals sample and conduct their own chemical evaluation to determine potential for use. Even so, a general analysis of residuals should be conducted prior to first contact with a manufacturer in order to more effectively market residuals.

Top Soil Blending Case Studies

Scott's-Earthgro, Inc. Earthgro, Inc. is a producer of commercial top soil and potting soil products. Earthgro has developed a process which allows for the successful use of alum and ferric water treatment plant residuals as a soil amendment or bulking agent for commercial top soils and potting soils. Earthgro accepts approximately 54,000 wet tons/yr (49,000 metric tons/yr) of residuals (averaging approximately 30 percent dry solids) from Pennsylvania utilities as well as neighboring states. Earthgro is authorized by the State of Connecticut to accept and use WTP residuals at its Lebanon, Conn. facility. Approximately 40 percent of the residuals generated by Connecticut utilities are delivered to Earthgro for processing. Utilities pay Earthgro a tipping fee for accepting residuals based on the total volume of residuals delivered.

Each utility must perform analytical testing on residuals prior to acceptance. The parameters evaluated for screening residuals include the following:

- TCLP metals (8 RCRA metals)
- TCLP pesticides
- TCLP semi-volatile
- TCLP volatile organics
- Total metals
- pH
- Soluble salts
- Moisture content

Earthgro's use of residuals is contingent primarily upon results from the TCLP toxicity tests and the moisture content of the residuals.

The residuals moisture content is also an important acceptance criteria. All residuals accepted by Earthgro must be greater than 15 percent solids. Residuals that have a solids concentration of 15 to 30 percent are considered a "paste" material and residuals with a solids concentration greater than 30 percent are considered a "granular" material. Earthgro's goal is to dry residuals by air drying and freeze thaw dewatering techniques to a solids concentration that is greater than 50 percent prior to blending with other materials.

Dried residuals are added to soil blends at a concentration of up to 30 percent. The residuals serve as a bulking agent for the compost piles and possibly add organics, minerals, nutrients, and water to the blend. Earthgro's finished compost product is blended with other soil or soil-like materials to produce commercially sold soil products.

The information provided on Earthgro's use of water residuals is based on the "Operations and Management Plan for the Processing of Alum Residuals" which is an agreement with the Connecticut Department of Environmental Protection Solid Waste Bureau. More information can be obtained by contacting Earthgro's Lebanon, Conn. process facility.

Elizabethtown, New Jersey. The Raritan-Millstone Water Treatment Plant (RM Plant) in New Jersey is owned and operated by the Elizabethtown Water Company. It was originally constructed in 1929 and is located adjacent to the Raritan River at its confluence with the Millstone River. The original plant, with a reliable water production capacity of 15 mgd (56,700 m^3/day), has undergone many upgrade and expansion projects to increase its capacity to approximately 165 mgd (624,000 m^3/day). The current average production rate is 155 mgd (587,000 m^3/day).

The plant has capabilities of withdrawing water from five intakes located along the Raritan River, Millstone River, and Delaware and Raritan Canal. The tributary area of the Raritan River upstream of the RM Plant can be classified primarily as suburban and rural, The raw water turbidity entering the RM Plant averages approximately 15 nephelometric turbidity units (ntu) with peaks over 1,000 ntu and 100 color units (cu).

The existing treatment facilities provide conventional treatment including mixing, flocculation, sedimentation, filtration and disinfection. Raw water enters the treatment plant through some of the five raw water intake pipes to the low lift pump station where various pretreatment chemicals are applied. These chemicals include alum, potassium permanganate, and caustic soda, or sulfuric acid, as needed for pH adjustment. It is common practice to use a cationic polymer and powdered activated carbon (PAC) to treat highly turbid water and storm runoff. The water is pumped from the low lift pump station to four sedimentation basins. Basin Nos. 1 and 2 provide conventional flocculation and sedimentation, and Basin Nos. 3 and 4 provide flocculation and high rate sedimentation with tube settlers. Settled water is dosed with lime for pre-filter pH control and chlorine and flows to 36 filters. A nonionic polymer may be added as a filter aid depending on treatment requirements. Filtered water flows to a clearwell for storage and secondary disinfection. The water is finally pumped to the distribution system by high service pumps.

Residuals production rates vary from month to month as a result of water demand, raw water quality, and corresponding chemical dosing. Peak residuals production typically occurs during the spring and summer months when demands are elevated and chemical dosing is increased to handle the changing raw water quality. The Raritan River is the primary water source due to its overall exceptional quality, the Delaware and Raritan Canal is used as a secondary source and the Millstone River is used as the third source.

The residuals generated at the plant consist of solids from the raw water and chemical precipitates associated with the addition of alum and other treatment chemicals such as lime, carbon, and polymer. All residuals are collected in the sedimentation basins and removed in a batch removal operation from Basin Nos. 1 and 2, and continuously from Basin Nos. 3 and 4. Washwater from the filters is recycled back to the head of the treatment process and mixed with the raw water. Lagoon decant from a residuals thickening basin is also recycled along with the spent filter backwash water back to the head of the treatment process. The thickener allows for approximately five days of settling prior to decanting for reuse.

Based on past operating experience, the residuals generated at the plant are relatively easy to gravity thicken. Presently, residuals settle and thicken up to a concentration of 5 to 8 percent solids in Basin Nos. 1 and 2. Thickening and dewatering processes are performed in a network of settling, drying and freeze-thaw dewatering lagoons. This process is capable of achieving 10 to 30 percent solids. Stockpiling of these residuals for the purpose of air drying has produced solids ranging from 35 to 50 percent solids depending on time and weather conditions.

In the past EWC disposed of residuals by landfilling or by reuse constructing flood protection barriers around the plant. A decrease in available landfill space, increasing landfill costs and regulations on stockpiling residuals, caused EWC to explore other markets for residuals disposal or reuse. The utility determined that land application and soil blending were potentially the best available methods of residuals beneficial use. Other possible reuse methods considered were composting and blending with wood chips.

Demonstration tests, organized and monitored by the NJDEP Division of Science and Research, were performed on the EWC residuals to obtain information required for obtaining a reuse permit. To obtain a NJDEP reuse permit. The demonstration study was approved after several

NJDEP research studies were performed on EWC residuals. Ultimately, to obtain a full-scale reuse permit, EWC had to accomplish the following tasks:

- Classify residuals as hazardous or nonhazardous
- Obtain a solid waste I.D.
- Develop a reuse plan

To determine if the residuals were hazardous, the utility had to analyze for the following parameters, TCLP (toxicity characteristic leaching procedure), metals analysis, reactivity, corrosivity, and ignitability and total petroleum hydrocarbons. The EWC residuals passed all of these tests and were classified as a nonhazardous material.

Formal growth studies were not performed by EWC, however, the landscaping and flood protection berms at the water treatment plant were all made of 100 percent water residuals and to date demonstrate very good grass growth. The NJDEP Division of Science and Research (DSR) along with the University of Pennsylvania researched the metal leaching from residuals versus native New Jersey top soils. The residuals leached less or equal amounts of metals as the native top soil.

A water treatment residuals reuse permit did not exist prior to EWC's efforts to initiate a program. EWC worked closely with the New Jersey Department of Environmental Protection (NJDEP) to obtain a reuse permit. The NJDEP identified the concerns with residuals reuse and outlined a number of procedures that would be used to regulate reuse. EWC completed all physical and chemical tests required by NJDEP and was the first utility to file for a permit from NJDEP. After review, NJDEP granted EWC a permit for residuals use in land application and soils blending operations.

EWC received a permit to both directly land apply and/or blend residuals with any other aggregate materials such as leaf compost, sand and/or fill. The company currently sells the dewatered residuals (approximately 35 percent solids) to a local topsoil supplier with mixed success depending on market supply and demand. This supplier, in turn, blends the residuals with soil to produce an enhanced product that has improved water retention ability. The mixture is 51 percent aggregate and 49 percent residuals on a volume basis. Land application has been a more consistent outlet for distribution of residuals, however competing interest for trucks., weather and space at local farms has hindered the operation at times. As a result of successful demonstration testing, the Farm Bureau has now began to recommend the use of EWC's residuals blends to farmers.

Through the utilization of soil blending and land application operations over landfilling at \$45 to \$55/ton (\$50 to \$60/metric ton), Elizabethtown has avoided construction of a centrifuge dewatering system that would have cost more than \$15 million. The company was also viewed as being environmentally responsible for recycling this material.

Table 3.15

Summary of utility beneficial reuse program

Utility	Options	Dewatering	Sludge age	Application rates	Cost
Elizabethtown Water Company	Soil blending	Dewatering, lagoon thickening, freeze thaw, windrow	>5 years	51% soil and compost 49% residuals (vol./vol.)	Sold for \$0.07/yd^3 (\$0.09/m^3)
	Land application	Decant and lagoon thickening	3 to 6 months	20 dry tons/acre (44.8 kg/hectare)	\$7.75/yd^3 (\$10.13/m^3)

Richmond Recycling Company - Rhode Island. The Richmond Sand and Gravel Company (also referred to as Richmond Recycling) located in Wyoming, Rhode Island manufactures and sells soil, sand, and gravel products. The company recently began accepting water treatment residuals for use as an ingredient in top soil production. It was recognized that blending residuals with top soil could provide a good quality soil product and could provide water utilities with a beneficial use alternative rather than disposal of residuals in a sanitary landfill. The company currently has a regulatory permit that allows residuals to be added to natural top soil at a 1:3 blend ratio. The residuals used, however, must first meet the criteria outlined by the Rhode Island Department of Environmental Management (RIDEM).

Regulatory approval of residuals reuse by RIDEM is subject to compliance with the following conditions:

- Residuals to top soil blending rates must be less than or equal to a 1:3 ratio, respectively.
- Richmond Recycling must keep records of quantity of residuals accepted, quantity of natural soil used, and total quantity of top soil generated.
- Residuals must be transported and blended in a manner in which no dust or odor problems occur.

Prior to acceptance and use of residuals by Richmond Recycling, the residuals must first be analyzed to determine concentrations for a number of chemical parameters. The RIDEM outlined a number of acceptance tests that must be conducted including:

- Total metals
- TCLP volatile organics
- TCLP semi-volatiles
- Pesticides/PCB's
- TCLP RCRA 8 metals

These tests are used to identify any hazardous properties associated with residuals reuse.

In 1998, Richmond Sand and Gravel received approval from RIDEM to accept and reuse approximately 2,000 tons (1,815 metric tons) of alum residuals from a water utility in Connecticut. The residuals were transported to the Richmond facility and were blended with natural soil at a 1:3 ratio. The added volume of residuals effectively increased the volume of top soil produced while decreasing the volume of natural materials used and total production costs. The utility also paid Richmond Recycling a disposal fee for accepting the residuals, at a lower disposal fee rate than the typical tipping fees charged by Connecticut landfills. Richmond Recycling also beneficially reuses other waste streams besides water treatment residuals to generate a resalable commodity.

City of Englewood, Colorado. The City of Englewood, Colorado operates the Allen Water Filtration Plant which has a rated capacity of 34 mgd (128,700 m^3/day). The Allen plant treats water by direct filtration and uses aluminum sulfate (alum) as the primary coagulant. Alum is fed to raw water entering an 80 MG (302,800 m^3) pre-sedimentation basin. Solids accumulation in the reservoir by 1988 had occupied 33 percent of the total reservoir volume. The alum residuals also caused algae growth in the pre-sedimentation basin which ultimately resulted in short filter run lengths. The City was forced to remove residuals from the basin and stockpile on-site while working on various alternatives for final disposal.

Residuals generated are dewatered to a solids concentration of 20 to 22 percent using a belt filter press. Residuals analyses for the following parameters was conducted:

- Nutrient analysis
- Metals analysis
- Physical analysis (sieve analysis, liquid and plastic limits, geotechnical tests)
- Quantity of residuals generated

A residuals production rate of approximately 300 dry tons/yr (272 metric tons/yr) was typical in the early 1990's. The residuals were allowed to accumulate and thicken in the pre-sedimentation basin and backwash pond. The residuals are characterized as having a high aluminum concentration and a relatively low concentrations of organic matter. The residuals consist primarily of colloidal clay. The City's watershed has a naturally high concentrations of natural uranium deposits which causes a high level of gross alpha radioactivity in the residuals. Toxicity characteristic leaching procedure (TCLP) tests showed that all metals, pesticides, herbicides, and volatile organic compounds (VOC's) were within regulatory guidelines.

The City explored a number of disposal options including landfilling, disposal to the sanitary sewer, and recycling the alum residuals. Landfill disposal was eliminated as a viable option due to the high costs for hauling and expensive landfill tipping fees. Disposal to the sanitary sewer was eliminated because it only shifted the disposal problem from the water plant to the wastewater plant without resolving the problem. The beneficial use options the City investigated are listed below:

- Use as a road fill material
- Backfill for a pipeline project
- Fill at a municipal golf course
- Dedicated landfill for alum residuals

The plan to use residuals as fill at a local golf course was determined to be the best available alternative and was selected for trial. The beneficial use plan was to construct a noise barrier that separated the golf course from a nearby street. The residuals were blended with equal parts of clean fill to simplify materials handling as well as to dilute any potentially hazardous properties. Approximately 2-ft (0.6-m) of topsoil was used to cover the mound to ensure good turf grass growth. The project proved to be a very successful beneficial use method.

It was estimated that at the current residuals accumulation rates, stored residuals would only have to be disposed of every two years. During the in-between periods, the City would focus on residuals marketing so that end users are located and committed prior to the next disposal event. Other berm locations on the golf course have been identified for future construction which will enable approximately ten years of alum residuals to be placed.

Regulatory requirements for disposal and reuse are imposed by the Solid Waste Division of the Colorado Department of Public Health and Environment (CDPHE). The City worked closely with CDPHE to receive a permit for each of their designated recycling sites. The major issue focused on by CDPHE was the presence of low level radioactivity in the residuals. Further testing was conducted by the Radiation Control Division of CDPHE and test results demonstrated that the residuals posed no potential danger to workers handling the material or to the public.

The cost required to haul residuals to the golf course and construct the berms is approximately \$16/yd^3 (\$20.92/m^3) of residuals. This cost includes cost for addition of a 2-ft (0.6-m) cap of clean fill dirt that is placed over the residuals.

Road Subgrade

General Description and Potential Benefits

Although this report does not detail beneficial uses for lime softening residuals, this particular market was unique and could potentially be beneficial to utilities. This application could also potentially be used to dispose of aluminum or iron residuals as well, although no case studies or research studies using coagulant residuals as a road subgrade material were found.

Lime softening residuals have been used successfully for years as a subgrade material for constructing foundations for roads and parking lots. In certain regions of the country the soil structure is very unstable and is not capable of supporting pavement without the addition of rock and soil materials. Road construction requires a hard base to prevent pot holes and cracking of concrete or asphalt. Lime softening residuals used is typically blended with various types of rock, gravel, or soil materials to form a hard stable road base.

Use of lime softening residuals for this application could significantly decrease the volume of other materials normally used for construction. Water treatment plants are typically willing to give away lime residuals at no cost, however, most require that the user provide all of the labor and equipment required for removal and transportation. Lime residuals use as a subgrade material generally benefits both parties involved and provides a reuse application that is safe as well as beneficial.

Market Size and Geographical Locations

The road construction industry is a very large business. Road construction or road improvement projects exist in every state in the U.S. The materials used for forming road bases are in high demand especially in regions of the U.S. with poor soil stability. This market could potentially dispose of large quantities of residuals.

To determine the market potential for residuals use as a road subgrade material, a utility should contact local road construction companies or the State Department of Transportation (DOT). A utility could also contact a local geologist to determine if the soil stability in their region of the U.S. and local area requires the use of additional subgrade materials for road construction.

Residuals Implementation Logistics

The process used for road construction is very simple. Contractors, or other users, collect the residuals from the treatment plant as needed and deliver it to either the road construction site or a blending facility. Residuals are mixed with shell rock, gravel, or other materials using some form of mechanical blending (pugmill, auger, front-end loader, etc.). The mixed subgrade material is then applied evenly over the road base and compacted. After the material dries and hardens it forms a stable road base capable of supporting pavement. No extra equipment is typically required by the road contractor for residuals use. A process schematic for application of residuals as a road subgrade material is included as Figure 3.11.

Residuals Quality Requirements

Physical Characteristics. The physical parameters that are important for use of residuals as subgrade are listed in Table 3.16. The physical characteristics of residuals for road construction applications are more important than the chemical constituents. Lime residuals is typically used, however, coagulant residuals could be experimented with as well to determine applicability. The physical properties of residuals including density, specific gravity, solids concentration, specific weight, and shear strength are all important properties for road base construction. Demonstration tests may be required to determine how well a particular residuals will compact and harden and to determine what blend ratios of residuals are optimal.

Table 3.16

Important residuals physical parameters for road subgrade applications

Parameters	Units
Solids concentration	%
Moisture content	%
Grain size analysis (clay/silt/sand)	%
Mass density	lb/ft^3 (kg/m^3)
Specific gravity	-
Shrinkage	%
Specific weight	lb/ft^3 (kg/m^3)
Shear strength	lb/ft^2 (kg/m^3)

Water treatment plant residuals must be mechanically dewatered to a semi-dry or dry material. Contractors prefer a dryer material that is at least 40 percent solids. Air drying may be required to further increase solids concentration prior to use.

Chemical Characteristics. The residuals chemical parameters that are recommended for analysis are listed in Table 3.17. A TCLP analysis including metals and volatiles should be conducted to determine the hazard potential of a residual.

Table 3.17

Important residuals chemical parameters for road subgrade applications

Parameters	Units
TCLP metals†	mg/L
TCLP volatiles/semi-volatiles†	mg/L

†TCLP analyses as specified by 40 CFR, Part 261 [Federal Register 1990].

Road Subgrade Case Study

City of Boynton Beach, Florida. The City of Boynton Beach owns and operates a 19.2 mgd (72,670 m^3/day) lime softening facility in coastal South Florida. The facility softens and filters municipal drinking water solely from groundwater supply wells. Raw water quality is good, however, the water contains a high concentration of calcium hardness (220 mg/L as $CaCO_3$) and high color (35 cfu). The plant treatment process includes two Infilco Degremont Accelerators and one EIMCO reactor clarifier for water softening and clarification. The average lime dosage necessary to increase the pH to 8.9 to 9.0 is 145 mg/L. This dosage effectively softens the water to 100 mg/L as $CaCO_3$ and reduces color to approximately 10 cfu. The softening/clarification process is followed by filtration through eight mixed media filters.

The water plant currently generates approximately 20,000 lbs (9,070 kg) of wet residuals per day (20 to 25 percent solids). Residuals from the softening basins are pumped to a holding tank and then transferred to a thickening basin for solid/liquid separation. Solids from the thickener are then dewatered using a vacuum filter press to produce a dry cake solid. Dewatered residuals are stockpiled on-site for further air drying prior to final disposal. The plant also has the capability of storing residuals in an on-site lagoon. The lagoon is only used when the mechanical dewatering equipment is not in operation. The lagoon typically stores residuals for approximately one year before residuals are removed and stockpiled on-site.

The Boynton Water Plant has beneficially used lime residuals for almost 20 years. For the last ten years the utility has had an agreement with a local road construction contractor to remove all residuals from the plant. The road contractor mixes the lime residuals with shell rock for use as a subgrade for roads and parking lots. The soil is very unstable in this area of the country and therefore a material that can provide soil stability is necessary for forming a hard road base. The contractor determined that by incorporating residuals, the quantity of shell rock required is significantly decreased.

The City of Boynton and the contractor currently have a letter agreement which includes insurance agreements. The agreement states that the City would not charge the contractor a fee for the residuals, however, the City would in return receive the contractors services for hauling and for yearly removal of residuals from the storage lagoon. The contractor has agreed to accept and is able to use all of the residuals generated by the plant.

The State of Florida Department of Environmental Protection (DEP) is responsible for regulating and permitting beneficial use of water treatment plant residuals. No specific guidelines or general permit currently exists for beneficial use of residuals, but permitting is accomplished on a case-by-case basis. The DEP considers the City of Boynton's residuals to be an "innocuous" material and therefore they do not require the utility to have a disposal permit. The local public health department also agrees that the material presents no environmental hazards and is acceptable for beneficial use disposal.

The City of Boynton initially looked at competitive bidding for the lime residuals. Based on those efforts, the City realized that the profit obtained from residuals sales were very insignificant. The final agreement with the contractor was established such that the residuals would be free and the cost savings would ultimately be realized from elimination of hauling costs and landfill tipping fees. The plant cost savings under the current agreement is estimated to be greater than $75,000/yr.

Forest Land Application

General Description

Many water utilities own and manage watershed properties which protect their raw water supply sources. Watershed property is typically protected forest land that is used as a buffer to prevent contamination of drinking water supply. Management of watershed includes planting trees, forest management, control of stormwater runoff, and harvesting trees for profit. An extensive forested watershed could also be valuable for land applying residuals generated by water treatment plants.

The principals used for forest application are similar to agricultural land application practices. Metals and nutrient loading rates, spreading methods, and compliance monitoring all need to be closely evaluated before initiating a forest application program. Forest application programs require extensive operator management and specialized heavy equipment for spreading residuals onto forest land.

Market Size and Geographical Locations

Unlike agricultural application, forest application of residuals is not commonly practiced by water utilities. Many utilities, however, have forested watersheds and/or are located in areas that have extensive tracts of public and private forest land. WTP residuals application to forest land is usually only possible when the land is owned by the water utility unless agreements can be reached with private land owners.

Implementation Logistics

To develop a forest land application program, the first step is to determine the quantity and quality of residuals that will be applied on a daily or yearly basis. This knowledge will help a utility determine the total acreage that would be required for maintaining a long-term program. The proposed land for residuals applications should be surveyed to determine which tracts of the land are suitable for this form of land application. Regulatory agencies that will potentially oversee the residuals application program will have specific criteria for selecting land application sites. Factors such as land slope, proximity to surface water, property lines, power lines, etc. must be considered when siting for residuals application. After identifying which tracts can be used, adequate roads must be constructed to allow spreader vehicles to reach application sites.

Forest applications during inclement weather or at other times may not be possible, therefore, a residuals storage facility is required at the forest application site or water treatment plant for short term storage. Dewatered residuals would need to be delivered and stockpiled at this facility until land spreading is possible.

Application rates are usually based on heavy metals and nutrient accumulation in the forest litter. Demonstration studies may be required to determine the effects on forest soils, groundwater, and plant species in order to determine a safe loading rate. During full-scale operation, a monitoring program would be necessary to track soil characteristics and groundwater quality over time. Monitoring is critical for determining how frequently residuals can be applied and ultimately how much residuals can be spread on each tract of land. A process schematic for incorporating residuals onto forest lands is included in Figure 3.12.

Residuals Quality Requirements

Physical Requirements. The physical parameters that are important for using residuals for forest land application are listed in Table 3.18. The physical qualities of residuals that are important for forest application include solids concentration, color, texture, and grain size analysis. Cake solids or liquid residuals applications are possible depending on the economic feasibility. Cake solids residuals applications are preferred due to decreased hauling costs and because liquid residuals could potentially coat forest leaves and block photosynthesis. The color and texture of residuals are also important for aesthetics and for residuals incorporation into the natural forest litter and soils.

Table 3.18

Important residuals physical parameters for forest land application

Parameters	Units
Solids concentration	%
Color	-
Texture	-
Soil aggregation	-
Moisture content	%
Grain size analysis (clay/silt/sand)	%
Specific weight	lb/ft^3 (kg/m^3)

Chemical Requirements. The chemical parameters that should be evaluated prior to marketing residuals for forest application are listed in Table 3.19. The chemical components of residuals that are most important are the metals and nutrient concentrations. Heavy metals such as copper and aluminum are typically the limiting factors for land application. The nutrient concentrations in residuals are typically low, however, nutrient analysis is important for determining loading rates. TCLP metals and volatiles analyses should be conducted in order to determine the hazard potential associated with leaching of residuals from the soils. On-site monitoring wells may also be required to determine impacts on groundwater quality.

Table 3.19

Important residuals chemical parameters for forest land application

Parameters	Units
Total Kjeldahl Nitrogen	lb/ton (mg/kg)
Total phosphorus	lb/ton (mg/kg)
Potassium	lb/ton (mg/kg)
Ammonia - Nitrogen	lb/ton (mg/kg)
Nitrate/Nitrite - N	lb/ton (mg/kg)
Calcium	lb/ton (mg/kg)
Calcium Carbonate Equiv. (CCE)	%
Total metals*	lb/ton (mg/kg)
TCLP metals†	mg/L

Continued

Table 3.19 (Continued)

Parameters	Units
Gross alpha	pCi/g
Gross beta	pCi/g
Radium - 226	pCi/g
Total organic carbon (TOC)	lb/ton (mg/kg)
Loss Of Ignition (LOI)	%
Phytotoxicity - Microtox test	
Total coliform	no/gram
pH	-

*Total metals analyses includes : Al, As, Ba, Cd, Cr, Cu, Fe, Pb, Mg, Mn, Hg, Ni, Se, Ag, Zn, Mo.

†TCLP analyses as specified by 40 CFR, Part 261 [Federal Register 1990].

Forest Land Application Case Study

Newport News Waterworks. The Newport News Department of Public Utilities (Waterworks) operates two water treatment plants that produce approximately 50 mgd (189,250 m^3/day). The treatment processes include conventional treatment at one facility and upflow clarification at the other. Both plants use aluminum sulfate (alum) as the primary coagulant at an average dosage of 50 to 60 mg/L. Powdered activated carbon is fed during the warm water months (as needed) for taste and odor removal. The quality of raw water obtained from the Waterworks reservoirs is generally good, however, there is a high concentration of organics and color. Frequent applications of copper sulfate are used during warm weather months to control algae in the reservoirs. These applications are responsible for the high copper concentration found in the residuals produced at each plant.

Alum residuals produced by the Lee Hall plant are piped to a common centrifuge facility located at the Harwoods Mill Water Treatment Plant. The centrifuge produces a residuals cake concentration of approximately 16 to 18 percent solids. The residuals are then trucked to a holding site prior to forest application.

Newport News Waterworks evaluated a number of alternative disposal methods and eliminated all but four options. They were as follows:

- Low rate land application
- Landfill disposal
- High rate land application
- Disposal to sanitary sewer

Disposal to the sanitary sewer was rejected by the local sanitation district and initially landfilling the residuals was eliminated due to the need for a high solids concentration that could only be achieved using a plate and frame filter press. The landfill agency, however, later approved a 17 percent residuals concentration for landfill disposal. The landfill tipping fees, however, were estimated to be approximately $500,000/yr which made this form of disposal economically unattractive. Low rate land application was ultimately selected as the best available alternative.

The Waterworks Department owns and manages approximately 8,000 acres (3,237 hectares) of watershed property. Studies determined that 2,000 acres (809 hectares) of the total watershed was suitable for land applying alum residuals. The Virginia State Water Control Board provided Waterworks with an interim land application permit to perform demonstration studies using alum residuals. Demonstration studies were conducted by the Waterworks along with Virginia Polytechnic Institute and State University (Geertsema, et al 1994) to determine the impacts of alum residuals on Loblolly pines. Both greenhouse and field studies were conducted to assess impacts on soil, soil-water, and plant growth. Results from these studies concluded that low rate residuals land application was a viable disposal alternative.

Information obtained from the demonstration study was necessary for securing a land application permit granted by the Virginia Department of Environmental Quality (VA DEQ). After receiving a permit in 1994, Waterworks began full-scale application to stands of Loblolly pines. Residuals are hauled to two covered storage facilities located on Waterworks property for storage and are land applied using an Aero-Spread application vehicle. The Waterworks DEQ permit specified the buffer widths and boundaries used to design the land application sites. Proper distances were maintained from roads, tributaries, surface water, and power poles as required by the permit. Copper, nitrogen, and aluminum loading rates are frequently monitored to maintain levels as regulated by VA DEQ permit. The land application program has in the past and continues to be an effective and accepted management alternative. Waterworks has been very satisfied with how well the alum residuals blend into the forest litter over time, even at very high loading rates.

The capital cost of the forest application program was approximately $19 million. This cost included the storage facilities, dewatering equipment, and vehicles necessary to land apply the residuals. Most of these expenses (dewatering and hauling residuals) would be necessary regardless of the residuals disposal alternatives selected. Land application of residuals eliminates landfill tipping fees and saves waterworks approximately $500,000/yr.

Waterworks continues to search for new and innovative beneficial use alternatives. Forest application is considered a safe economical alternative, however, the monitoring program has shown that land application does not significantly benefit or harm the pine trees. Waterworks is currently investigating the possibility of using residuals for co-composting with yard waste, and have recently applied for a VA DEQ permit to perform demonstration studies with a local landfill agency.

Citrus Grove Application

General Description

Citrus crops grown in southern U.S. states include oranges, grapefruits, and many other citrus species. Soils in these regions of the U.S. are typically low in iron, which is vital for the growth of citrus crops. Citrus farmers in these regions frequently apply agricultural iron amendments to grove soils to satisfy the tree's demand for this element. The use of ferric sulfate ($Fe_2(SO_4)_3$) as a primary coagulant generates a residuals that is rich in iron humate. Many utilities in these regions have switched from using alum coagulants to a high purity ferric sulfate to increase residuals value and make the residuals more marketable for land application. High purity ferric sulfate has a reduced concentration of heavy metals that would otherwise limit citrus grove application rates. Ferric residuals used on citrus crop soils have been demonstrated to be as effective as the other commercial iron products normally used.

Market Size and Demand

Citrus farming in the U.S. is a large industry that has thousands of acres dedicated to growth and production of citrus crops. For utilities located in these regions of the U.S. this form of alternative use may be possible. A number of companies including chemical producers and "turnkey" recycling contractors provide their service for assisting with the development of a beneficial use program using ferric residuals for citrus groves applications. Farmers spend millions of dollars to apply tons of commercial iron fertilizers necessary for supporting good citrus crop growth. There is a high demand for low cost materials that could provide a beneficial iron supplement to citrus grove soils

Implementation Logistics

Dewatered ferric residuals are usually delivered to the citrus farm by utility trucks or by contractors and surface applied to the citrus grove. Application rates should be determined based on the chemical quality of residuals and should be verified through demonstration testing. The application process is similar to applications using other commercial iron products. Monitoring of heavy metals accumulation in citrus grove soil should be routinely performed to prevent soil contamination. A process schematic for application of residuals to citrus groves is included as Figure 3.13.

Residuals Quality Requirements

Physical Requirements. The physical parameters that are important for using residuals for citrus grove application are listed in Table 3.20. The physical quality of residuals that is most important for this application is the solids concentration. Residuals are applied to citrus groves as a dewatered cake solid. Mechanical dewatering and air drying is required to produce a cake that is greater than 35 percent solids. Existing citrus farm equipment should be adequate for handling and apply dry residuals. The transportation volumes and cost is also decreased by dewatering residuals.

Table 3.20

Important residuals physical parameters for citrus grove applications

Parameters	Units
Solids concentration	%
Color	-
Texture	-
Soil aggregation	-
Moisture content	%
Grain size analysis (clay/silt/sand)	%
Specific weight	lb/ft^3 (kg/m^3)

Chemical Requirements. The chemical parameters that are important when applying residuals to citrus groves are listed in Table 3.21. The most important element in residuals for citrus applications is iron. Using $Fe_2(SO_4)_3$ as a coagulant for drinking water treatment generates a iron humate residual. Ferric residuals is basically a modified iron humate material that provides a very efficient transfer of iron to citrus crops. Heavy metals and other nutrient concentrations should also be evaluated to determine the allowable loading rates. TCLP analyses will determine the hazard potential due to leaching from the soil.

Table 3.21

Important residuals chemical parameters for citrus grove applications

Parameters	Units
Total Kjeldahl Nitrogen	lb/ton (mg/kg)
Total phosphorus	lb/ton (mg/kg)
Potassium	lb/ton (mg/kg)
Ammonia - Nitrogen	lb/ton (mg/kg)
Nitrate/Nitrite - N	lb/ton (mg/kg)
Calcium	lb/ton (mg/kg)
Calcium Carbonate Equiv. (CCE)	%
Total metals*	lb/ton (mg/kg)
TCLP metals†	mg/L
Gross alpha	pCi/g

Continued

Table 3.21 (Continued)

Parameters	Units
Gross beta	pCi/g
Radium - 226	pCi/g
Total organic carbon (TOC)	lb/ton (mg/kg)
Loss Of Ignition (LOI)	%
Phytotoxicity - Microtox test	
Total coliform	no/gram
pH	-

*Total metals analyses includes : Al, As, Ba, Cd, Cr, Cu, Fe, Pb, Mg, Mn, Hg, Ni, Se, Ag, Zn, Mo.
†TCLP analyses as specified by 40 CFR, Part 261 [Federal Register 1990].

Citrus Grove Application Case Study

Tampa Water Department. The Tampa Water Department (TWD), located in Tampa, Florida, operates two water treatment facilities—Hillsborough River and Morris Bridge. The Hillsborough River plant is the largest surface water treatment plant in Florida with a maximum capacity of 100-mgd (378,500-m^3/day). The Hillsborough plant utilizes conventional treatment processes with ferric sulfate ($Fe_2(SO_4)_3$) as the primary coagulant. The Morris Bridge plant has the capacity to treat 40-mgd (151,400-m^3/day) of groundwater from 20-deep groundwater wells using a catalytic lime softening process.

The TWD plants each generate different types of residuals. The Hillsborough plant use ferric sulfate enhanced coagulation at a pH range of 4 to 5 for coagulating raw water which ultimately produces an "iron humate" residual. The raw water treated is characterized by low turbidity but has a high concentration of natural organic matter (NOM). Hillsborough residuals are gravity thickened and then dewatered by a belt filter press. The residuals are then further air dried in drying beds to a 35 percent solids concentration.

The Morris Bridge plant generates a lime residual called "prill" from the softening process. These residuals are stockpiled at the plant and are periodically trucked away by a local contractor for beneficial use applications.

The TWD in the past used aluminum sulfate (alum) at the Hillsborough plant as the primary coagulant. The utility experimented with beneficial use of alum residuals using a number of different alternatives including lake restoration, cement production, and disposal through incineration. All options evaluated were found to be economically unfeasible. The TWD then entered into a partnership with Kemiron (a manufacturer of iron coagulants and beneficial use contractor) in order to develop a complete plan for water treatment and residuals beneficial use. As part of the agreement with Kemiron, the utility switched to high purity ferric sulfate as the primary coagulant. The ferric sulfate coagulant is manufactured to have a low concentration of metals, thereby reducing the contaminant concentrations in the residuals.

The decision to switch to ferric sulfate as the primary coagulant was simplified due to the extremely low iron concentrations present in local soils. Agricultural applications of iron are necessary for obtaining good citrus crop yields. Due to the market demand for agricultural iron amendments, TWD and Kemiron selected agricultural land application as the best available beneficial use for further evaluation.

Residuals generated at the Morris Bridge facility amounted to a much lower total volume than the Hillsborough plant. A local contractor pays the TWD a very small yearly fee to haul away and beneficially use the residuals or "prill". The contractor adds the prill to commercial fertilizer as a bulking agent.

A greenhouse study was conducted by the University of Florida to compare the iron humate residuals from Hillsborough to commercial agricultural iron products. Results from the study demonstrated that the modified iron humate outperformed the commercial iron products at a substantially lower loading rate. Based on the success of this research project, TWD and Kemiron began marketing the ferric residuals as a soil iron amendment for agricultural use.

TWD was able to obtain permits from a number of state regulatory agencies to initiate the application program. The agencies involved with the beneficial use program are the Florida Department of Environmental Protection (FDEP), the Southwest Florida Water Management District (SWFWMD), and the Hillsborough County Health Department.

The partnership between TWD and Kemiron limited the amount of work that the utility had to do to market the ferric residuals to potential users. Kemiron handled the selection of citrus farms as well as other agricultural markets to pursue and was responsible for residuals sales to end users.

The profits made by retail sales of the ferric residuals are shared by the TWD and Kemiron. The utility receives a percentage of the total sales profit.

Nutrient Control

General Description

A promising and innovative application for beneficially using coagulant residuals is application for the reduction of available nutrients (phosphorus and nitrogen) in polluted soils. This potential alternative has been used previously and is currently being researched to develop new application techniques. The ability of coagulant residuals to bind soluble soil nutrient has in the past been viewed as a potential negative quality for agricultural applications. Current research is focusing on using this unique property of residuals as an advantage. Full-scale land application programs have been used to successfully decrease the available nutrient concentrations in polluted soils. Buffer strips made with residuals have also been used to prevent nutrient runoff into adjacent waterways.

Market Size and Demand

Nutrient pollution in soils and water are increasingly becoming regulatory concern. Uncontrolled nutrient runoff into waterways can result in severe eutrophication and cause water quality deterioration. A large contributor to nutrient contamination is the livestock and poultry industries. Both industries generate tons of waste products rich in nutrients that must be carefully controlled and disposed of to prevent environmental contamination. These industries exist in every region of the U.S. The market potential for using coagulant residuals for nutrient control applications is unlimited and the demand for a product with this capability is steadily increasing.

Implementation Logistics

Water treatment residuals can be applied for nutrient control using a number of different techniques. Residuals can be land applied to crop land, pasture land, or feed lots using typical land application procedures. Other applications include formation of buffer strips to protect waterways, and blending with animal waste, litter, or manure. A process schematic detailing the various residuals application methods is included in Figure 3.14.

Land application of residuals to nutrient contaminated soils is used to bind available soluble phosphorus and nitrogen. Demonstration studies should be conducted to determine a particular residual's potential for nutrient reduction. Application rates can then be established to achieve a desired reduction of nutrient concentrations in soils.

Buffer strips around feed lots, poultry houses, and crop land could be constructed to minimize nutrient runoff into adjacent waterways. Buffer strip application rates would also need to be determined through demonstration testing.

Blending of residuals with animal waste products for use as agricultural fertilizer could serve to lower the nutrient concentrations to non-polluting levels while still providing a fertilizer value to crops. Residuals could be blended to animal waste products prior to or during application.

Residual Quality Requirements

Physical Requirements. The physical parameters that are important for using residuals for nutrient control applications are listed in Table 3.22. The same physical characteristics that are important for other cropland applications also apply to use for nutrient control. Residuals could be dewatered to a solids concentration consistent with a dry or semi-dry material, or could be used as a liquid depending on the nutrient control application used.

Table 3.22

Important residuals physical parameters for nutrient control applications

Parameters	Units
Solids concentration	%
Soil aggregation	-
Specific gravity	-
Specific weight	lb/ft^3 (kg/m^3)

Chemical Requirements. The chemical requirements for residuals used for nutrient control (Table 3.23) are also similar to the other land application uses. Metals and nutrient concentrations should be analyzed to determine how a particular residuals will alter the natural soil characteristics. The most important chemical quality is the ability of a residuals to bind soil phosphorus and nitrogen. The soluble phosphorus concentration or equilibrium phosphorus concentration (EPC), total phosphorus, and total kjeldahl nitrogen (TKN) levels should be analyzed for each residuals/soil blend used to determine the reduction in nutrient concentrations that can be expected. Residuals that are able to reduce soil nutrient concentrations using low application rates are optimal for this type of beneficial use. A demonstration study may be necessary in order to identify the nutrient binding ability of a particular residual.

Table 3.23

Important residuals chemical parameters for nutrient control applications

Parameters	Units
Total Kjeldahl Nitrogen	lb/ton (mg/kg)
Total phosphorus	lb/ton (mg/kg)
Potassium	lb/ton (mg/kg)
Ammonia - Nitrogen	lb/ton (mg/kg)
Nitrate/Nitrite - N	lb/ton (mg/kg)
Calcium	lb/ton (mg/kg)
Calcium Carbonate Equiv. (CCE)	%
Total metals*	lb/ton (mg/kg)
TCLP metals†	mg/L
Gross alpha	pCi/g
Gross beta	pCi/g
Radium - 226	pCi/g
Total organic carbon (TOC)	lb/ton (mg/kg)
Phytotoxicity - Microtox test	
Total coliform	no/gram
pH	-

*Total metals analyses includes : Al, As, Ba, Cd, Cr, Cu, Fe, Pb, Mg, Mn, Hg, Ni, Se, Ag, Zn, Mo.

†TCLP analyses as specified by 40 CFR, Part 261 [Federal Register 1990].

Danville, Pennsylvania Municipal Authority. The Danville Municipal Authority (DMA) located in Danville, Pennsylvania operates a 4-mgd (15,140-m^3/day) conventional water treatment plant. The primary coagulant used for water treatment is aluminum sulfate (alum). Residuals from the sedimentation basin and filter backwash water are collected in on-site dewatering lagoons. Residuals had been stored in these lagoons for the past ten years with no removal. The storage capacity of the lagoons gradually decreased over time to the point that the Authority was forced to dredge and dispose of the residuals.

The Authority conducted a bench-top demonstration study to evaluate various residuals management alternatives. Landfilling was no longer economical due to the high cost of dewatering and hauling residuals. A beneficial use alternative seemed to be the most economically attractive method for residuals management.

In order to get a beneficial use permit necessary for conducting a demonstration study, DMA had to address and/or provide information on the following issues:

- Water treatment residuals quality (chemical and physical analysis)
- Background soil chemical analyses
- Receive landowner approval for disposal
- Provide a plan for residuals application

The Authority was able to provide the necessary information on each of these issues and was granted a General Permit to use water residuals as a soil additive by the Pennsylvania Department of Environmental Protection (PA DEP). The PA DEP permit specifically allowed DMA to use water treatment residuals for reducing high phosphate (P_2O_5) levels in farmland soil. The soil phosphate level was 780 lb/acre (874 kg/hectare) which was approximately six times higher than the desired concentration for soybean growth of 140 lb/acre (157 kg/hectare). The demonstration study was conducted to determine if alum residuals were capable of binding soil phosphate and to better understand the phosphate reduction that could be expected.

DMA applied alum residuals (at 15 percent solids) to the farmland soil at a loading rate of 11.5 dry tons/acre (25.7 metric tons/hectare). Prior to residuals application, the soil was limed to increase the pH to 6.5. The General Permit specifically required that the soil pH must be greater than pH 5.0 prior to residuals addition in order to minimize aluminum solubility. After residuals addition, soybeans were planted on the farmland. A soil analysis was performed to determine the impacts of residuals on pre- and post-treatment soil chemistry. The following soil characteristics were noted:

- Soil phosphate (P_2O_5) was reduced 34 percent by residuals addition from 781 to 512 lb/acre (875 to 574 kg/hectare)
- Extractable manganese (Mn) levels decreased, but Mn activity increased
- Extractable soil aluminum concentration increased, but aluminum solubility did not change
- The soybean crop was only half of the expected harvest due to severe weather conditions

The results show that alum residuals effectively lowered soil phosphates, however, the phosphate concentration still remained at a polluting level. It was determined that residuals could continue to be added to the farmland at a higher loading rate to further decrease soil phosphorus.

DMA was anticipating that the cost for sludge removal from the lagoons, dewatering, hauling to landfill would cost $250,000. Total cost for land application to farmland cost approximately $50,000.

Landfill Cover

General Description

For years, dewatered residuals have been transported to sanitary landfills for final disposal. Development of alternative disposal practices and increased tipping fees have significantly reduced the volume of residuals landfilled. Some utilities have developed agreements with municipal solid waste landfills to use residuals as a daily cover material instead of just burying the material. Landfills require a large volume of fill material for covering up the different cells of garbage on a daily basis. This material is generally supplied from borrow pits or from previous landfill excavation. By blending residuals with other daily fill materials, residuals qualities are diluted and the volume of fill material is increased. Due to the residuals value as a fill material, some landfills will lower tipping fees for accepting residuals, thereby making it more economical to utilities. Many utilities still view landfills as the safest location for disposal of solid wastes, limiting the potential for future liability due to environmental contamination caused by residuals.

Market Size and Demand

Municipal solid waste landfills are located within close proximity to almost every water treatment plant. The economics involved with dewatering and transportation are typically used to determine if this form of application is feasible. Landfills are required to use fill material daily to cover solid wastes, therefore, there is a continuous demand for cover materials.

Implementation Logistics

Dewatered residuals are delivered to the landfill and stockpiled for later use. Depending on local or state regulations, a concrete storage pad with drainage collection may or may not be required. Residuals are transported by the water treatment plant and a tipping fee is normally charged depending on the agreement with the landfill. The landfill may use the residuals directly as cover material or blend with other fill material. Front-end loaders and dump trucks that typically exist at landfills are capable of handling and applying residuals. A summary of the general process used for applying residuals as a landfill cover material is included as Figure 3.15.

Residuals Quality Requirements

The physical and chemical parameters that are important for using residuals as a landfill cover material are listed in Table 3.24. The physical and chemical requirements of residuals are not as high of a concern as for the other beneficial use applications due to the location for disposal. Most landfills require that residuals be dewatered to a solids concentration of greater than 25 percent prior to disposal must pass the paint filter test. TCLP analyses for metals and volatiles should be used to determine the hazard potential due to leaching of contaminants from the soil.

Table 3.24

Important residuals quality parameters for landfill cover applications

Parameters	Units
Solids concentration	%
Moisture content	%
Grain size analysis (clay/silt/sand)	%
Specific weight	lb/ft^3 (kg/m^3)
TCLP metals*	mg/L
TCLP volatiles/semi-volatiles*	mg/L
pH	-

*TCLP analyses as specified by 40 CFR, Part 261 [Federal Register 1990].

Landfill Cover Case Studies

Rivanna Water and Sewer Authority. The RWSA demonstrated that joint composting of water treatment residuals and wastewater treatment plant residuals was a viable alternative, however, the Authority later determined that a more economical option would be to use the water residuals as daily cover at a local landfill. Currently the Authority delivers all of the residuals produced to the landfill at a cost of $9/ wet ton ($9.90/metric ton) and there is no landfill tipping fee.

Santa Clara Valley Water District. Due to various operational problems, and because the brick company went out of business, SCVWD's work with brick production was discontinued. SCVWD currently uses residuals as landfill cover. This method of disposal was considered to be the easiest means of disposal. After delivery to the landfill, SCVWD is no longer responsible for the material. SCVWD has a disposal contract with the landfill, and the landfill is responsible for obtaining the required regulatory permits.

Land Reclamation

General Description

Land reclamation is the process of improving the ability of environmentally damaged land to support plant growth. Damaged land could include abandoned strip mines, quarries, borrow pits, etc. The goal of land reclamation is to add fertile soil back to areas that are not capable of supporting vegetation. Strip mine operations remove the top soil from areas and leave behind sites that are incapable of supporting plant life and are susceptible to erosion. Recently residuals have been used successfully as a material for reclaiming damaged land. Water treatment residuals are typically low in nutrient content, however, the material provides a good base of clay, sand, silt, and trace minerals that can support growth. Nutrients can be added along with residuals using fertilizers, composted materials, biosolids, or other nutrient rich materials.

Materials Demand

There are many environmentally damaged sites within the U.S. that are in need of land reclamation. Abandoned quarries, mines, and borrow pits are present almost everywhere. There is a very high demand for low cost materials that are capable of restoring damaged land. This beneficial use alternative has the potential for accepting large quantities of residuals and could possibly provide a utility with a long-term disposal plan.

Implementation Logistics

The procedures used for land reclamation are very similar to methods used for land application. Dewatered residuals, however, are applied to the reclamation area at much higher loading rates than for agricultural land application. The optimal loading rates should be determined through demonstration testing using test and control plots located at the reclamation site. To improve the soil fertility for supporting plant growth nutrient rich materials could be blended along with residuals or added after residuals application. Materials such as grass, leaves, compost, other yard wastes, or even biosolids could be added to provide valuable nutrients to the soil.

Land reclamation is completed by introducing different species of grasses, crops, or trees to the application site. Different species of grasses should be used for early restoration followed by shrubs, bushes, and trees. Grasses will provide a quick form of ground cover that will stabilize the soil and prevent erosion.

The general process used for reclaiming damaged land using water treatment residuals is summarized in Figure 3.16.

Residuals Chemical Requirements

The physical and chemical parameters that are important for using residuals for land reclamation are listed in Table 3.25. The physical and chemical requirements of residuals important for land reclamation use are very similar to requirements for agricultural land application. The residuals loading rates are, however, much higher for land reclamation than for agricultural application. Increased loading rates means higher concentrations of heavy metals applied to the land, therefore, TCLP and total metals concentrations are very important for determining hazard potential and ultimately obtaining regulatory approval. Residuals nutrient concentrations should also be evaluated to determine what additional nutrient concentration must be supplemented to the soil to support good plant growth.

Table 3.25

Important residuals quality parameters for land reclamation applications

Parameters	Units
Physical tests	
Solids concentration	%
Color	-
Texture	-
Soil aggregation	-
Moisture content	%
Grain size analysis (clay/silt/sand)	%
Liquid limit	% solids

Continued

Table 3.25 (Continued)

Parameters	Units
Plastic limit	% solids
Mass density	lb/ft^3 (kg/m^3)
Specific gravity	-
Shrinkage	%
Specific weight	lb/ft^3 (kg/m^3)
Shear strength	lb/ft^2 (kg/m^3)
Chemical tests	
Nutrients	
Total Kjeldahl Nitrogen	lb/ton (mg/kg)
Total phosphorus	lb/ton (mg/kg)
Potassium	lb/ton (mg/kg)
Ammonia - Nitrogen	lb/ton (mg/kg)
Nitrate/Nitrite - N	lb/ton (mg/kg)
Calcium	lb/ton (mg/kg)
Calcium Carbonate Equiv. (CCE)	%
Metals	
Total metals*	lb/ton (mg/kg)
TCLP metals†	mg/L
Radionuclides	
Gross alpha	pCi/g
Gross beta	pCi/g
Radium - 226	pCi/g
Organics	
Total organic carbon (TOC)	lb/ton (mg/kg)
Loss Of Ignition (LOI)	%
Toxicity	
Phytotoxicity - Microtox test	
Other tests	
Total coliform	no/gram
pH	-

*Total metals analyses includes : Al, As, Ba, Cd, Cr, Cu, Fe, Pb, Mg, Mn, Hg, Ni, Se, Ag, Zn, Mo.

†TCLP analyses as specified by 40 CFR, Part 261 [Federal Register 1990].

Case Study

Bradford City Water Authority, Pennsylvania. The Bradford City Water Authority (BCWA) Treatment plant is a conventional treatment system that has a design capacity of 6.2-mgd (23,500-m^3/day) with an average daily production of 4.5 mgd (17,000 m^3/day). Chemicals used for water treatment include polyaluminum chloride (PACl), potassium permanganate, chlorine, and caustic soda. The Authority owns and manages a 10,000-acre (4,047-hectares) watershed.

Residuals generated during water treatment are disposed of in two 900,000-gal (3,406-m^3) storage lagoons. While BCWA was in the process of developing a disposal plan one lagoon was 20 percent full while the other was completely full. The solids concentration of residuals in the storage lagoons ranged from 6 to 50 percent solids.

BCWA looked into a number of different methods for disposal of residuals accumulated in the lagoons. The preliminary options investigated include the following:

- Disposal to sanitary sewer
- Landfilling
- Land application
- Land reclamation

The Authority ultimately selected land reclamation as the best disposal alternative to pursue. Land reclamation was selected primarily to restore land within the BCWA watershed that had been damaged and was in need of reclamation. An abandoned sandstone quarry within the watershed was selected as a potential site for reclamation.

To pursue land reclamation BCWA hired a local contractor to oversee residuals removal, dewatering, disposal, and regulatory permitting. In order to obtain regulatory approval from the Pennsylvania Department of Environmental Protection (PA DEP), BCWA had to report the total residuals metals concentrations for review. PA DEP determined that the residuals metals concentrations were acceptable for use. After receiving approval from PA DEP the contractor began removing residuals from the lagoons and delivering them to a subcontractor for mechanical dewatering.

After dewatering residuals were hauled to the abandoned sandstone quarry and land applied. Land application consisted of placing approximately 6-in. of residuals on approximately 2 acres of the reclamation site. To increase the nutrient value of the residuals organic yard waste was delivered to the site and mixed into the soil. After residuals application was completed, a seed mixture including rye grass, fescue, and wheat was added to begin the revegetation process. The seeds germinated and quickly provided ground cover for the site.

Use of land reclamation for disposal of residuals provided a significant cost savings to BCWA. Conventional handling and disposal practices would have cost BCWA nearly $500,000. The land reclamation project only cost BCWA $250,000. Due to the successful recovery of this site, BCWA has proposed additional sites within the watershed for reclamation using residuals.

Hydrogen Sulfide (H_2S) Binding

General Description

Utility experiences using iron coagulant residuals for control of hydrogen sulfide was documented in "Slib, Schlamm, Sludge" (Cornwell and Koppers 1990). A number of experiments along with some full-scale applications were performed using iron residuals from water treatment plants in place of conventional methods used for H_2S binding such as ferric chloride addition and biogas washing. Hydrogen sulfide gas is generated from the decomposition of wastewater and causes severe corrosion of concrete and metals. Hydrogen sulfide also has a strong offensive odor at concentrations as low as 0.1 ppm. Ferric chloride has historically been used to bind sulfides to prevent the formation of H_2S. Researchers in the Netherlands have demonstrated that WTP iron residuals can be equally or more effective than ferric chloride for sulfide binding. Four different applications are presented in "Slib, Schlamm, Sludge" which detail experiences using iron residuals for H_2S binding in the Netherlands. These applications are as follows:

- Sulfide binding in sewer pipes
- Hydrogen sulfide control in WWTPs
- Sulfide binding during anaerobic liquid manure processing
- Sulfide biding in tannery wastewater treatment

Each of these potential markets are briefly summarized in the following paragraphs. More detailed information should be referenced from "Slib, Schlamm, Sludge" (Cornwell and Koppers 1990).

Sulfide Binding in Sewers

Experimentation in the Netherlands using iron residuals for sulfide binding in sewers proved to be very successful. Iron residuals were metered into a sewer system at a dose rate of 31 mg/L. The study demonstrated that the residuals were capable of reducing H_2S by up to 95 percent (Baltussen 1985). A number of WTPs in the Netherlands using ferric coagulants discharge backwash wastewater directly into sewers primarily for residuals disposal, as well as, for the added benefit of sulfide binding. Reduction of H_2S in sewer pipes significantly reduces corrosion.

Hydrogen Sulfide Control in WWTPs

The Dutch have also used iron residuals in place of other H_2S reduction methods for reducing odor and corrosion. A regional wastewater authority in the Netherlands De Dommel/De Aa conducted a study on using iron residuals into the sludge digestion process.

The study resulted in the following conclusions (Cornwell and Koppers 1990):

- Iron residuals lowered the H_2S concentration from over 600 mg/L to less than 50 mg/L
- No adverse effects on the digestion process were noted
- Use of iron residuals was more cost effective than other means of sulfide control

A second study was performed by West-Overijsel which is a regional wastewater authority in the Netherlands. West-Overijsel treatment plant used liquid iron residuals (7 percent solids) from a groundwater treatment process for sulfide control. Conclusions from this study were as follows (Cornwell and Koppers 1990):

- Iron residuals were able to keep H_2S levels below 500 mg/L
- No adverse effects on the wastewater digestion process
- Use of ferric chloride was eliminated which decreases the chloride concentration in the WWTP biosolids generated
- Costs were decreased 50 percent using iron residuals

Sulfide Binding in Manure Processing

Livestock production is a very large industry in the Netherlands and as a result manure wastes are a significant environmental problem. There are a number of liquid manure processing plants that handle wastes from pig farms. These plants convert pig manure into a dry granular fertilizer for agricultural use. Research demonstrated that the addition of iron residuals into the manure digestion process effectively decreases H_2S production. Excessive H_2S concentrations generated during this process cause corrosion to gas engines (Cornwell and Koppers 1990).

Tannery Wastewater Treatment

Iron residuals have also been used to reduce sulfide odors in tannery wastewater treatment processes. Sulfides are used in the treatment of animal hides and as a result, H_2S is formed in the wastewater equalization basin. The iron residuals were shown to have reduced H_2S production to a limited extent. Further research is being conducted to improve the methods for using iron residuals in this process (Cornwell and Koppers 1990).

Figure 3.1 Case study locations

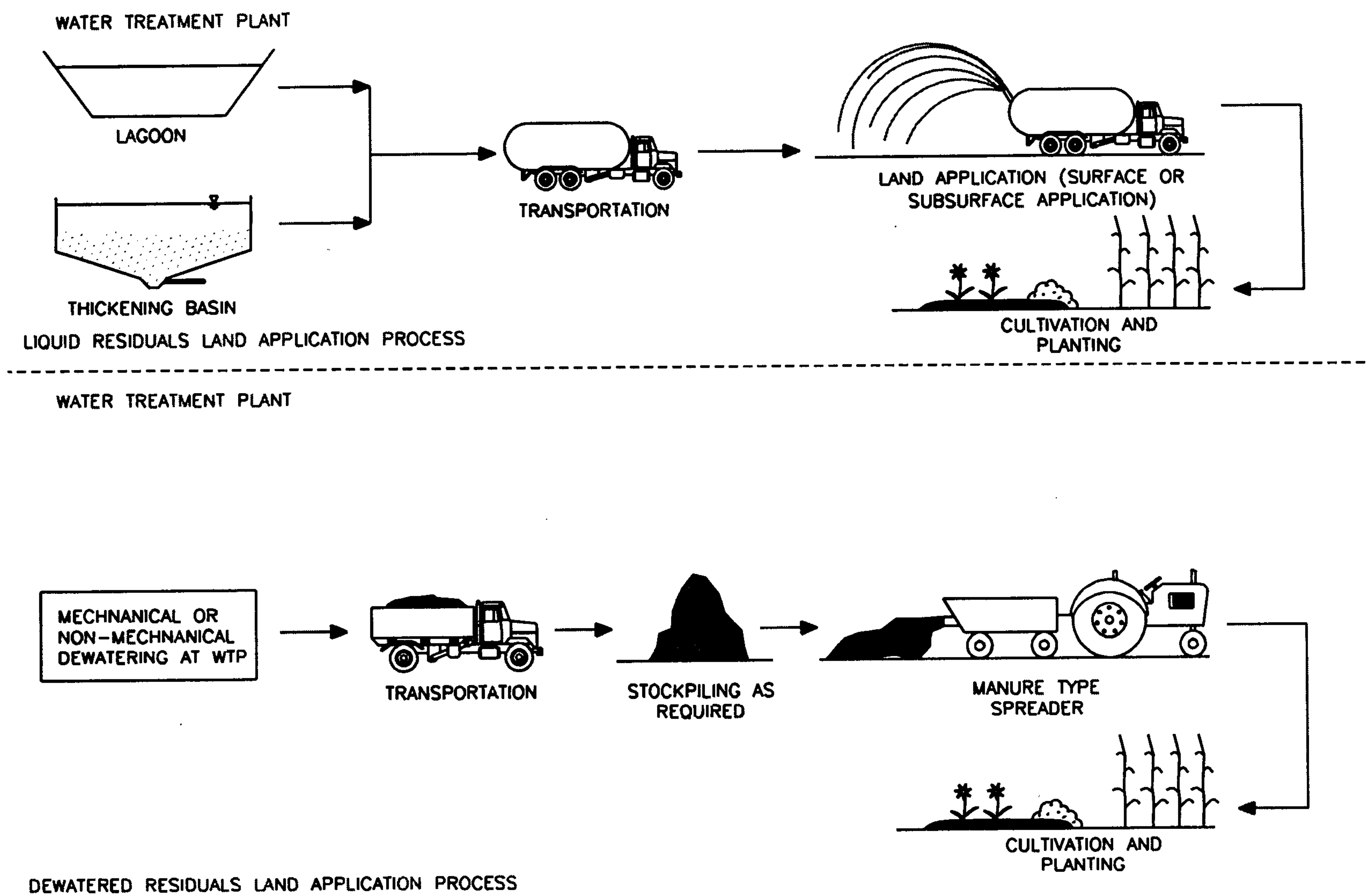
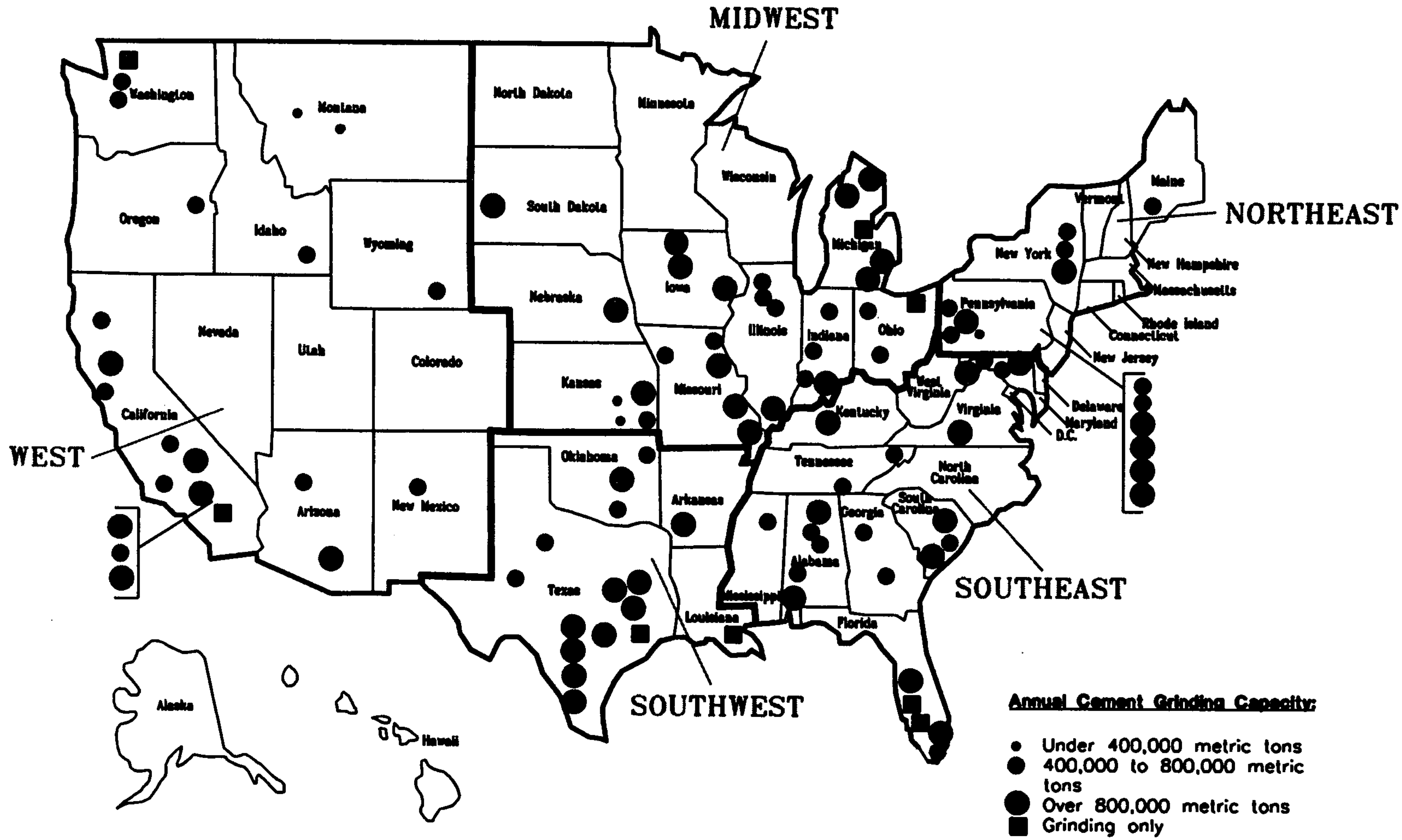


Figure 3.2 Residuals application process onto agricultural land



Source: Portland Cement Association 1997.

Figure 3.3 U.S. Portland Cement plant locations and capacities

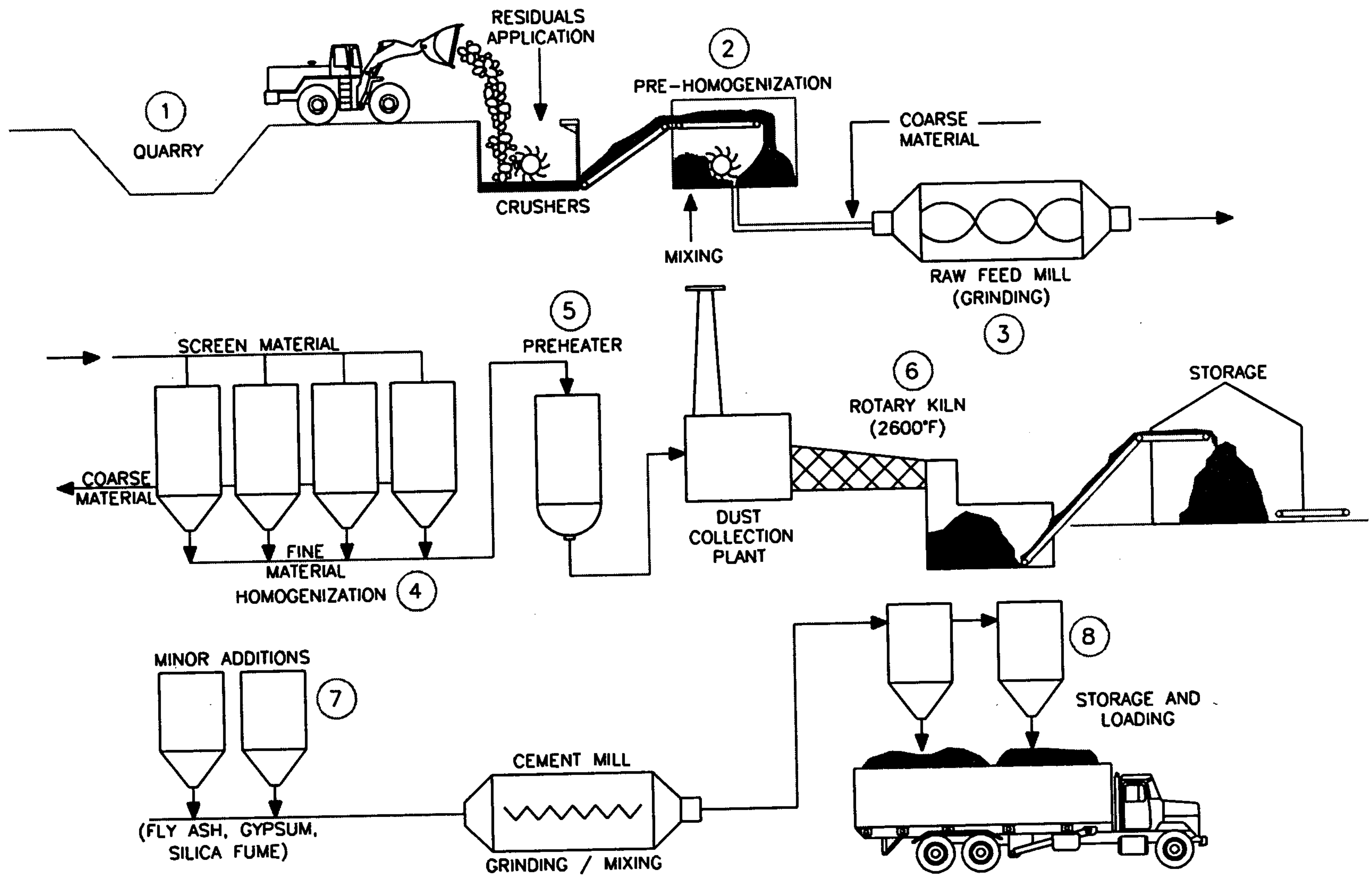


Figure 3.4 Cement manufacturing process

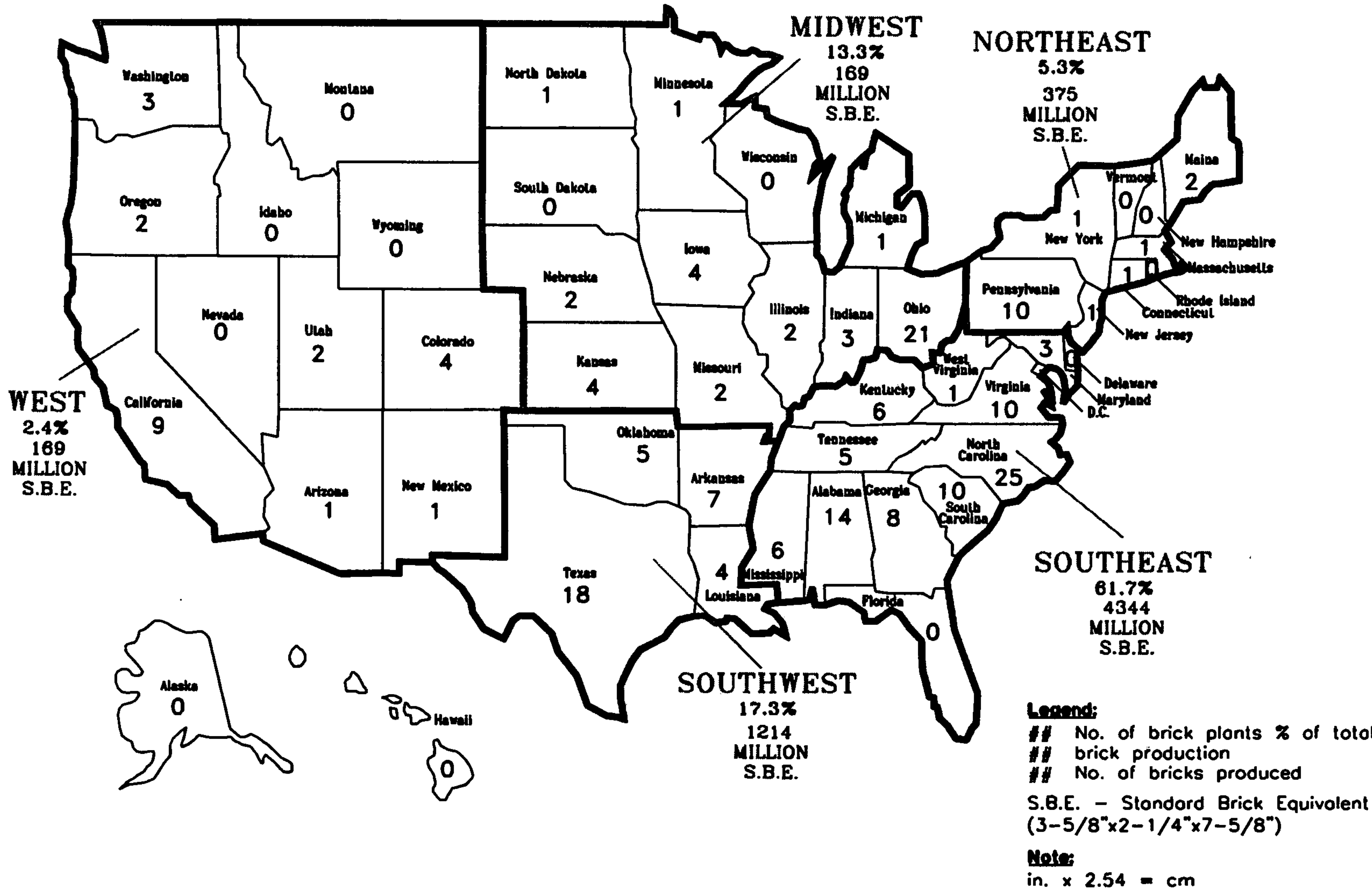


Figure 3.5 U.S. brick manufacturing: State and regional production

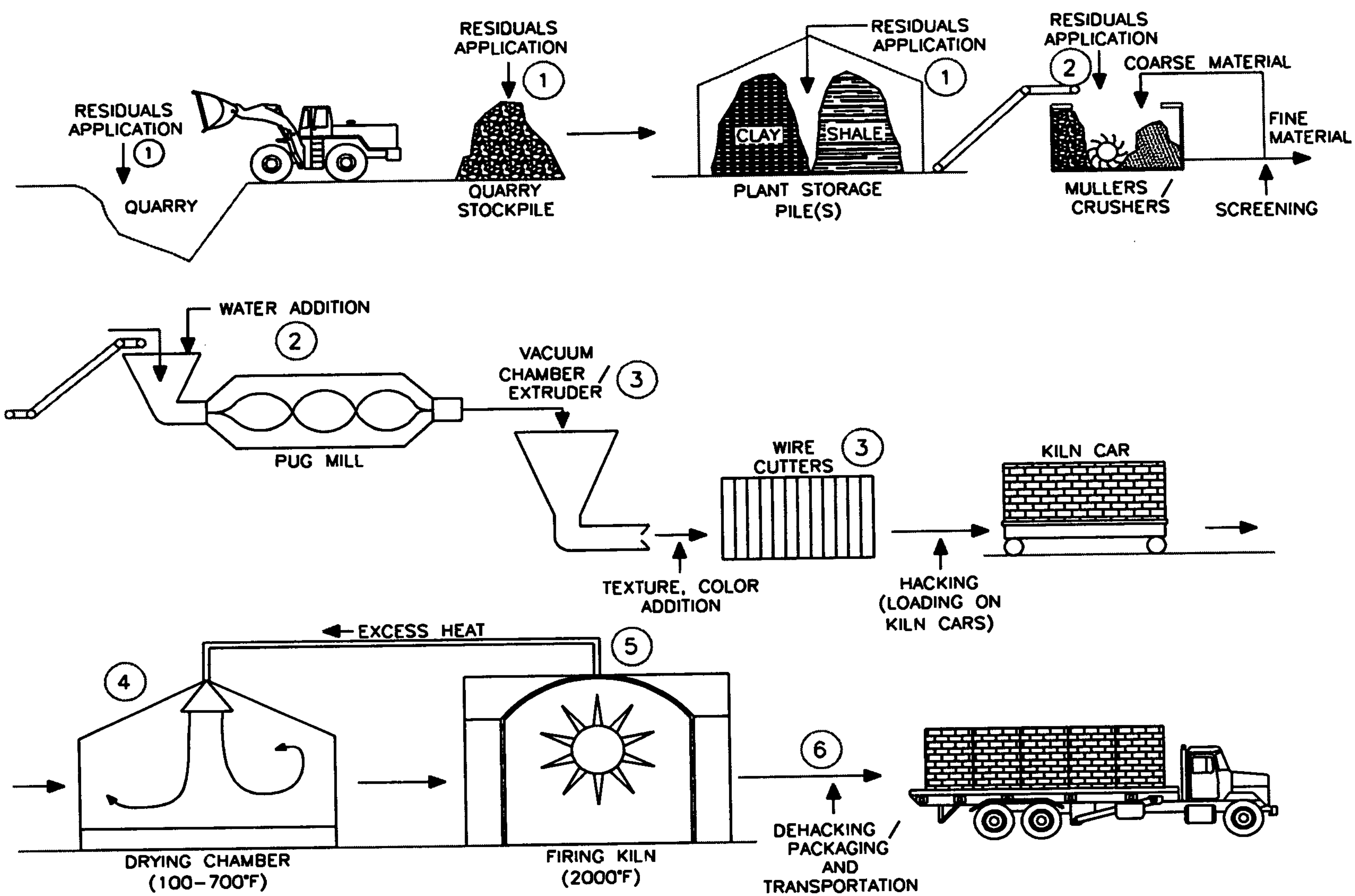


Figure 3.6 Brick manufacturing process

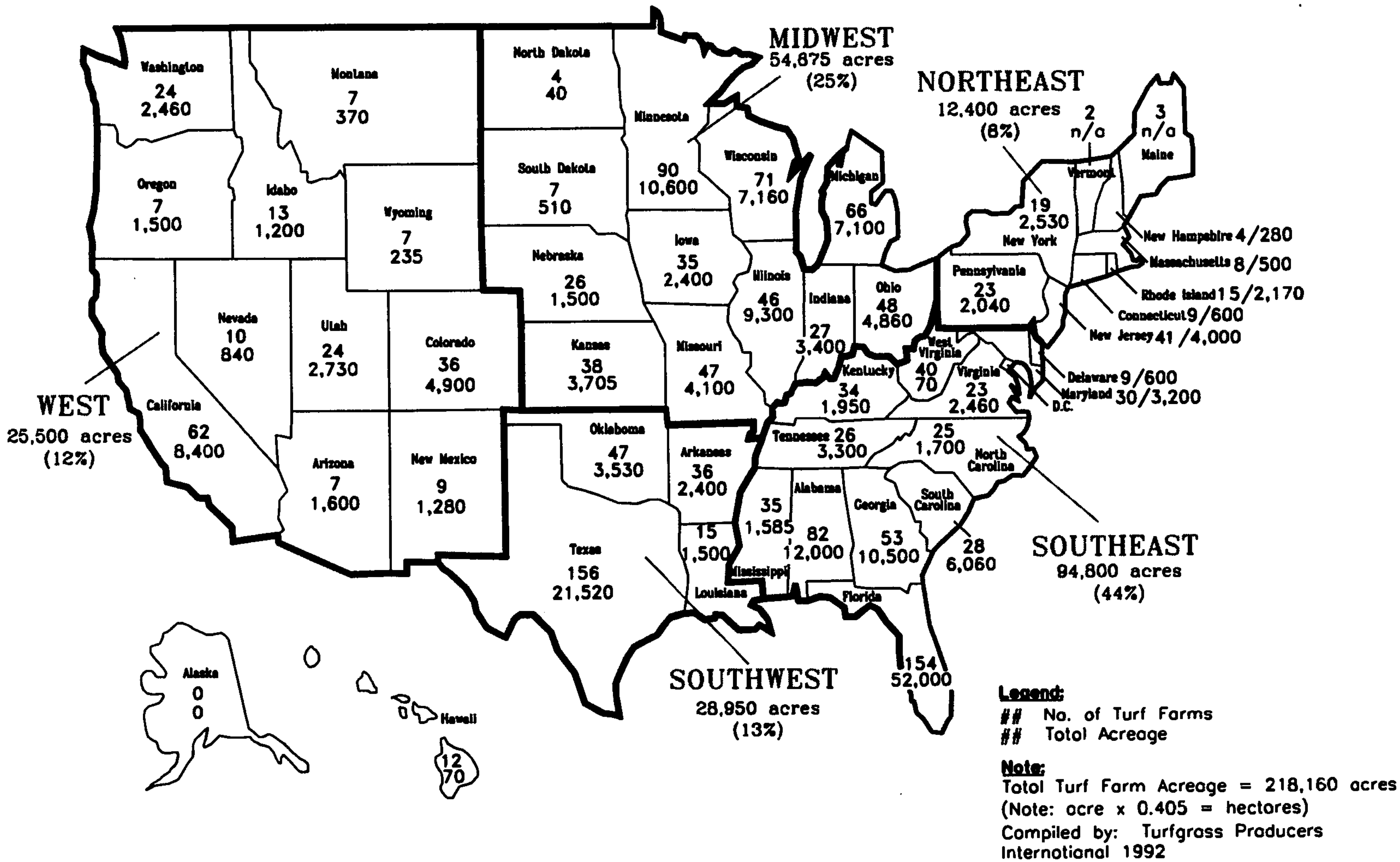


Figure 3.7 U.S. turfgrass and sod production industry: 1992 census
(data represents 80 percent of the total U.S. turf farm acreage)

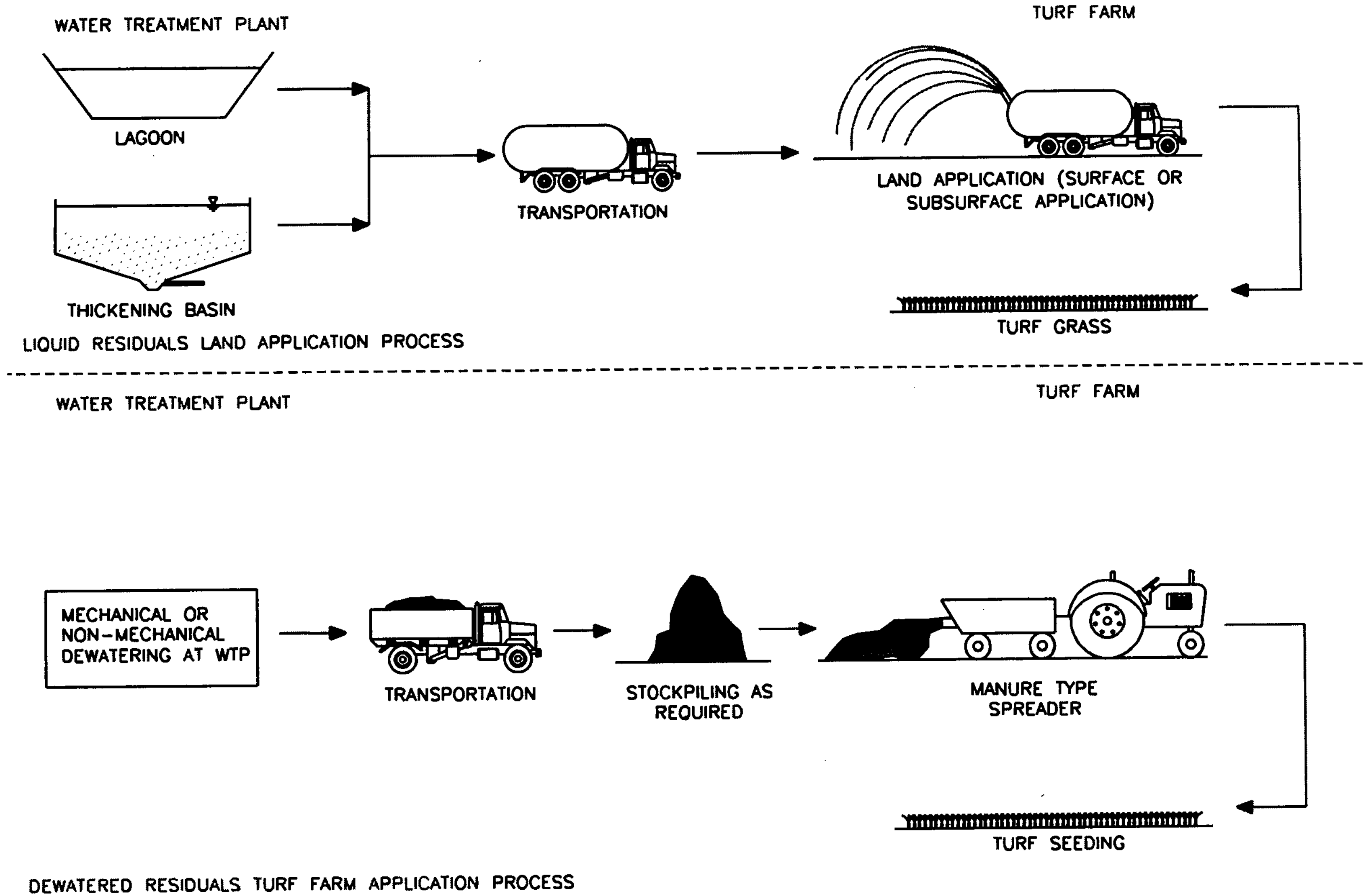


Figure 3.8 Turf farm residuals application process

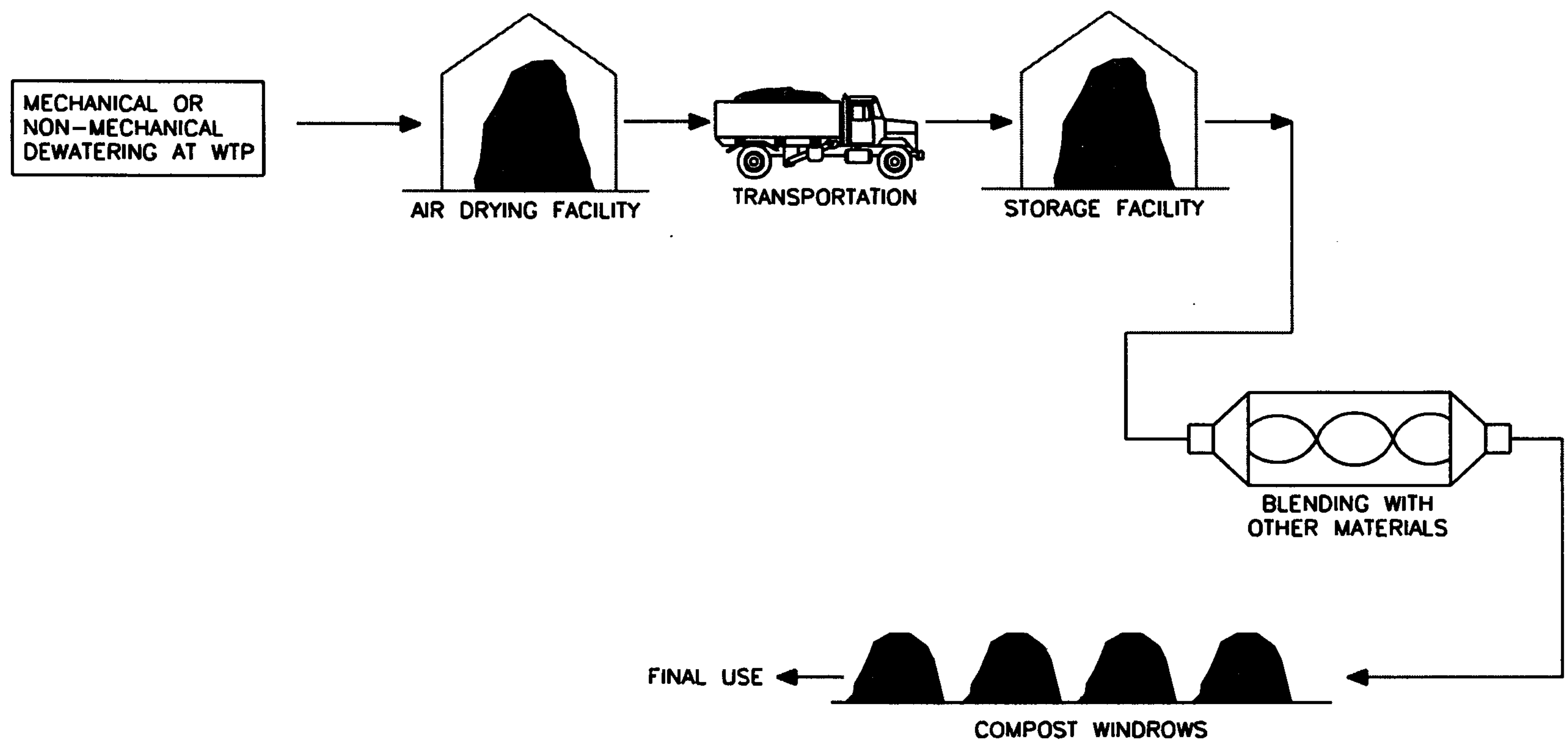


Figure 3.9 Residuals application process for incorporation into compost piles

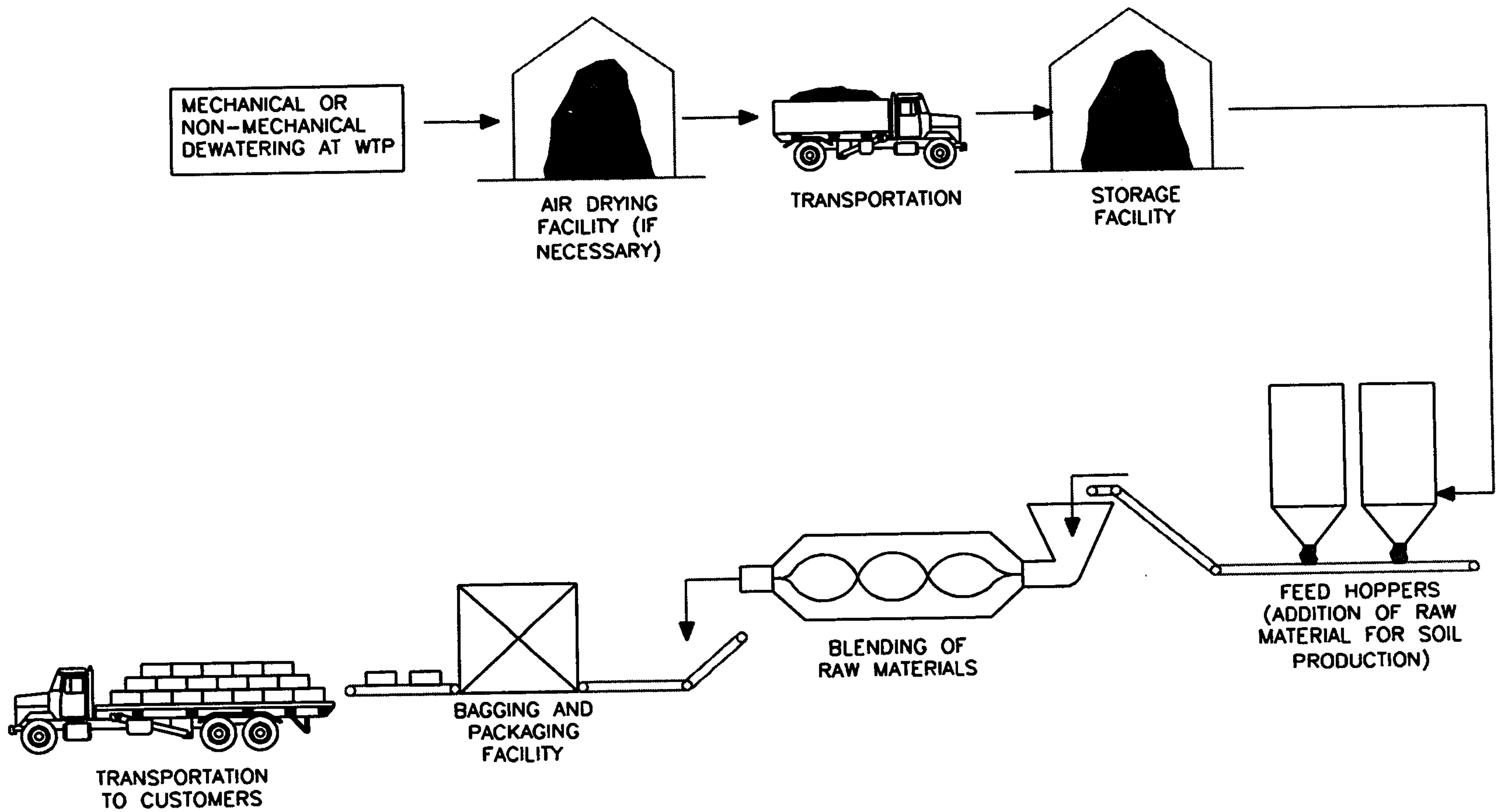


Figure 3.10 Residuals application process for production of commercial top soil and potting soil

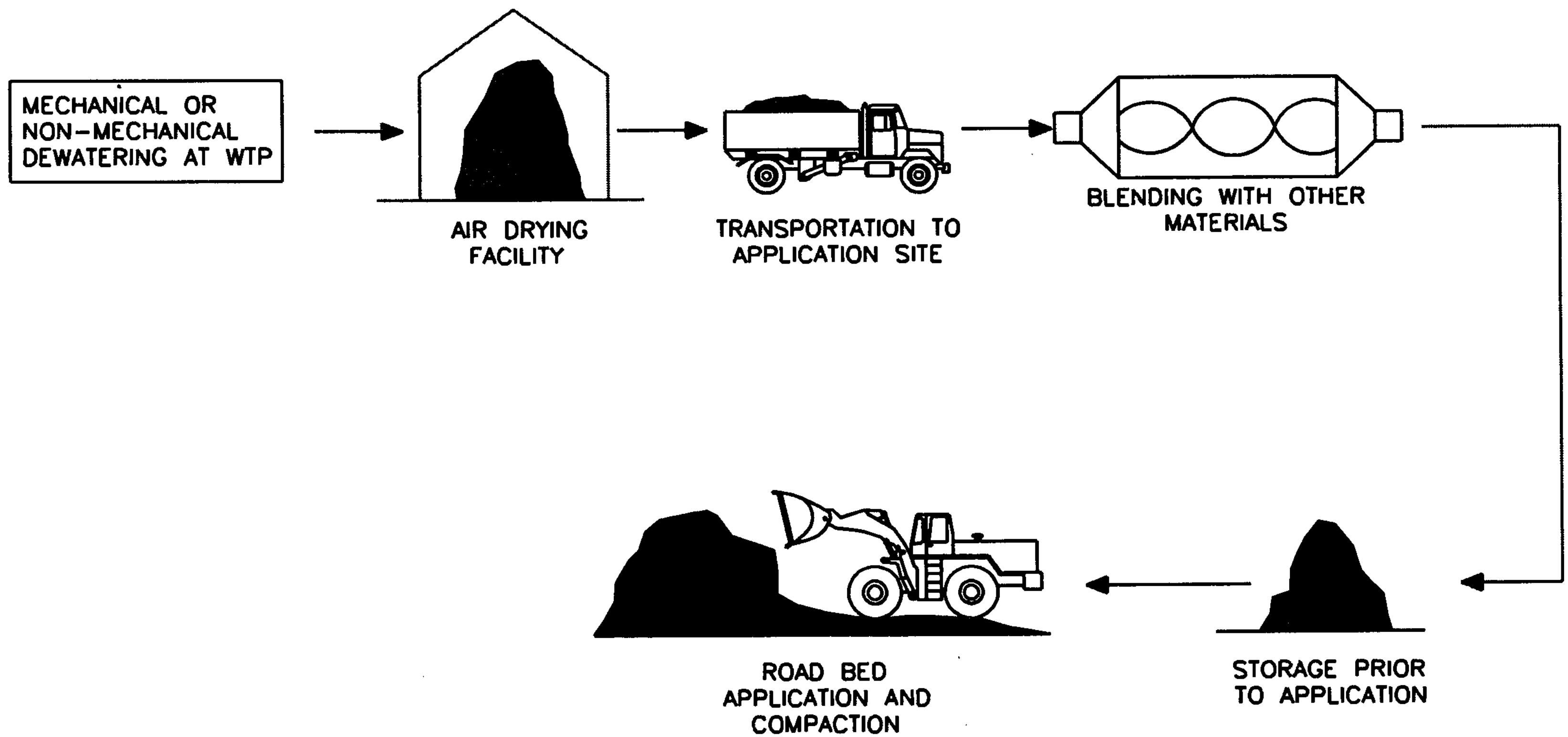


Figure 3.11 Residuals application process for use as a road subgrade material

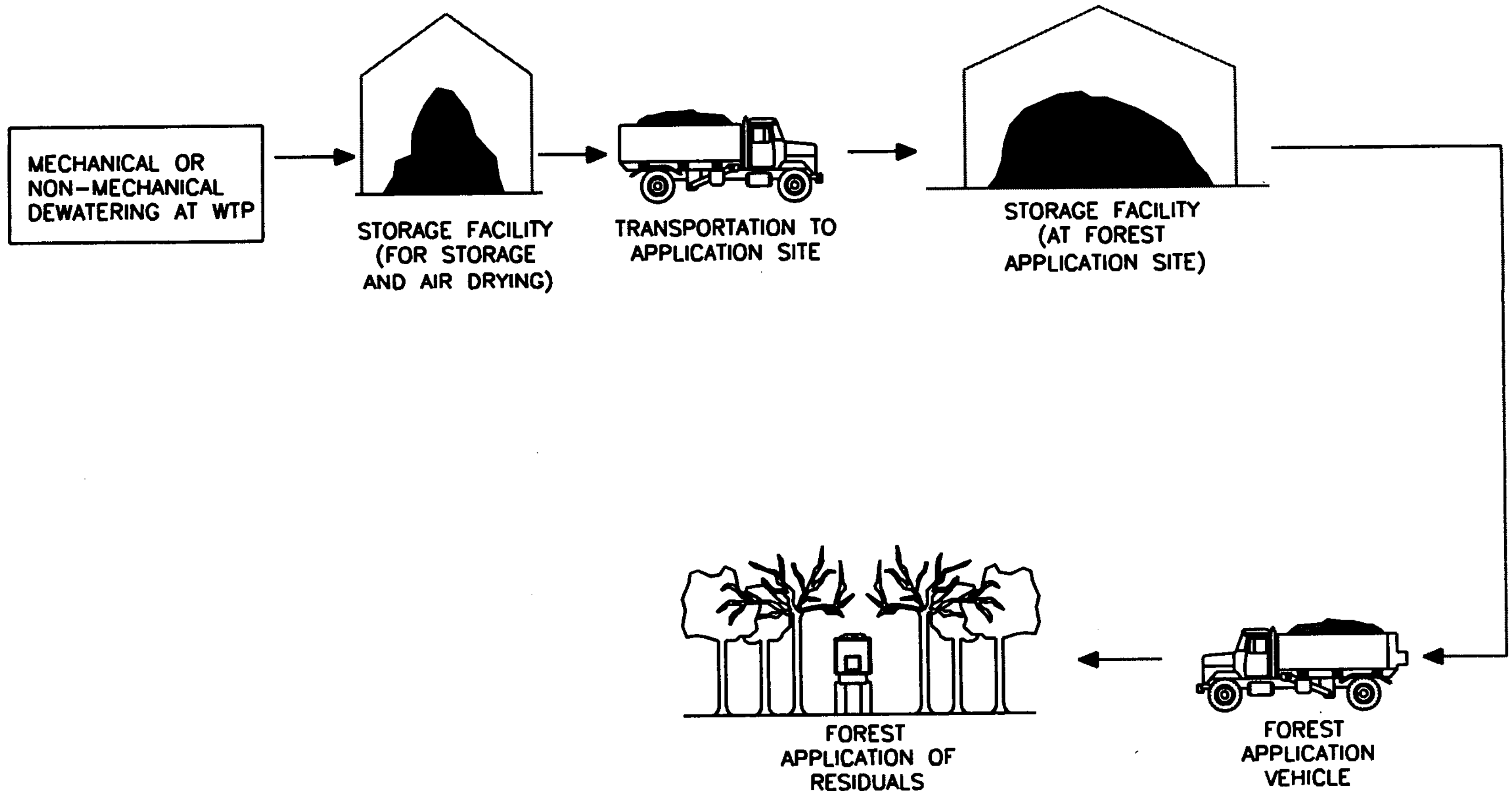


Figure 3.12 Forest land residuals application process

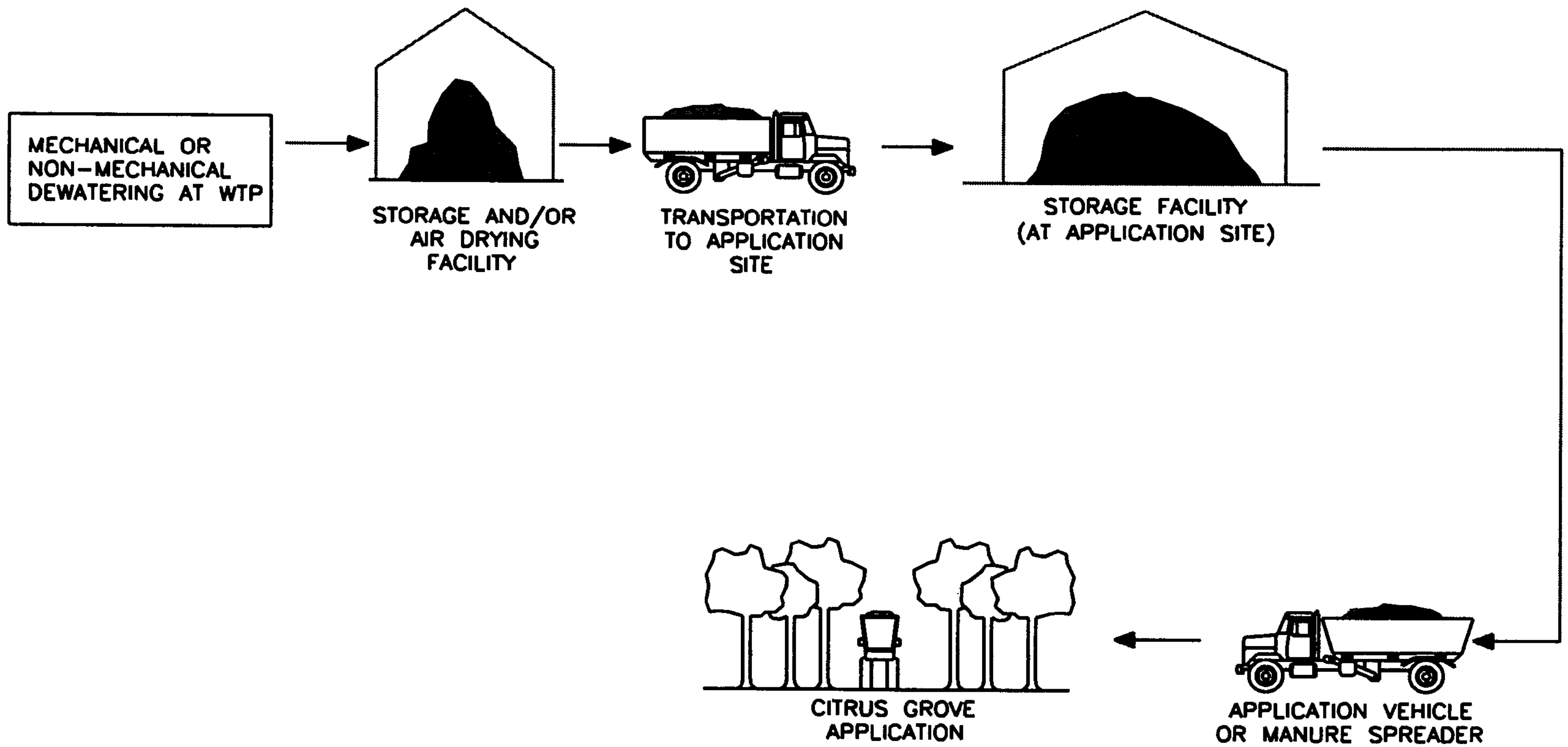


Figure 3.13 Citrus grove residuals application process

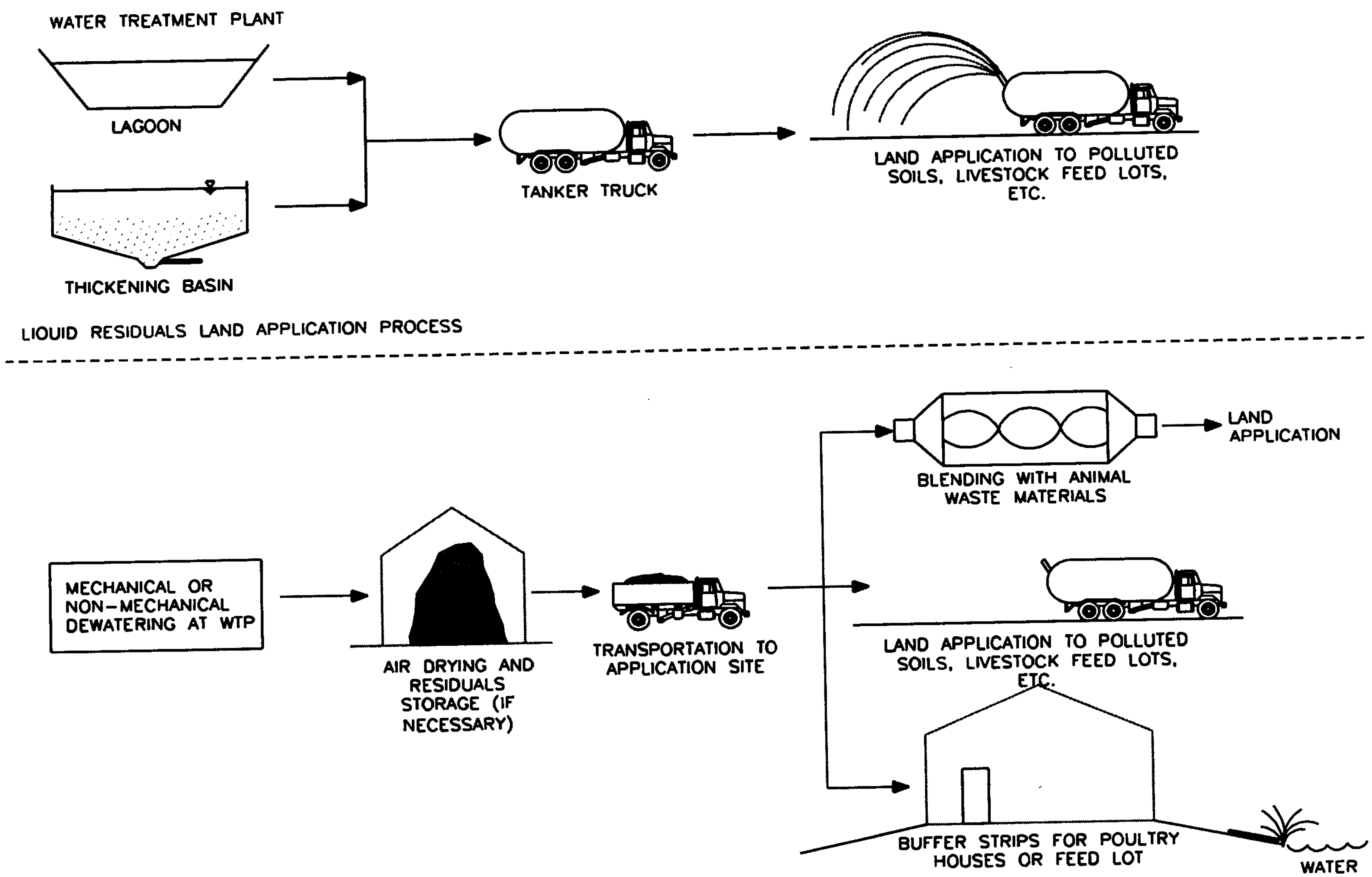


Figure 3.14 Residuals application process for nutrient control

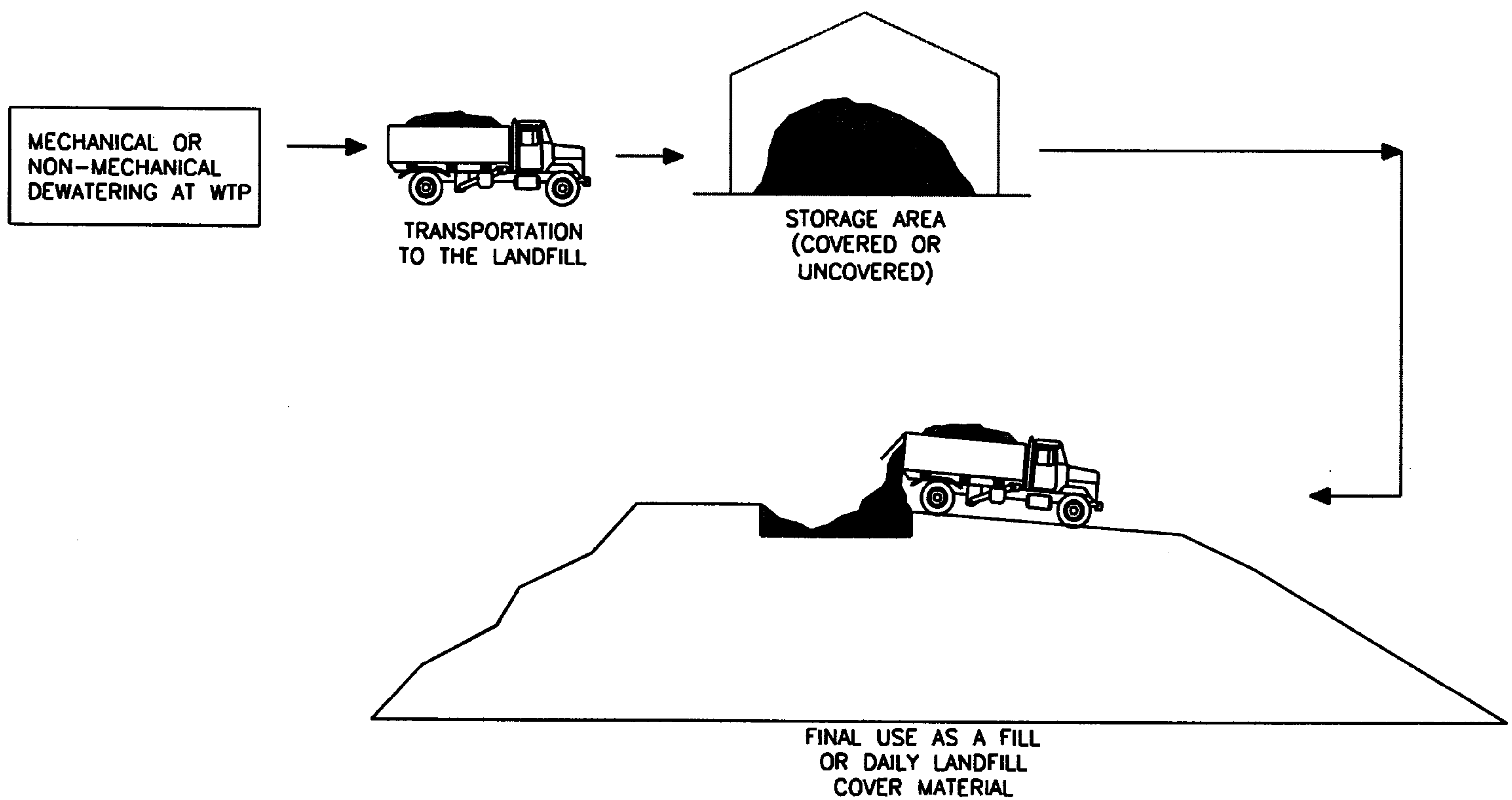


Figure 3.15 Residuals application process for use as a landfill cover material

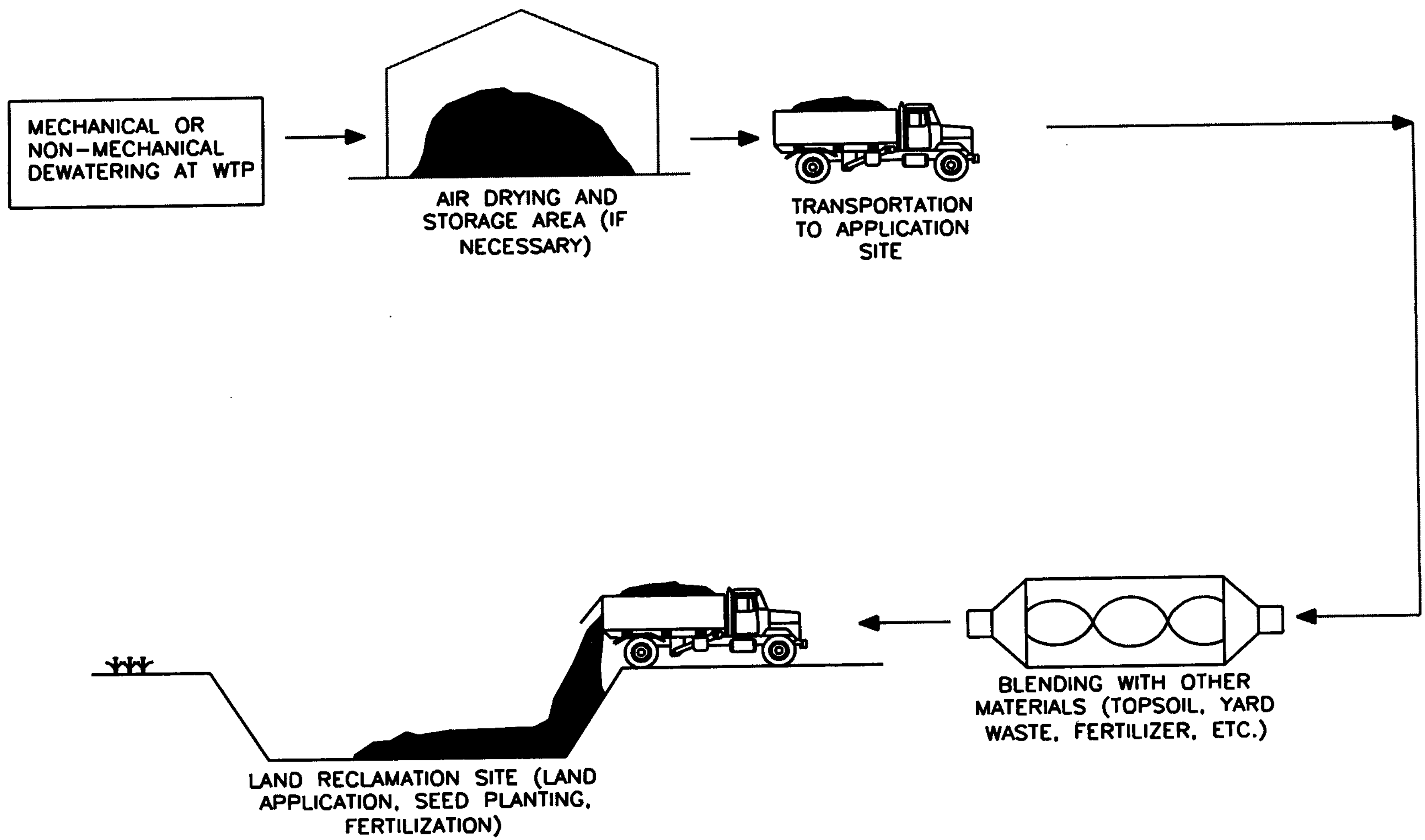


Figure 3.16 Residuals application process for performing land reclamation

CHAPTER 4

ECONOMIC CONSIDERATIONS

INTRODUCTION

Implementation of a beneficial use program requires careful financial considerations by a utility. This is to ensure that the overall beneficial use program is attractive based on total capital and operational costs. A proposed beneficial use program could require a residuals handling process that a utility would not yet have in place. Examples of such residuals handling processes would include:

- Dewatering
- Air drying
- Altering residuals characteristics
- Residuals storage
- Residuals transportation

Each of these processes would have specific capital and operational costs. These costs must be factored into the overall beneficial use plan to determine if it is truly cost effective relative to a base case condition. Furthermore, a utility may prefer to evaluate several beneficial use programs in detail to identify the most cost effective plan.

Since the purpose of this manual is to serve as a residuals marketing guidance document, conceptual capital and operational costs for a number of residuals handling processes were developed. The intent of these cost data were to assist a utility with estimating the potential total cost for a particular beneficial use program. The intent was not to develop firm budgetary costs for a beneficial use program since each water treatment plant would have unique requirements or features that could affect the cost of residuals handling. As a minimum, the cost curves presented in this manual should be incorporated in a larger, site specific, model that a utility would develop in the process of screening and evaluating beneficial use alternatives.

The market investigations conducted for each beneficial use alternative in Chapter 3 provided information concerning the residuals solids concentration that is optimal for each alternative. The residuals solids concentrations suggested for each application was provided to allow a utility to estimate residuals handling costs. Cost curves were developed to provide utilities with capital costs and operation and maintenance (O&M) costs for selected residuals dewatering and handling facilities. Costs were estimated for the following facilities and residuals handling equipment:

- Equalization basins
- Thickeners
- Centrifuge facility
- Belt filter press facility
- Sand drying beds
- Air drying facility/storage pad
- Residuals blending equipment
- Transportation

The curves were calculated based on the total dry weight of residuals generated per day by a water treatment plant. The cost curves include a residuals production range which includes small, medium, and large utilities. A residuals production range of 2,000 to 14,000 dry lb/day (900 to 6,350 dry kg/day) was evaluated. Other assumptions used are listed in a table included for each cost analysis. Construction and O&M costs were based on a national average basis, but it is recognized that these costs could vary geographically based on where a utility is located and adjustment factors may have to be applied. Economic costs do not consider potential revenue that could be generated from final use of residuals.

Other commonly used mechanical dewatering practices include plate and frame presses and diaphragm presses. Cost curves are not included for these systems, however, cost information for residuals management practices could be referenced from "Management of Water Treatment Plant Residuals" (ASCE, AWWA, and USEPA 1996).

RESIDUALS MANAGEMENT FACILITIES

A process schematic which includes the residuals dewatering practices evaluated is presented in Figure 4.1. The figure shows the basic methods used for thickening and dewatering residuals prior to disposal or reuse. As discussed previously, residuals can be utilized by some beneficial use methods in both a liquid or cake solids form. For applications that use liquid residuals, the dewatering process would be complete after gravity settling and thickening. Equalization basins and gravity thickeners would provide solids concentrations of up to 4 percent. Reuse applications that accept only residuals solids concentrations greater than 4 percent would require mechanical dewatering equipment, sand drying beds, or dewatering lagoons. Mechanical dewatering would have the ability to provide residuals solids concentrations of greater than 20 percent. Sand drying beds could achieve solids concentrations of greater than 25 percent. Separate air drying of the residuals following mechanical or nonmechanical dewatering can further increase solids concentrations to 60 percent, depending on the climate and drying time allowed.

Transportation of residuals is another key component of any beneficial use plan. Hauling and residuals handling costs significantly impact the project economics. Dewatering residuals prior to transportation significantly reduces cost. Applications that accept liquid residuals would need to be within very close proximity to the water treatment plant to be economically feasible.

FACILITY COST CURVES

Equalization Basin

Equalization basins are used to collect sidestreams from the different water treatment processes and blend the treatment wastes into a uniform solution. Discharges from sedimentation basins and filter backwashing have different solids concentrations, chemical characteristics, and volumes. Blending and mixing the different waste streams together provides a common solution that can be evenly distributed to a thickener without upsetting the thickening basin process. Equalization basins are generally circular basins with mixing capability.

Equalization basins are sized based on the total volume of wastewater generated by the water treatment plant. Assumptions used for sizing and estimating cost for construction of a typical equalization basin are listed in Table 4.1. Capital cost curves are shown in Figure 4.2.

Table 4.1

Equalization basin sizing assumptions

Item	Parameter
Residuals production	2,000 to 14,000 dry lb/day (900 to 6,350 dry kg/day)
Effluent solids concentration	0.5 percent
Sidewall depth	12 ft (3.65 m)
Number of mixers	3

Residuals Thickeners

Initial solid separation is accomplished using gravity thickening. The goal of thickening is to remove as much water as possible from the liquid residuals prior to mechanical dewatering. Thickening basins can significantly decrease the residuals volume. Influent solids concentration of 0.5 percent are typically thickened to a concentration of up to 4 percent for coagulant residuals. Thickeners are sized based on a design loading rate, operating time, and total volume of residuals to be treated. The assumptions used for calculating basin sizes are listed in Table 4.2. The capital cost curve for construction of a gravity thickener are presented in Figure 4.3.

Table 4.2

Gravity thickening sizing assumptions

Item	Parameter
Residuals production	2,000 to 14,000 dry lb/day (900 to 6,350 dry kg/day)
Design loading rate	0.15 lb/hr/ft^2 (0.73 kg/hr/m^2)
Hours of operation	16 hr/d
Sidewall depth	12 ft (3.65 m)
Bottom slope	2¾ in./ft (23 cm/m)
Influent solids concentration	0.5 percent

Centrifuge Dewatering

Solid bowl centrifuges are typically used for dewatering residuals. Centrifuges use centrifugal force to separate suspended solids from water. The centrifuge bowl rotates at speeds between 1,000 to 3,000 rpm. The dewatered residual is gravity fed to a dump truck located below centrifuge unit and the water or centrate is usually recycled to the water treatment plant. Centrifuge dewatering usually requires use of polymers. Polymers are injected into the residuals stream prior to entering the centrifuge. Coagulant residuals are commonly dewatered to a solids concentration of up to 25 percent, while lime residuals can be dewatered to as high as 50 percent.

Centrifuge dewatering facilities include building space for housing the centrifuges, a polymer feed system, conveyor, and instrumentation for process control. At least one centrifuge should be included as a standby unit.

Standard centrifuge equipment is manufactured to handle maximum loading rates of 50, 100, 150, and 250 gpm (0.19, 0.39, 0.57, and 0.95 m^3/min). Centrifuge sizes were calculated using the assumptions listed in Table 4.3.

Table 4.3

Centrifuge sizing assumptions

Item	Parameter
Residuals production	2,000 to 14,000 dry lb/day (900 to 6,350 dry kg/day)
Feed solids concentration	3 percent
Polymer dose	6 to 8 lb/ton (3 to 4 kg/metric ton)
Number of standby units	1
Operation schedule	5 d/wk at 6 hr/d

Capital cost and O&M cost curves were calculated based on the centrifuge equipment and support facilities necessary for handling the residuals production range listed in Table 4.3. The capital and O&M cost curves are shown in Figures 4.4 and 4.5, respectively.

Belt Filter Press Dewatering

Belt filter press dewatering equipment uses compressive force and shear to squeeze water out of residuals. Polymer conditioned residuals are pressed between two filter belts through three zones—1) gravity drainage, 2) low pressure zone, 3) high pressure zone. The process produces a cake solids concentration of up to 20 percent solids. A polymer feed system is required to condition residuals prior to pressing. Belt filter presses with belt widths of 1 m and 2 m are standard for processing residuals.

Belt filter press dewatering requires support facilities for housing the equipment, feeding polymer, conveying residuals, and process instrumentation. At least one filter press should be included in the design as a standby unit. Belt filter press equipment sizes were calculated using the assumptions listed in Table 4.4.

Table 4.4

Belt filter press sizing assumptions

Item	Parameter
Residuals production	2,000 to 14,000 dry lb/day (900 to 6,350 dry kg/day)
Loading rate (per 1-m of belt width)	400 to 600 lb/hr (180 to 270 kg/hr)
Feed solids concentration	3 percent
Polymer dose	6 to 8 lb/ton (3 to 4 kg/metric ton)
Number of standby units	1
Operation schedule	5 d/wk at 6 hr/d

Capital and O&M cost curves were developed based on unit sizes of belt filter presses, along with the other ancillary facilities and equipment required. O&M costs include electric power, labor, polymers, and maintenance costs. The capital and O&M cost curves are shown in Figures 4.6 and 4.7, respectively.

Sand Drying Bed Dewatering

Sand drying beds effectively dewater residuals using drainage and evaporation. Drying beds are constructed using a shallow rectangular concrete basin with a PVC underdrain piping system and a layer of sand for solid-liquid separation. The underdrain system is used to collect the filtrate from the residuals, while the remainder of dewatering is accomplished by decanting and/or air drying. Drying times required are dependent on the type of residuals and the climate. After drying is completed, dewatered residuals are cleaned off the drying beds using a front-end loader. Drying beds also require the use of polymers to condition residuals prior to bed application. Polymers allow greater solid/liquid separation which allows the free water from the residuals to drain and decant more freely, thereby decreasing the total drying time.

Drying bed sizes required for handling a wide range of residuals production volumes were calculated based on the assumptions listed in Table 4.5.

Table 4.5

Sand drying bed design assumptions

Item	Parameter
Residuals production	2,000 to 14,000 dry lb/day (900 to 6,350 dry kg/day)
Feed solids concentration	3 percent
Polymer dose	8 to 15 lb/ton (4.0 to 7.5 kg/metric ton)
Bed yield	12.5 lb/ft^2/yr (61 kg/m^2/yr)

Capital cost for each sand drying bed facility included a residuals pump station to feed residuals to the beds, a polymer feed system, instrumentation, and a front-end loader. The capital cost curve is shown in Figure 4.8. O&M costs include labor, front-end loader maintenance, polymer costs, and sand replacement. The O&M cost curve is shown in Figure 4.9.

Air Drying Facilities

Supplemental air drying is required to achieve residuals solids concentrations greater than 30 percent. Dewatered residuals are stockpiled in windrows on a covered concrete storage pad to maximum surface area for drying. Windrows are mounds of residuals that are shaped liked a trapezoid with a desired base width, height, and are typically a 100-ft (30.5-m) long. The total drying pad area is dependent on the volume of residuals produced and the drying time allowed. Windrows are periodically turned over to speed up drying time. Air drying facilities also include a drainage collection system, push walls, a steel roof enclosure, and a front-end loader for residuals handling.

Air drying facility sizes required for handling a wide range of residuals production were calculated based on the design assumptions listed in Table 4.6.

Table 4.6

Air drying facilities design assumptions

Item	Parameter
Residuals production	2,000 to 14,000 dry lb/day (900 to 6,350 dry kg/day)
Number of storage days	120
Windrow size (h x b)	6 ft x 10 ft (trapezoidal) (1.8 m x 3 m)
Windrow separation distance	8 ft (2.4 m)
Initial solids concentration	20 percent

The capital cost curve for constructing an air drying facility is shown in Figure 4.10. The O&M costs include primarily building and front-end loader maintenance and labor costs.

Residuals Blending

Residuals blending equipment is required for mixing residuals with other soil-like materials for certain beneficial use applications. The mechanical blending equipment often used is a pugmill. Pugmills can provide rapid blending of two or more materials using desired blending ratios. Pugmill equipment includes storage hoppers, conveyors, and a screw auger for mixing. The blending ratios of residuals used is typically between 10 and 50 percent. Other materials blended with residuals could include biosolids, lime, top soil, fertilizer, yard wastes, finished compost, etc. Typical pugmill blending rates range from 3,000 to 11,000 ft^3/hr (85 to 311 m^3/hr). The capital cost curve for pugmill blending equipment is shown in Figure 4.11.

Removal and Transportation

A significant economic consideration that must be considered for all of the different beneficial use applications is transportation of residuals from the water treatment plant to the beneficial use location.

Water treatment residuals could be transported either as a liquid or cake solid. Liquid residuals applications require a greater total volume of residuals to be transported which significantly increases costs. A typical "turnkey" cost for liquid removal, transportation, and application for up to 6 percent solids residuals is \$0.035/gal (\$9.25/m^3). Liquid residuals removal, hauling, and disposal cost curve for a residuals production range of 2,000 to 14,000 dry lb/day (900 to 6,350 dry kg/day) is included as Figure 4.12. The cost curve is developed for applications with an average hauling distance of 30 miles (48 km) from the water treatment plant.

Cake solids applications have a significantly lower transported volume than for liquid applications. Residuals are dewatered to at least 15 percent solids prior to removal and hauling. The "turnkey" cost for a 25 percent solids residuals is about \$17.50/wet ton (\$19.27/metric ton). This cost includes removal from water treatment plant, transportation, and end use application. The cost curve for transporting dewatered residuals is found in Figure 4.13. These costs also assume an average hauling distance of 30 miles from the water treatment plant for a residuals production volume of 2,000 to 14,000 dry lb/day (900 to 6,350 dry kg/day).

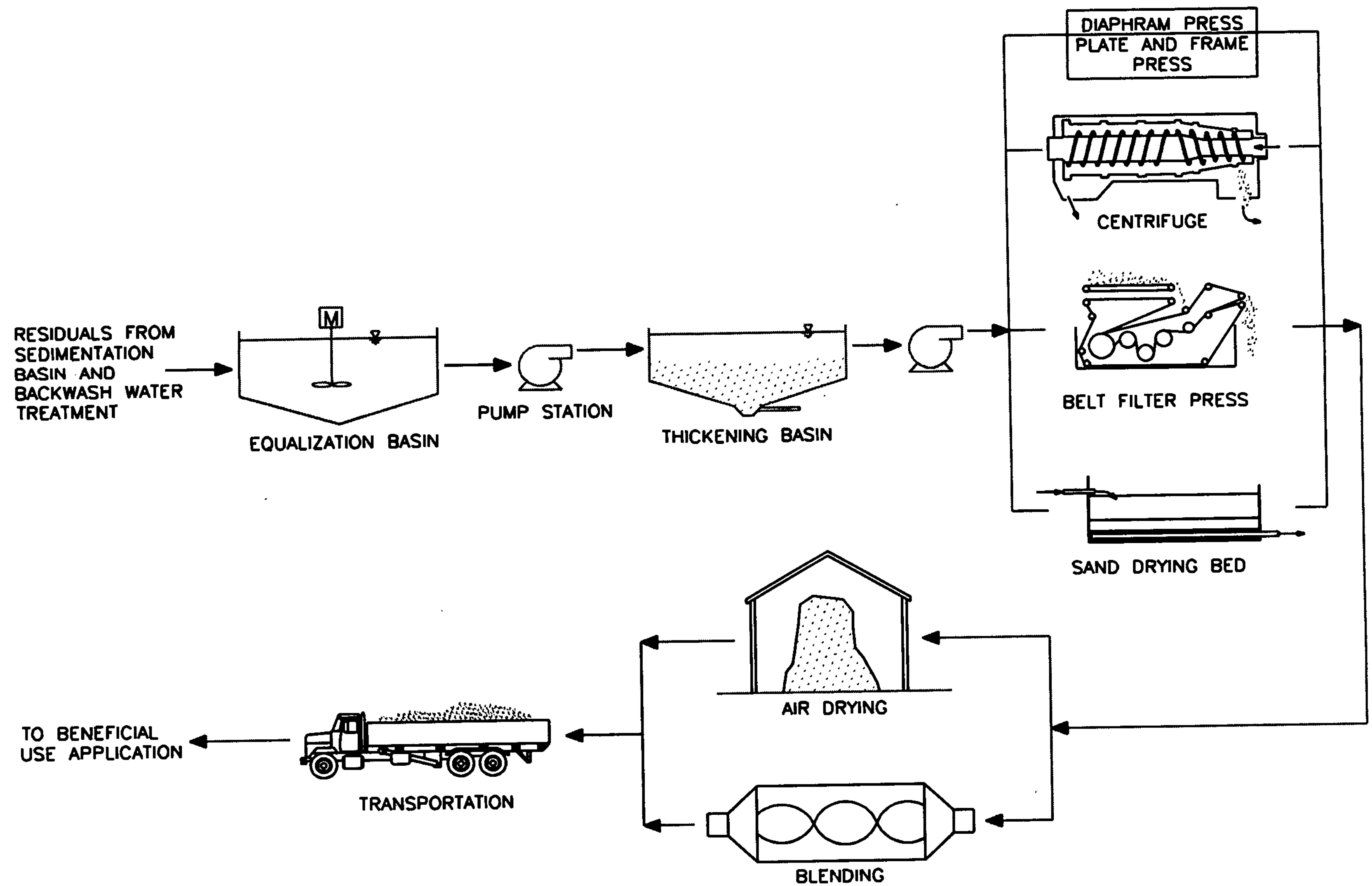


Figure 4.1 Residuals management facilities and equipment

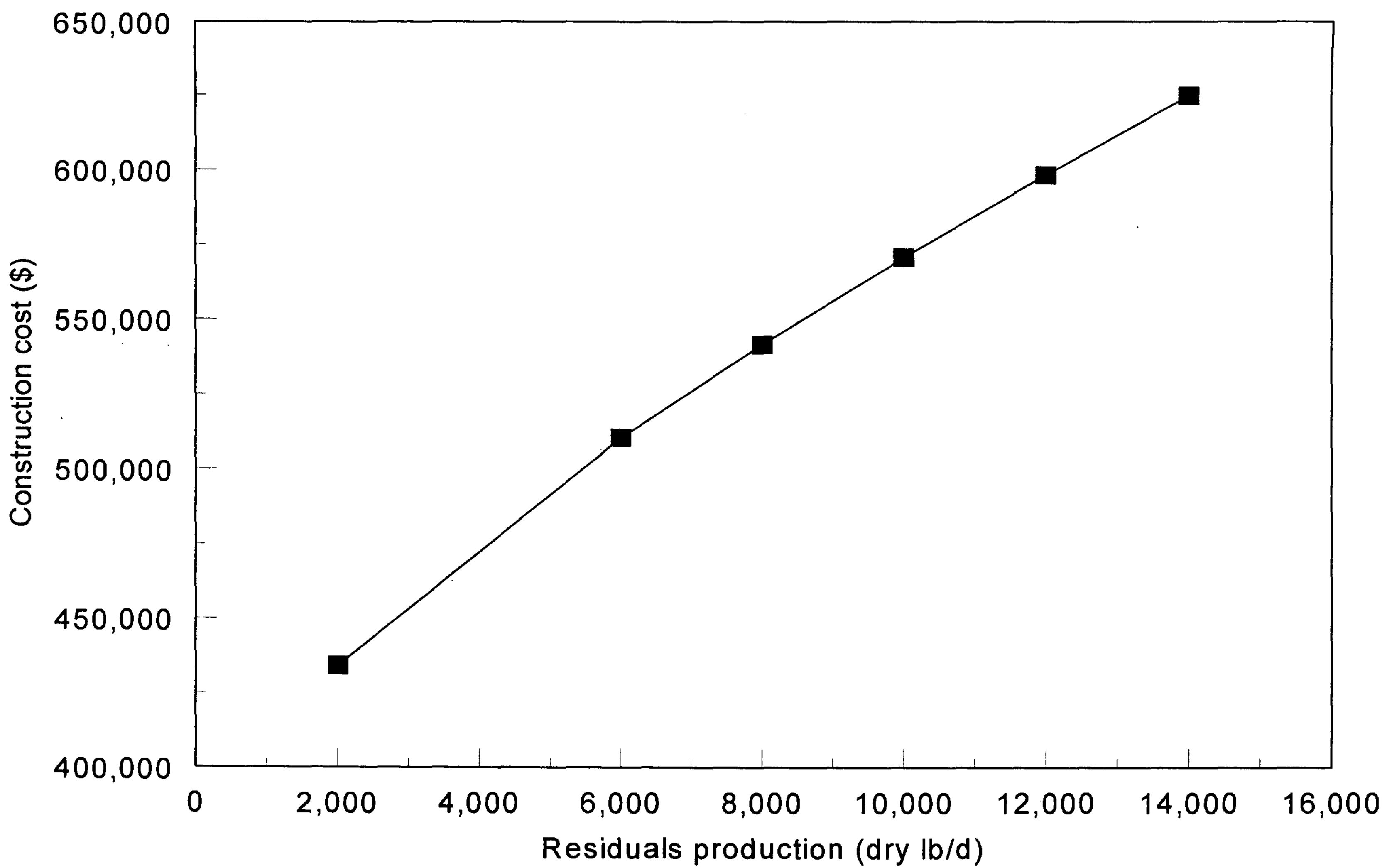


Figure 4.2 Construction cost for equalization basins

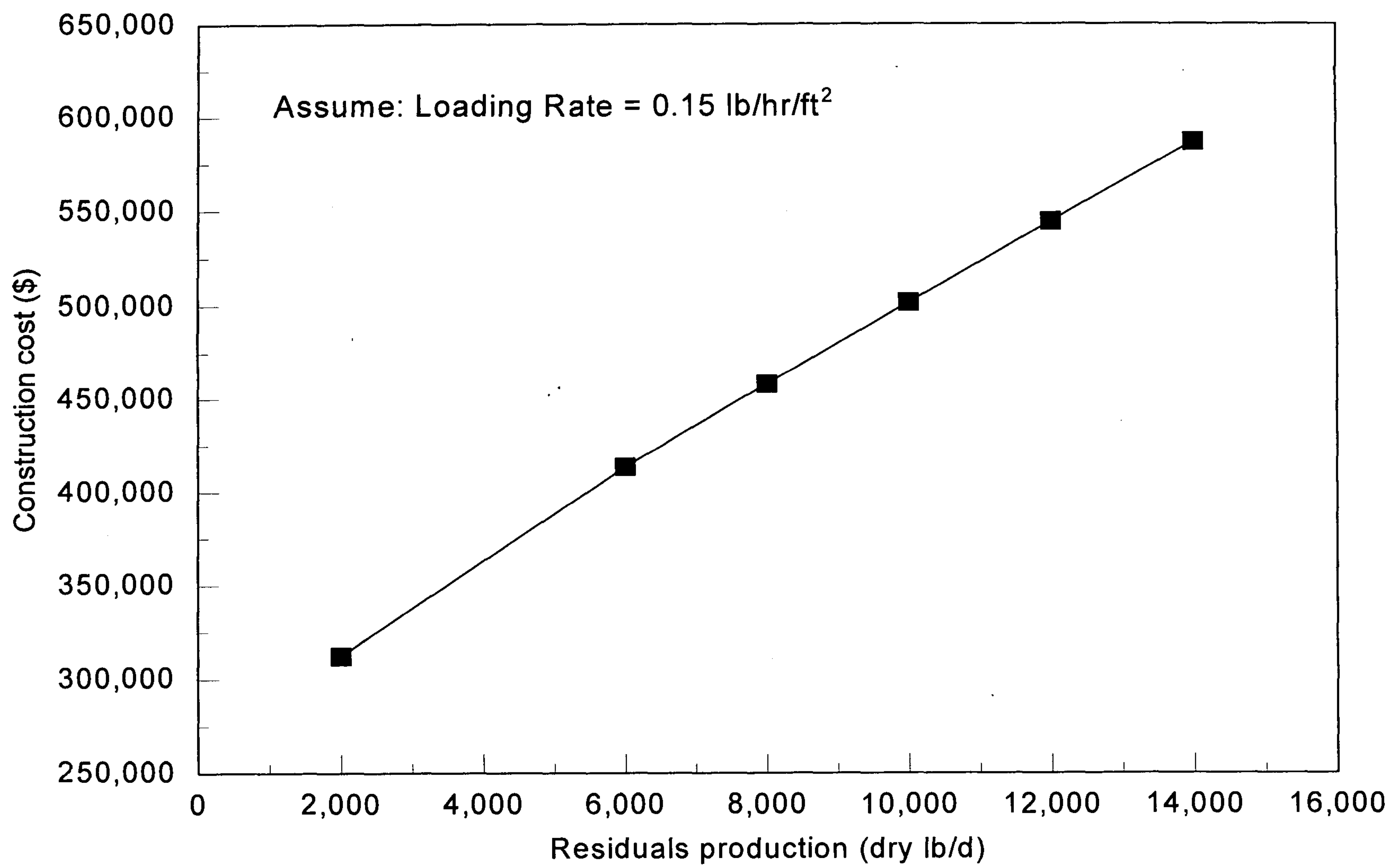


Figure 4.3 Construction cost for thickening basins

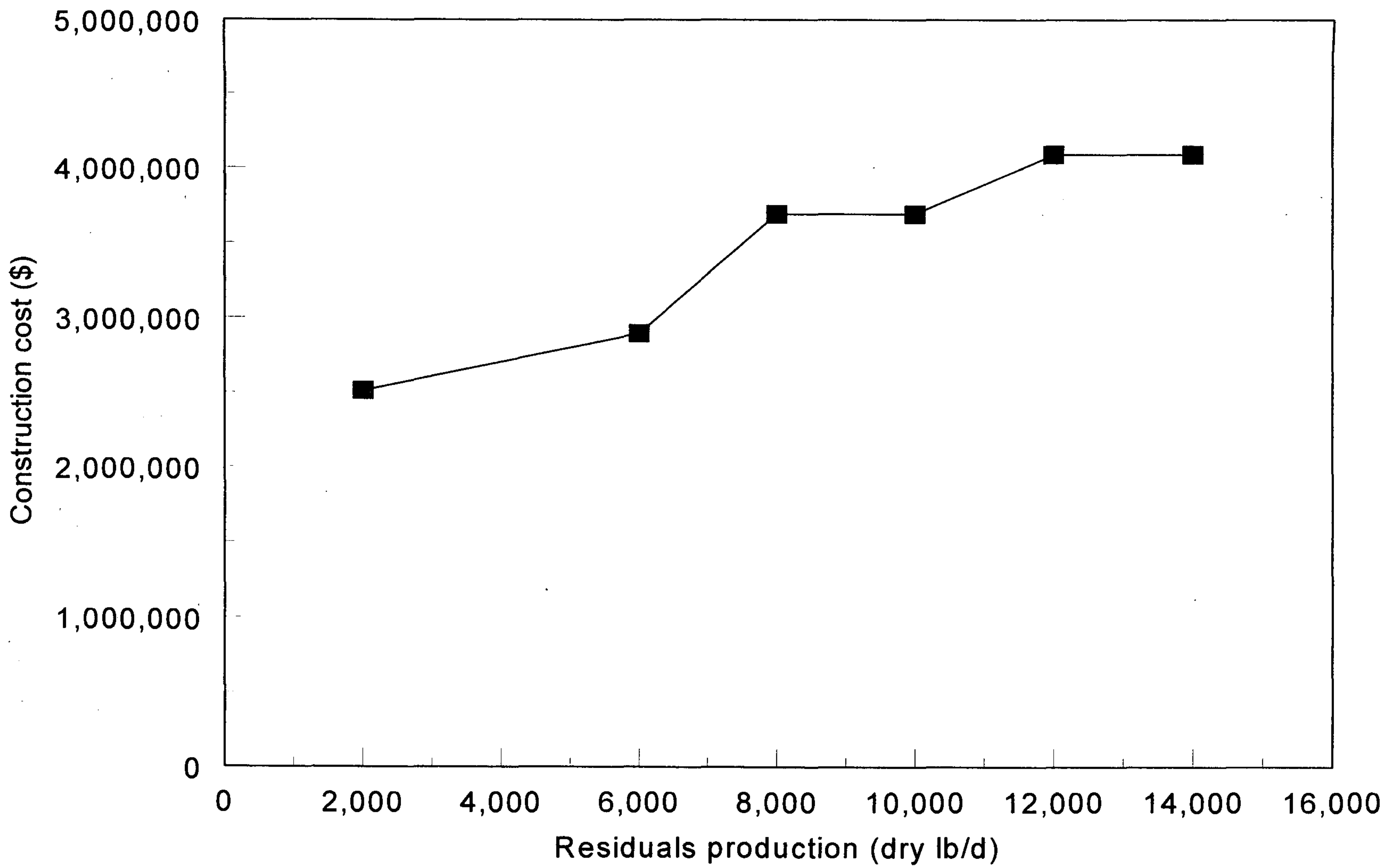


Figure 4.4 Construction cost for centrifuge facilities

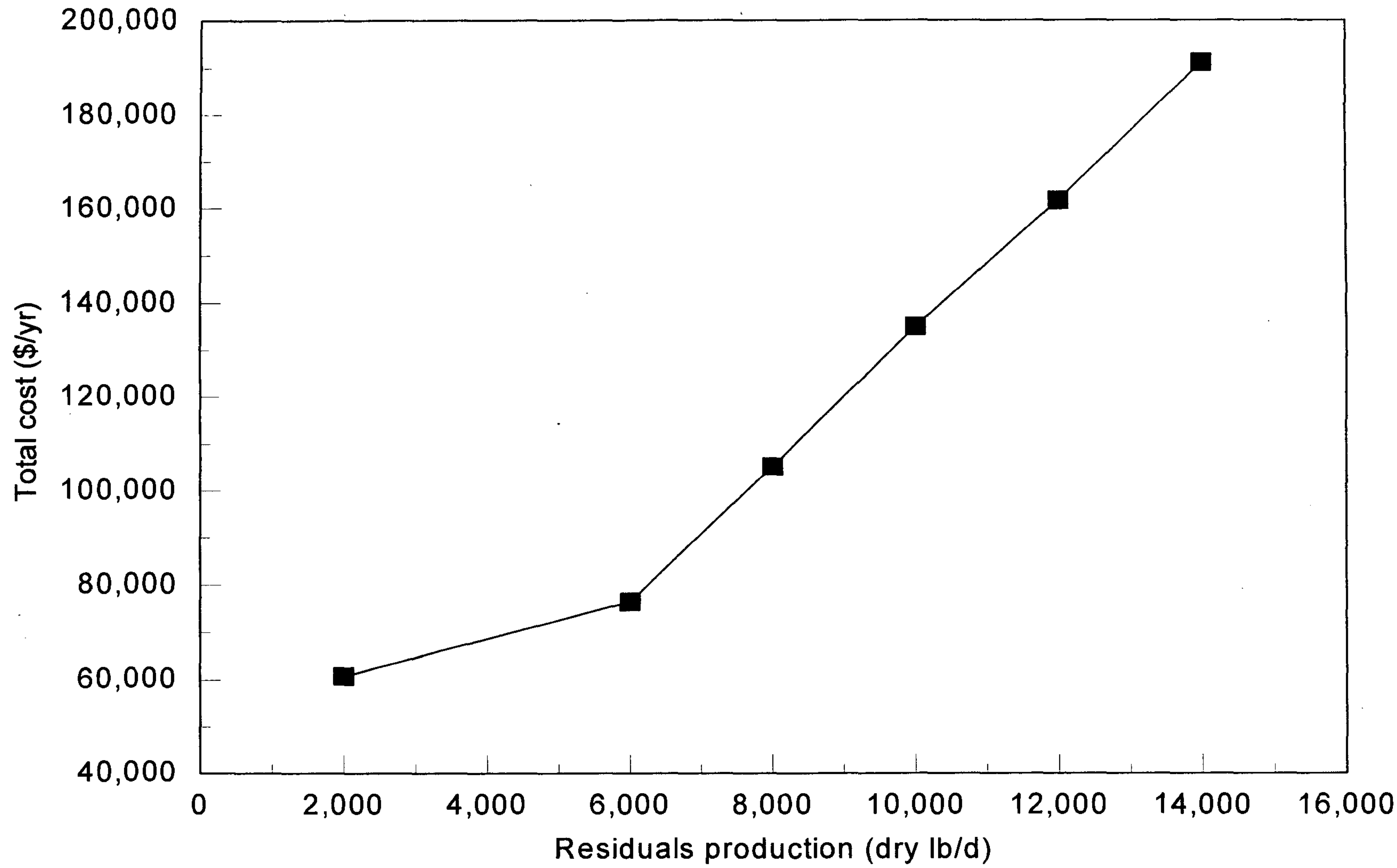


Figure 4.5 Operation and maintenance cost for centrifuge facilities

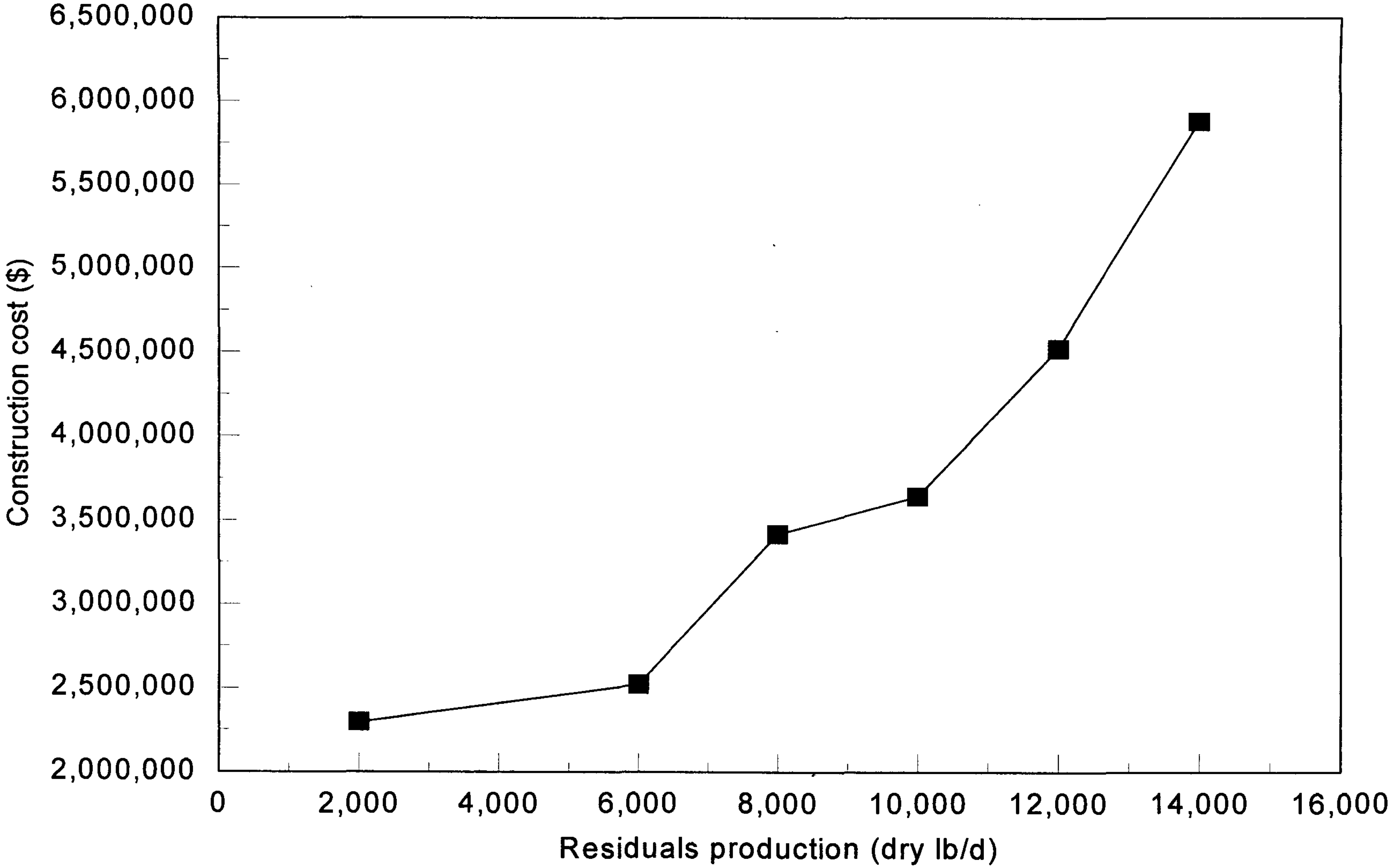


Figure 4.6 Construction cost for belt filter press facilities

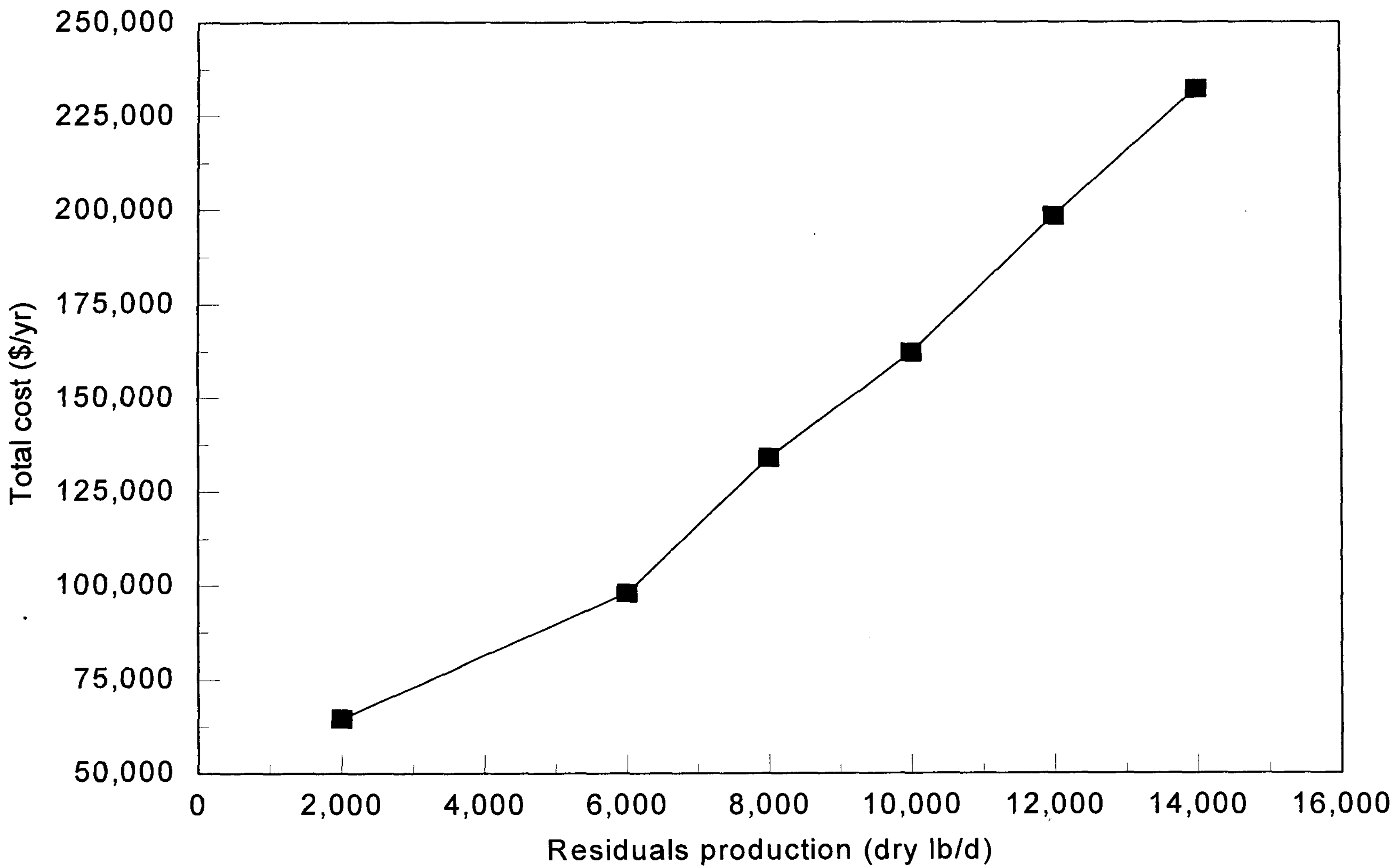


Figure 4.7 Operation and maintenance cost for belt filter press facilities

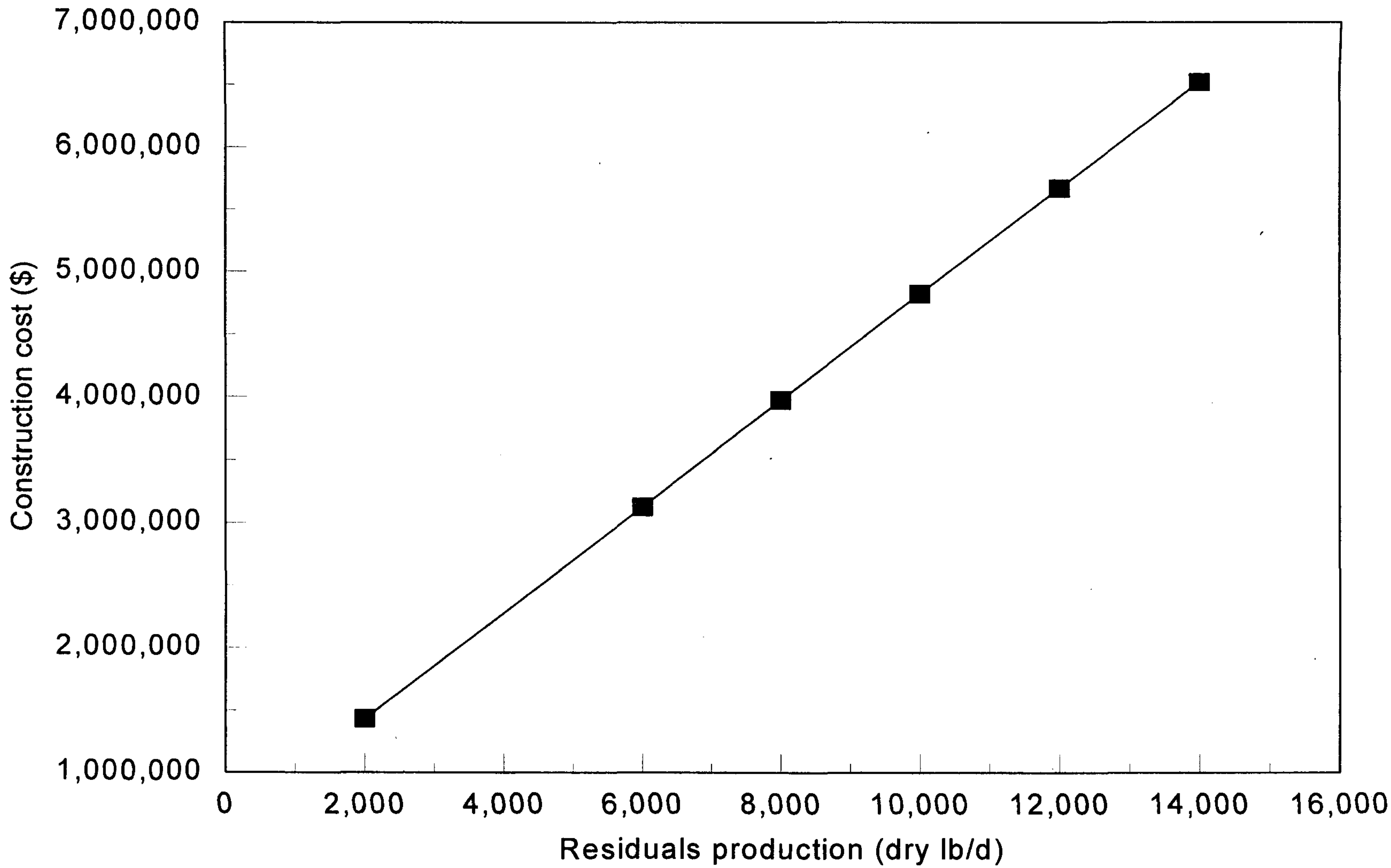


Figure 4.8 Construction cost for sand drying bed facilities

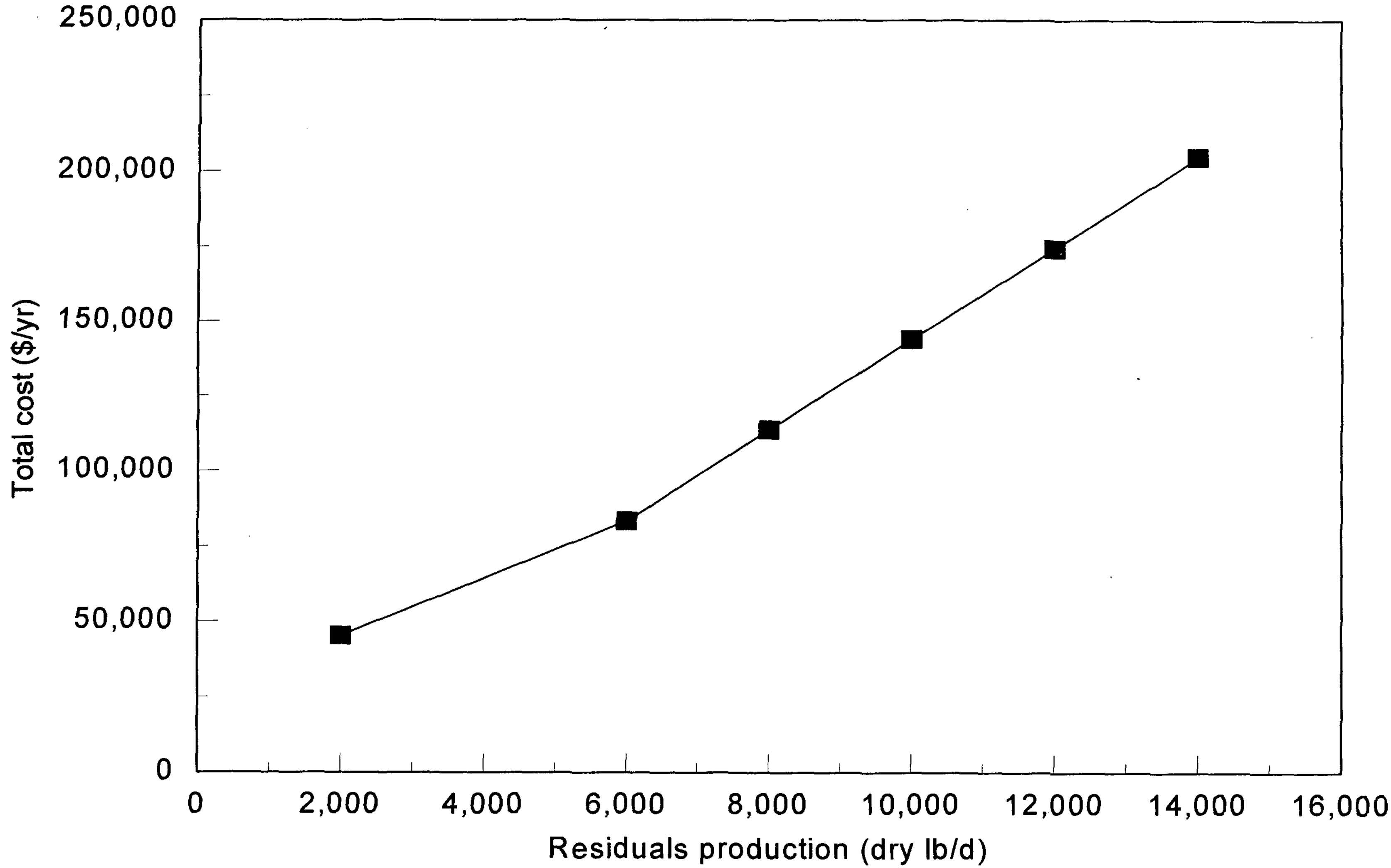


Figure 4.9 Operation and maintenance cost for sand drying bed facilities

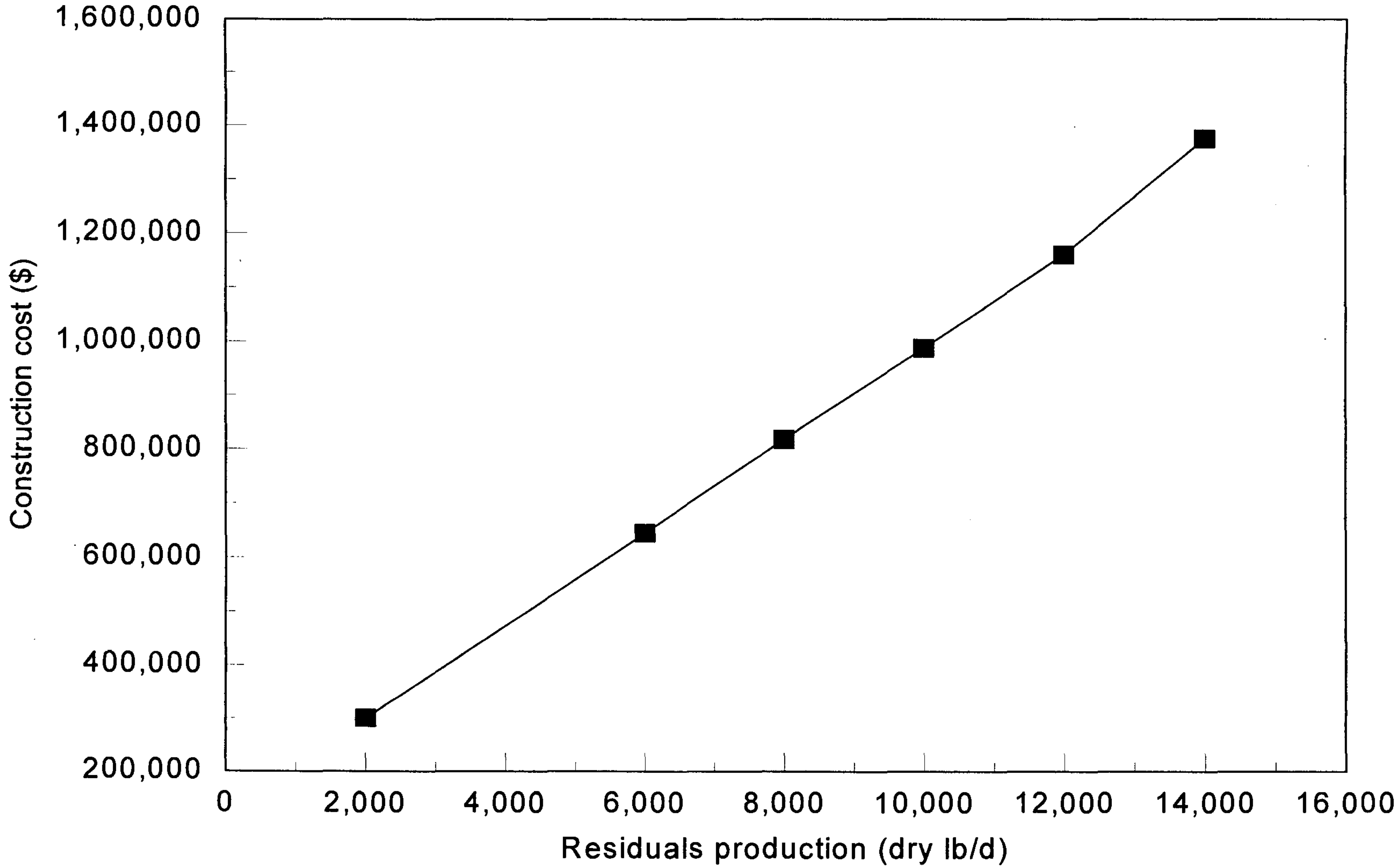


Figure 4.10 Construction cost for residuals air drying facilities

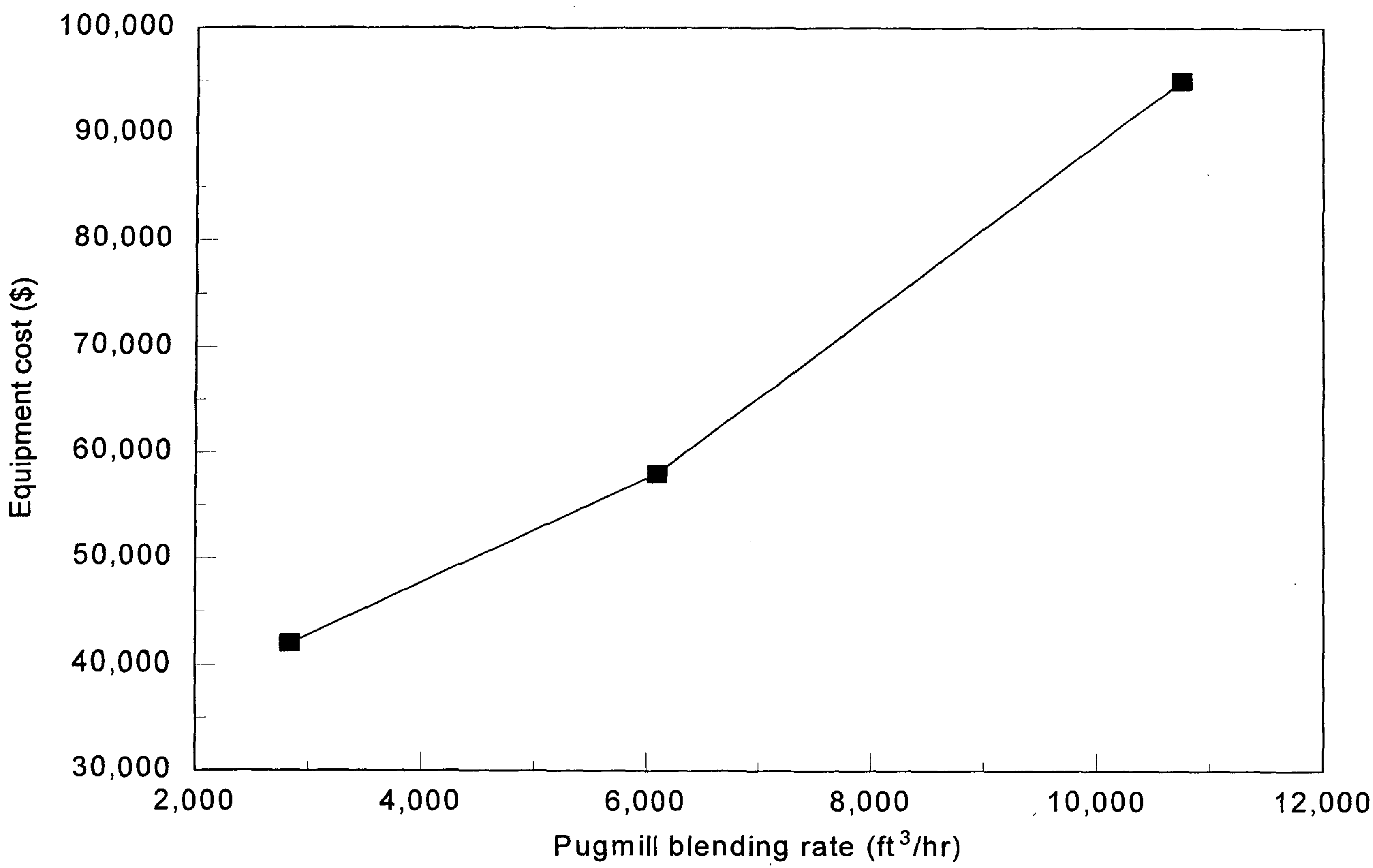
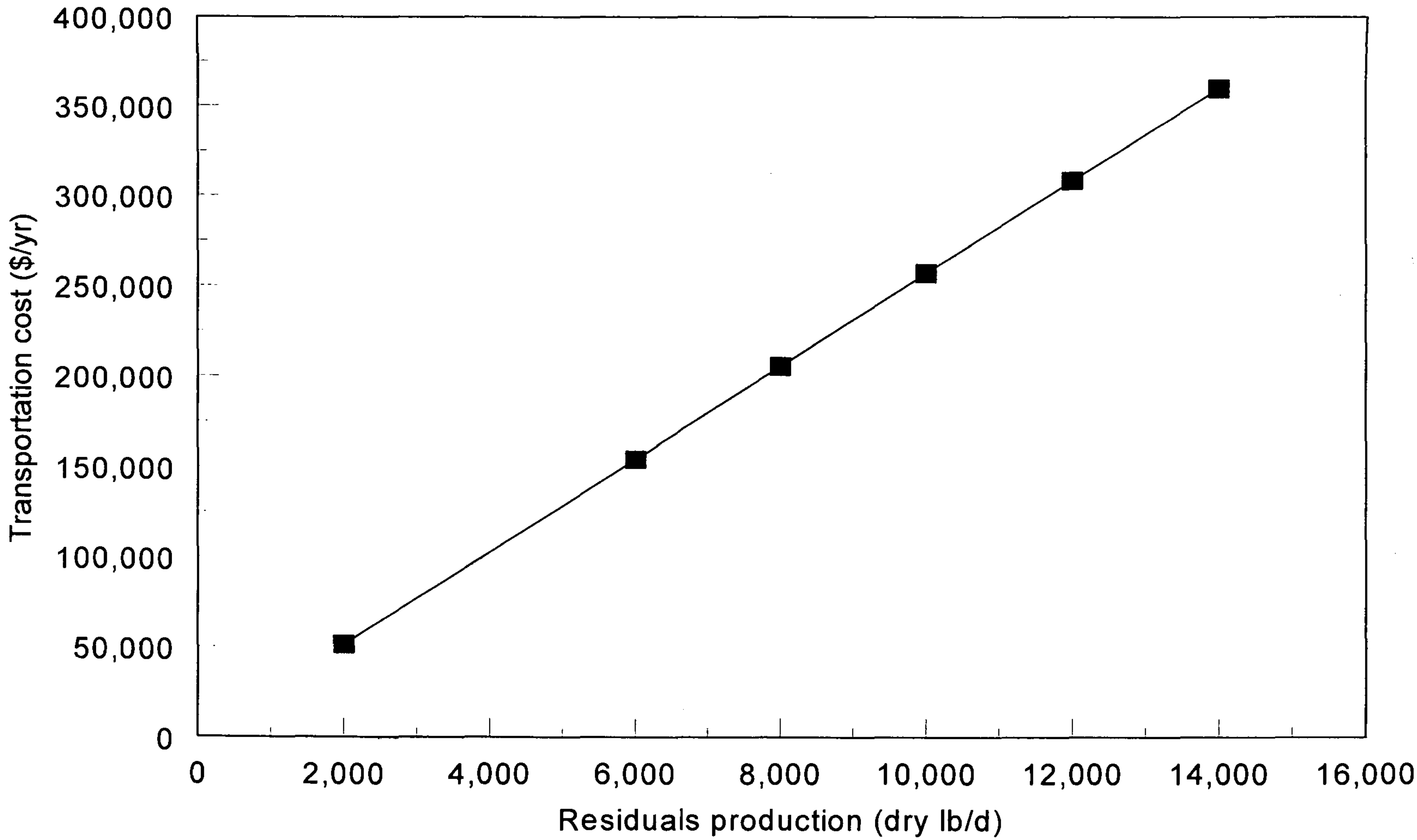
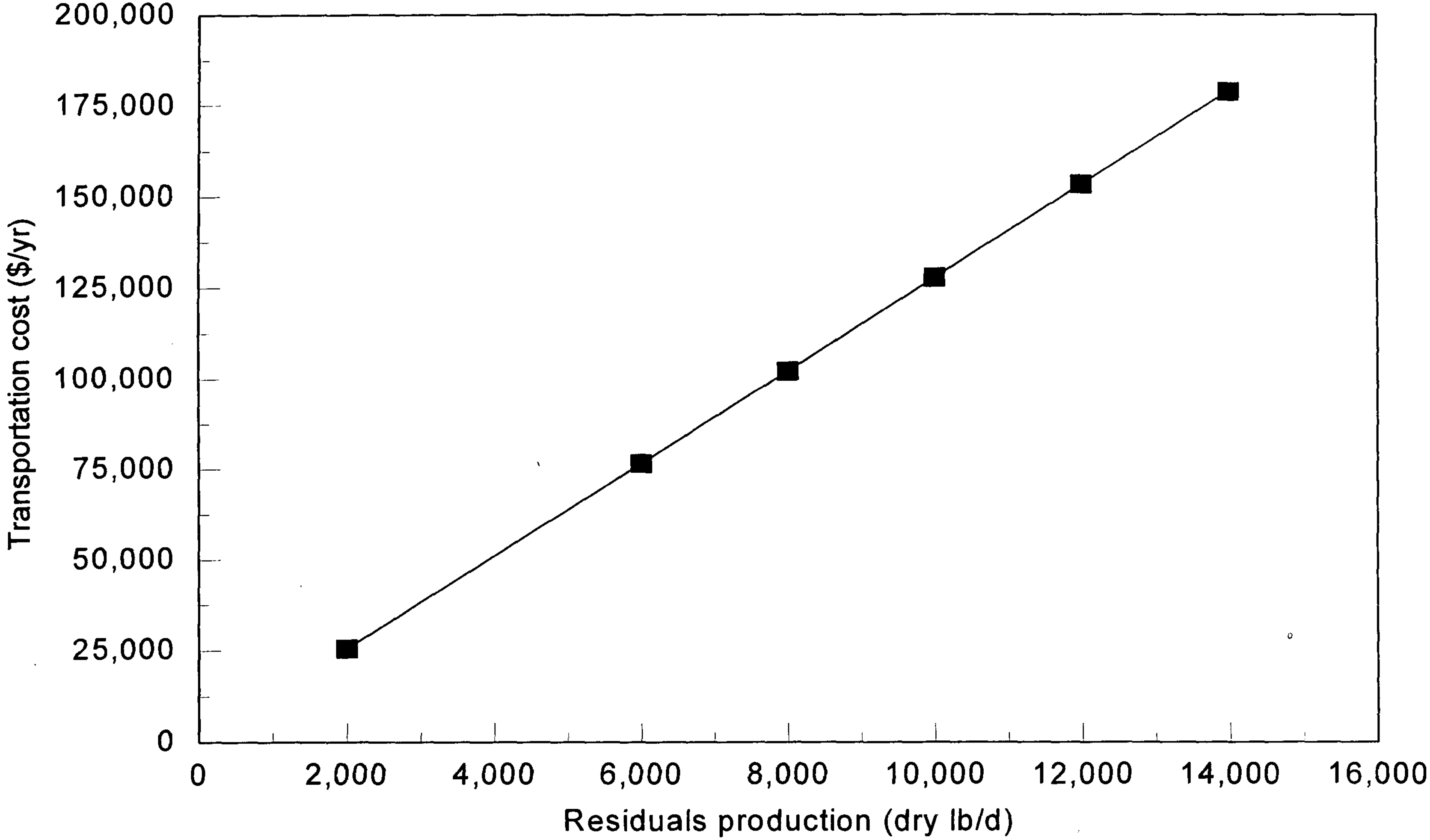


Figure 4.11 Equipment cost for pugmill blending equipment



Note: Costs calculated for an average hauling distance of 30 miles

Figure 4.12 Transportation and application cost for liquid residuals at 6 percent solids concentration



Note: Costs calculated for an average hauling distance of 30 miles

Figure 4.13 Transportation and application cost for cake residuals at 25 percent solids concentration

CHAPTER 5
NONECONOMIC CONSIDERATIONS

INTRODUCTION

The objective of a noneconomic analysis is to evaluate non-monetary considerations for each beneficial use plan. The results of the non-economic analysis are then compared with the other considerations to determine which markets are best suited to a particular utility's needs. Since residuals management is an integral part of the overall water treatment process, the final use of the residuals must be reliable and flexible enough to facilitate routine plant operations. When more than one beneficial use markets are available and economically viable, a utility should conduct a noneconomic analysis to determine which beneficial use alternative would provide the greatest benefit separate from financial issues. Essentially this type of analysis provides a ranking of the various alternatives that can be used to identify which beneficial use alternative is optimal for a utility. The noneconomic weighting parameters that are frequently evaluated are listed below and further defined in the following paragraphs:

- Reliability
- Flexibility
- Permitting and regulatory impacts
- Liability
- User experience and time in business
- Operational complexity
- Expandability
- On-site land requirements
- Compatibility with existing processes
- Environmental impacts
- Vehicle traffic
- Disposal volume

Reliability

Reliability is a measure of an alternatives ability to provide a continuous, long-term method of residuals disposal. This criterion considers the reliability of the dewatering process as well as the final end use. Simple disposal processes that require minimal amounts of mechanical equipment and provide year-round disposal of residuals should be viewed as a more favorable alternative.

Flexibility

Flexibility is defined as the ability of a beneficial use plan to adapt to seasonal or other variations in residuals quantities or qualities. End use applications or manufacturing processes that are not easily upset by residuals changes should be viewed more favorably.

Permitting and Regulatory Impacts

This is the ability of an alternative use plan to meet local, state or federal regulatory criteria. Beneficial use alternatives that are closely regulated and have extensive sampling and monitoring requirements are given less favorable consideration. Processes that have been used successfully in the past and are widely recognized by the water industry as a good disposal alternative should be viewed as more favorable.

Liability

Alternatives that directly or indirectly involve human or animal exposure or consumption should receive less favorable consideration. Any alternative in which residuals could potentially cause soil pollution (i.e., heavy metals), crop damage, or equipment damage should be given less favorable consideration.

User Experience and Time in Business

This parameter takes into account each markets historical business or manufacturing track record. Considerations such as time in business, success and/or productivity, environmental record, etc. could be used as weighting factors. The markets that have successfully used water residuals in the past should be given a more favorable consideration.

Expandability

This is the ability to expand the beneficial use process in modular phases to account for unforseen changes or eventual increases in residuals production quantities. Water treatment plant expansions, new plants, or increases in water production could generate more residuals for disposal. Alternative uses that can accept increased residuals quantities should be viewed more favorably.

On-Site Land Requirements

Evaluation of each market should include an estimation of how much on-site area at the water treatment plant is required for construction of facilities necessary for supporting each disposal alternative. In most cases, negative consideration should be given to beneficial uses that require large amounts of on-site space for residuals dewatering and storage.

Compatibility with Existing Processes

Beneficial use application requirements that most nearly match the existing solids handling facilities and equipment at the water treatment plant should be given positive consideration. Operator familiarity with the process and compatibility with routine operations should also be considered.

Vehicle Traffic

Beneficial use alternatives that cause significant traffic increases to and from the water treatment plant which could potentially cause damaged roadways, create traffic nuisances, increase dust generation, and may require road improvements should be given less favorable consideration.

Environmental Impacts

Disposal plans that provide a safe beneficial disposal option without causing harm to the environment, or even provide a benefit to the environment should be given a more positive consideration.

Disposal Volume

Disposal alternatives that can potentially accept large volumes of residuals on a continuous basis should be given a more positive consideration.

NON-ECONOMIC EVALUATION

The goal of a non-economic analysis is to rank the different beneficial use alternatives in order of most favorable to least favorable for a particular utility. To assist with this task, a spreadsheet method was devised to provide a numerical score for each alternative based on the various criteria evaluated. A utility can select which parameters are most important for the residuals management plan under consideration for use.

An example noneconomic analysis spreadsheet is included in Table 5.1. This spreadsheet includes all of the alternative use plans included in this manual along with each non-economic analysis parameter. To set up the spreadsheet each beneficial use alternative is placed in a column that includes a location for an individual score and a calculated weighted score. The individual score is the value that a utility assigns a parameter to denote relative importance. Individual scores are defined as follows:

5 = Very favorable

4 = Favorable

3 = Neutral

2 = Less favorable

1 = Least favorable

Individual scores are then multiplied by the weighting factor listed next to each parameter. The weighting factor is listed as 1, 2, or 3. A factor of 3 is given to the most important parameters, 2 to important parameters, and 1 to less important parameters. The overall score is the sum of all the weighted parameter scores. For the example shown in Table 5.1, the maximum overall score possible is 150. The alternative ranking is then provided in the last row to show the alternative rank from 1 to 12. For this example landfill cover was found to be the best alternative use considering the parameters evaluated. Ultimately, this ranking system provides one more valuable screening method that can assist a utility in determining which beneficial use alternatives to further investigate.

Table 5.1

Noneconomic evaluation of beneficial use alternatives

Weighting parameters	Weighting factor	Beneficial use alternatives																							
		Co-use with biosolids		Compost-ing with yard waste		Turf farming		Top soil blending		Potting soil		Landfill cover		Land application		Brick making		Cement manufac-turing		Nutrient control		Road subgrade		Land reclama-tion	
		IS	WS	IS	WS	IS	WS	IS	WS	IS	WS	IS	WS	IS	WS	IS	WS	IS	WS	IS	WS	IS	WS	IS	WS
Reliability	3	3	9	2	6	3	9	3	9	4	12	5	15	4	12	4	12	3	9	2	6	3	9	2	6
Flexibility	3	3	9	3	9	2	6	4	12	2	6	5	15	4	12	4	12	4	12	3	9	4	12	4	12
Permitting and regulatory impacts	3	3	9	2	6	4	12	4	12	4	12	3	9	3	9	4	12	4	12	3	9	4	12	2	6
Liability	2	4	8	2	4	3	6	3	6	2	4	4	8	3	6	4	8	4	8	3	6	4	8	2	4
User experience and time in business	3	3	9	3	9	4	12	3	9	4	12	4	12	4	12	5	15	5	15	2	6	4	12	3	9
Operational complexity	2	3	6	2	4	3	6	4	8	4	8	5	10	4	8	3	6	3	6	4	8	5	10	2	4
Expandability	2	4	8	4	8	3	6	4	8	4	8	3	6	4	8	3	6	3	6	5	10	3	6	4	8
On-site land requirements	3	4	12	4	12	5	15	2	6	4	12	4	12	2	6	4	12	4	12	3	9	3	9	3	9
Compatibility with existing processes	2	4	8	4	8	4	8	3	6	4	8	5	10	5	10	4	8	4	8	3	6	4	8	3	6
Environmental impacts	3	4	12	4	12	3	9	3	9	3	9	4	12	4	12	3	9	3	9	5	15	3	9	5	15
Vehicle traffic	2	3	6	3	6	2	4	2	4	2	4	2	4	2	4	2	4	2	4	2	4	4	8	3	6
Disposal volume	2	4	8	4	8	3	6	4	8	5	10	5	10	4	8	5	10	5	10	5	10	5	10	5	10
Overall score		**104**		**92**		**99**		**97**		**105**		**123**		**107**		**114**		**111**		**98**		**113**		**95**	
Alternative ranking		**7**		**12**		**8**		**10**		**6**		**1**		**5**		**2**		**4**		**9**		**3**		**11**	

IS = Individual score (1 = least favorable, 2 = less favorable, 3 = neutral, 4 = favorable, 5 = very favorable)

WS = Weighted score (1= less important, 2 = important, 3 = very important)

CHAPTER 6
IMPLEMENTATION GUIDELINES

INTRODUCTION

The focus of this chapter is to summarize all of the information presented in this manual into a simplified step by step guideline that can be used by a utility to investigate, develop, and implement a successful beneficial use program. The marketing strategy guidelines include information concerning the following tasks necessary for developing a program:

- Review of local and state regulations and history of beneficial use within the state
- Perform residuals characterization
- Screen potential beneficial use options
- Determine the requirements for performing beneficial use
- Assessment of existing and future required facilities
- Economic and noneconomic analysis
- Regulatory permitting
- Development of marketing package
- Marketing residuals to potential end users
- Contractual agreements
- Project development and implementation
- Compliance sampling and monitoring (if required)

The guidelines presented in this chapter could be modified to be applicable to any of the different beneficial use markets included in this manual as well as any other beneficial use application.

GUIDELINES FOR PROGRAM DEVELOPMENT

Regulatory Evaluation

The first task that should be performed by a utility when attempting to initiate a beneficial use program is to determine if any state or local regulatory guidelines exist for beneficial use of water treatment residuals. Many states have previous experience dealing with residuals regulation and some states have guidelines that could provide a framework of how to develop a beneficial use program. It is best to involve the regulatory agency which will oversee the permitting process at the beginning of the project to determine which tasks must be accomplished for establishing a successful program. Regulatory involvement can be accomplished by simply providing a written summary which outlines the goals and objectives of the project. This could be followed up by a face to face meeting with regulators for further discussion.

If regulatory guidelines for beneficial use exist, than an effort should be made to locate utilities that have received beneficial permits in the past and review that utility's experiences. Nearby utilities that have experience with one or more forms of residuals beneficial use could provide invaluable information on "how to" develop a successful program or why a certain program did not succeed.

Residuals Characterization

The next task necessary for marketing residuals for beneficial use applications is to sample residuals and perform a complete chemical and physical analysis of the contents. The chemical and physical properties of the residuals will ultimately dictate how a particular residual could be beneficially used in a safe manner. Accurate analysis of the residuals is critical and a utility should be aware that residuals quantities could change seasonally. A listing of recommended physical and chemical parameters that should be analyzed as a minimum was previously presented in Table 3.1. Analysis of these parameters should provide enough information to initiate the marketing of residuals to end users. Also, compliance with regulatory guidelines can be assessed at this point. Due to seasonal changes in raw water quality and changes in treatment chemicals applied during different times of the year, quarterly sampling of residuals may be necessary to fully characterize the variations in the residuals quality. Even more samples would be required for any type of statistical analyses with a 95 percent confidence level.

Residuals quantities generated during water treatment should also be accurately evaluated to determine the current and future volume and weight of residuals. Residuals quantity evaluations should include daily, monthly, and yearly estimates of the total wet and dry quantities generated. Residuals estimations should also include the volume of materials that have been stockpiled on-site or are currently contained in storage lagoons. Seasonal patterns in residuals production volumes should also be investigated to accurately assess the quantities that can be expected for beneficial use.

A utility also needs to determine if any process changes, plant upgrades, new raw water sources or coagulant changes are foreseen in the near future. All of these modifications to the existing process could alter the quality and quantity of residuals generated.

Selection of Potential Beneficial Use Options

The selection of potential beneficial use markets should be simplified after reviewing the market descriptions and case studies provide in Chapter 3 of this manual, as well as, by investigating the practices used by nearby water utilities. Beneficial use or "turn key" contractors, if available, may also provide insight on which applications that are most promising. Ultimately, a utility should select a short list of beneficial use applications that have the greatest potential based on the following topics:

- Is this alternative available within close proximity to the treatment plant?
- Will this application potentially meet regulatory acceptance?
- Are the potential costs attractive?
- Would the end use of residuals be beneficial to this market?
- Is this alternative a realistic option based on information supplied by this manual or other utilities experiences?

If these questions can be answered positively then the particular alternative in question should be included in the short list of potential beneficial uses.

After establishing a short list, a general search can be used to identify which particular end users exist. The goal should be to establish as many agreements as possible with potential end users in order to have a variety of outlets for beneficial use in case some are unsuccessful. In order to locate potential end users, the following techniques could be used:

- Discussions with utility staff and with neighboring cities, towns, and villages
- Search the yellow pages to determine what businesses exist within the area
- Contact local municipal landfills and composting facilities
- Contact national organizations for the different markets as described in Chapter 3.
- Review the maps in Chapter 3 for brick making, turf farming, and cement making to determine if these markets potentially exist in the area
- Discussions with employees at a local nursery or lawn and garden center to determine where top soil and potting soil products are manufactured
- Discussions with local county farm extension agents, or direct contact with farmers
- Contact with local university agriculture extension
- Contact the local university waste reuse center

A series of phone interviews will help determine if potential end users would be seriously interested in using residuals.

User Requirements

Prior to marketing residuals for a particular application, a utility must first determine the needs of the potential end user, storage requirements, and residuals characteristic requirements. Facility requirements must also be considered and could significantly impact project costs. Based on the information provided by this manual and any other information obtainable, a utility's goal should be to fully understand the potential user's operation, how the residuals could be incorporated, and which residuals characteristics would enhance the user's product or application. Some key issues to be addressed include:

- What is the optimal or desired solids concentration and is further dewatering such as air drying required?
- What are the residuals chemical and physical properties that are most important?
- Are any addition such as lime, fertilizers, or other additives required?
- What quantity of residuals could the end user accept?
- Are residuals storage facilities and additional equipment required by the utility or the end user?

A complete evaluation of each of these questions should be performed to determine if each alternative is feasible.

Facility Assessment

After identifying the requirements that are necessary for each potential beneficial use, a complete facility assessment should be conducted to determine what, if any, modifications are necessary. A facility evaluation should be conducted for the water treatment facility as well as for the facilities used for performing the beneficial use. The facility assessment of the water treatment plant should include the following tasks:

- Assessment of residuals dewatering facilities to determine if the capacity and extent of dewatering is acceptable.
- Assessment of on-site residuals storage facilities to determine if enough space is available.
- Assessment of existing equipment to determine if residuals handling, transportation, and application is feasible.
- Assessment of driveways and roads to determine if road conditions are acceptable.

Any facility modifications that may be required to perform a particular beneficial use plan could impact the overall project costs and, therefore, should be thoroughly evaluated prior to reviewing the project economics.

Preliminary Economic Analysis

The economics associated with a beneficial use program would be an important parameter for determining project feasibility. A utility must evaluate the costs associated with performing each potential beneficial use alternative to determine if the beneficial use alternative is economical. The probable capital and viable operating and maintenance (O&M) costs for each potential alternative should be evaluated at this point. This would serve as a reality check to determine if further pursuit of beneficial use alternative is economically warranted. The alternatives should be compared to a base case disposal option such as landfilling or the existing residuals disposal method the utility is using. The key cost elements that need to be considered are presented below. The cost curves provided in Chapter 4 may assist with estimating the costs for construction and O&M for residuals handling and dewatering facilities.

<u>Capital costs</u>

- Residuals equalization basins
- Residuals thickeners
- Residuals dewatering equipment
- Residuals air drying facilities
- Residuals storage facilities
- Residuals blending equipment
- Equipment for residuals handling/transportation

<u>Operating costs</u>

- Dewatering
- Residuals handling/loading
- Transportation

- User fees
- Compliance sampling and analysis

Noneconomic Analysis

A noneconomic analysis should also be conducted to evaluate non-monetary considerations for each beneficial use plan. A detailed strategy for conducting this analysis is provided in Chapter 5. Results from the noneconomic analysis will further assist a utility in screening the potential beneficial use options. The results from the noneconomic analysis should be linked with the beneficial use economics in order to confirm that beneficial use is economically and noneconomically attractive relative to a base case alternative.

Regulatory Discussions

If the economic and noneconomic assessments demonstrate that a particular beneficial use option is feasible and attractive, then the next task is to determine the specific tasks that must be completed to receive regulatory approval. At this point, a formal meeting with regulators should be conducted to discuss the specific information or applications needed for regulatory review. The potential beneficial use applications should be discussed as well as the potential users. The utility staff should enquire if the potential end users have a general permit and whether or not any permit violations have occurred in the past. This information will vary from state to state, as demonstrated by the state regulatory survey responses presented in Appendix Table A.1. Regulatory approval tends to focus primarily on the following issues:

- Residuals quality and quantity data
- Hazard potential of residuals
- Final use for residuals
- Who is the end user(s)
- Impacts on the natural environment

Residuals quality and quantity information at this point should be readily available. However, demonstration studies may be required to answer the questions of how residuals will be used and what impacts residuals will have on the environment.

Informational Package

Data collected from previous tasks such as the residuals characterization, facility assessment, and regulatory discussions should be summarized into a simple, educational, and informative document that could be distributed to potential end users. The informational package could include other utility case studies, treatment plant process information, treatment chemicals used, and possibly a small sample of the residuals. This informational package should be very useful when meeting with potential end users. It would also provide the necessary information for the end user to understand the basic water treatment process and how the residuals could potentially benefit them.

Marketing Residuals to Potential End Users

By now a utility should have a good idea which beneficial use alternatives are the most promising. The next task is to locate specific end users such as farmers, manufacturers, and others that are interested in using residuals. The goal at this point is to establish a relationship with a number of potential end users. The utility should meet with prospective end users to discuss residuals as well as tour the users facilities. The utility should provide an explanation of what residuals are and review the informational package with the user. A utility may also want to cite other case studies where residuals have been used for the same purpose. Discussions with end users will provide the utility with a better understanding of how residuals could benefit the application and how residuals would be introduced into the process. All potential end users visited by the utility should also be invited to tour the water treatment plant where the residuals are generated. This will allow potential users to see exactly how residuals are formed, and handled prior to disposal.

Water Treatment Plant Tour

A group tour of the water treatment plant with all the potential users should be conducted at this point. The objective of this tour is two-fold. First, it allows the utility to demonstrate to the potential users that the water treatment process is performed, monitored, and managed by a professional staff. Also, it would be a good educational opportunity to explain to the potential users the water treatment process and how the residuals are generated.

The second objective would be to let each potential user know that there are other users interested in the residuals. This could provide a higher comfort level to the potential users, recognizing that their competitors are also interested.

Screening of Potential Users

At this point, a final list of potential users that are seriously interested should be developed. It would also be useful to assess what type of contract or agreement each user would prefer and how that compares with the utility's legal council's requirements. Also, preliminary user fees should be established to update the capital and operating costs.

Regulatory Approval

With one or more acceptable users that would be interested in the residuals, the utility's remaining task would be to obtain regulatory approval. If the regulators were extensively involved throughout the development of a beneficial use program, obtaining regulatory approval should be relatively straight forward. The utility should coordinate an appropriate sampling and monitoring program with the regulators, if required. Sampling and monitoring programs would be determined on a case-by-case basis as directed by the regulatory agency overseeing the project. Also, a site visit with the regulator who will prepare the permit to the water treatment plant and to the potential end users would also be very helpful.

Contractual Agreements

Utilities should recognize that writing the actual permit by the regulatory agency could be a detailed and time consuming process even if the regulators were involved throughout the development of the beneficial use plan. While the regulators are preparing the permit, it would be appropriate to prepare draft agreements between the utility and the user. A generic agreement would be difficult to present in this manual because each utility may have its own legal requirements. However, an agreement should at a minimum address the following:

- Acceptable physical residuals characteristics
- Residuals quantity
- Frequency of delivery and time of day
- Measure of payment such as a certified scale or other measuring method
- Suitable storage areas at the user's facility that prevent runoff into the environment
- Inspection of the trucks when they arrive at the water treatment plant
- Method of loading the trucks at the water treatment plant
- Driver's responsibilities and conduct at the water plant site
- Minimum condition of the vendor's transportation equipment
- Monthly reporting parameters
- Ownership and liability of the residuals once loaded onto the vendor's trucks

The potential users should also fully explain the intended beneficial use plan for the residuals, including the location where the beneficial use will take place. Also, the potential users should provide information on any portion of the service that may be subcontracted and the qualifications of the subcontractors. Finally, the users should be willing to provide access to the regulatory agencies to inspect the intended facility where the beneficial use will take place as part of the approval process.

Project Development and Implementation

At this stage in the project it must be determined who will be responsible for what activities and when they are to be accomplished. It is also very important that the project manager be able to coordinate the activities of all of the participants to insure a successful project. Once the project is initiated it will require operational and financial monitoring. Some of the specific activities which must be addressed include the following:

1. Identification of all utility project members and their responsibilities
2. Identification of activities to be accomplished by outside firms or agencies
3. Budgeting and funding of all tasks
4. Development of necessary construction projects
5. Determination of time deadlines for accomplishment of various tasks
6. Supervision of all tasks
7. Start-up of new processes and equipment
8. Scheduling of residuals utilization based on plant production and needs of residuals customers
9. Monitoring of residuals quality and status of utilization project
10. Financial evaluation of project on an ongoing basis

Compliance Sampling and Monitoring

Compliance sampling and monitoring will be determined by the regulatory permit requirements and/or the desires of the utility. An evaluation must be made to compare the need for project information with the cost of sampling and monitoring. Because of the potential liability of the utility from any customers utilizing the residuals it may be beneficial to conduct additional monitoring especially in the early stages of the project. Some elements of the sampling and monitoring program which may be included depending on the beneficial use market selected for residuals disposal include residuals characterization, background soil analysis, background plant tissue analysis, or other tests suggested by the manual that would limit liability due to potential problems which are not caused as a result of residuals use in a particular market.

Reporting the results from project monitoring may be required by the regulatory agency involved. It may also be desirable to transmit the results from some or all of the monitoring to the residuals end-users. Publication of the monitoring information may also be useful to other utilities which are considering beneficial use programs.

APPENDIX A

STATE REGULATORY SURVEY

Table A.1

State	How are water treatment residuals classified	State agency responsible for water treatment residuals beneficial use?	State regulatory guidelines for beneficial use	Water treatment residuals analyses are required?
Alabama	Liquid waste	Department of Environmental Management Municipal Waste Division	None established	NA
Alaska	Solid waste	Division of Environmental Health Drinking Water Regulations	None established	NA
Arizona	Unclassified	Department of Environmental Quality Solid Waste Division	Must meet federal regulations	Reuse - requires routine monitoring
Arkansas	Unclassified	Department of Pollution Control and Ecology	Obtain water pollution control permit	Aluminum, 503 metals, nitrogen, pH, phosphorus
California	Unclassified	Regional Water Quality Control Board	Regulated based on type of beneficial use (case by case)	Leachate tests
Colorado	Solid waste	Department of Public Health and Environment Solid Waste Division	Water quality and control regulatory guidelines for beneficial use	Radionuclides, metals
Connecticut	Special waste	Department of Environmental Protection Solid Waste Division	None established	Annual testing
Delaware	Biosolid	Department of Natural Resources Division of Surface Water Discharges	Permit for residuals reuse as a soil amendment	TCLP, metals, 503 metals, nutrients
Florida	Unclassified	Department of Environmental Management Solid Waste Division	Beneficial use permit (case by case)	No
Georgia	Unclassified	Department of Natural Resources Environmental Protection Division Drinking Water Program	None established	503 biosolids regulations
Hawaii	Solid waste	Department of Health Safe Drinking Water Division	None established	Determined on case by case basis
Idaho	Solid waste	Division of Environmental Quality	None established (case by case)	Determined based on site specific conditions
Illinois	Special waste	Division of Public Water Pollution Control	Land application permit (case by case)	Based on land application permit requirements

Table A.1 (continued)

State	How are water treatment residuals classified	State agency responsible for water treatment residuals beneficial use?	State regulatory guidelines for beneficial use	Water treatment residuals analyses are required?
Indiana	Special waste	Department of Environmental Management Special Waste Compliance	Must obtain reuse approval	PCBs, metals, organics
Iowa	Solid waste	department of Natural Resources	None established	NA
Kansas	Unclassified	Department of Health and Environment	None established	Analysis of pH and TSS for landfilling
Kentucky	Biosolid	Division of Waste Management	Permit for residuals application	TCLP test
Louisiana	Unclassified	Department of Environmental Quality Solid Waste Division	None established	NA
Maine	Solid waste	Department of Environmental Quality Solid Waste Program	Obtain a license from state	Determined case by case
Maryland	Unclassified	Department of the Environment Public Drinking Water Program	None established	Chlorine residual, TSS, Iron, Aluminum (for stream discharge)
Massachusetts	Biosolid	Division of Solid Waste and Hazardous Waste	Must meet land application requirements	Determined by regulations
Michigan	Special waste	Department of Environmental Quality	Must obtain a general permit	NA
Minnesota	Unclassified	Pollution Control Agency	None established	NA
Mississippi	Solid waste	Department of Environmental Quality Solid Waste Division	None established	Yes
Missouri	Special waste	Department of Natural Resources Water Pollution Control Division	Requires residuals lab analysis and development of beneficial use plan	Metals, pollutants
Montana	Solid waste	Solid Waste Division	None established	NA
Nebraska	Special waste	Department of Environmental Quality	Regulated case by case	NA
Nevada	Solid waste	Bureau of Waste Management	None established Utility must prove application is environmentally safe	Not a liquid, TCLP test, no PCBs
New Hampshire	Unclassified	Waste management Division	Demonstrate that residuals provide a beneficial use (case by case)	NA

Table A.1 (continued)

State	How are water treatment residuals classified	State agency responsible for water treatment residuals beneficial use?	State regulatory guidelines for beneficial use	Water treatment residuals analyses are required?
New Jersey	Solid waste	Department of Environmental Protection Bureau of Pretreatment and Residuals	Require an NPDES permit to land apply	Sludge quality assurance rules and regulations
New Mexico	Special waste	Environmental Department EPA non-delegated state	None established	NA
New York	Solid waste	Division of Solid and Hazardous Waste	Requires laboratory analysis of water treatment residuals to apply for a permit	Metals, solids
North Carolina	Biosolid	Department of Environment and Natural Resources Division of Water Quality	Require water treatment residuals chemical analysis for permit application (case by case)	Pollutants, metals, buffers, nutrients
North Dakota	Solid waste	Department of Health Solid Waste Division	None established	NA
Ohio	Unclassified	Environmental Protection Agency Division of Surface Water	Requires a land application permit Lime residuals only	Metals, pH
Oklahoma	Solid waste	Department of Environmental Quality	Must have DEQ approval for reuse	Metals
Oregon	Unclassified	Department of Environmental Quality Solid Waste Division	None established	None
Pennsylvania	Solid waste	Department of Environmental Protection Waste Management Program	Need a land application general permit	Annual chemical analysis
Rhode Island	Unclassified	Department of Environmental Management	None established	Metal, EP toxicity
South Carolina	Special waste	Department of Health and Environmental Control	Requirements listed in manual for water treatment residuals land application	Sludge must be non-hazardous
South Dakota	Solid Waste	Department of Environmental and Natural Resources	None established	NA
Tennessee	Special waste	Division of Water Pollution and Control	None established	Determined on case by case basis
Texas	Special waste	Natural Resource Conservation Commission	Permit based on federal regulations	TCLP, initial sludge testing 503 metal requirements
Utah	Special waste	Bureau of Water Pollution Control Division of Solid Waste	None established	Pass TCLP test

Table A.1 (continued)

State	How are water treatment residuals classified	State agency responsible for water treatment residuals beneficial use?	State regulatory guidelines for beneficial use	Water treatment residuals analyses are required?
Vermont	Solid waste	Solid Waste Division	None established	TCLP, paint filter test
Virginia	Industrial waste	Department of Environmental Quality	Must receive a Pollution Abatement (VPA) permit	Outlined in VPA permit
Washington	Industrial waste	Local Government Health Departments	Residuals must have no toxic characteristics	TCLP test
West Virginia	Biosolid	Division of Environmental Protection	None established	TCLP, paint filter more for submittal
Wisconsin	Solid waste	Department of Natural Resources Solid Waste Division	None established	Metals
Wyoming	Industrial waste	Department of Environmental Quality Water Quality Division	None established	Metals, nutrients

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ABBREVIATIONS

APHA – American Public Health Association

ASCE – American Society of Civil Engineers

ASTM – American Society for Testing and Materials

AWWA – American Water Works Association

AWWARF – American Water Works Association Research Foundation

°C – degrees Celsius

CERCLA – Comprehensive Environmental Response, Compensation, and Liability Act

CFR – Code of Federal Regulations

cm – centimeter

cm^2 – square centimeters

cu – color unit

CWA – Clean Water Act

EP – extraction procedure

°F – degrees Fahrenheit

ft – foot

ft^2 – square feet

ft^3 – cubic feet

ft-lb – foot-pound

g – gram

i.e. – that is

in. – inch

kg – kilogram

KIWA – Keuringsinstituut voor Waterleidingartikelen

kN – kilo-Newton

kPa – kiloPascal

L – liter

lb – pound

lb/ton – pounds per ton

m – meter

m^2 – square meters

m^3 - cubic meters

MCL – maximum contaminant level

mg – milligram

mgd – million gallons per day

mg/kg – milligrams per kilogram

mg/L – milligrams per liter

MG – million gallons

min – minute

mL – milliliter

mm – millimeter

MSW – municipal solid waste

MSWLF – municipal solid waste landfill

N – Newton

NPDES – National Pollutant Discharge Elimination System

ntu – nephelometric turbidity unit

O&M – operation and maintenance

PACl – polyaluminum chloride

pH – negative logarithm of the effective hydrogen ion concentration

ppm – parts per million

RCRA – Resource Conservation and Recovery Act

s – second

SARA – Superfund Amendments and Reauthorization Act

sp. gr. – specific gravity

SWTR – Surface Water Treatment Rule

TCLP – toxicity characteristic leaching procedure

TOC – total organic carbon

TOX – total organic halide

TSS – total suspended solids

U.K. – United Kingdom

U.S. – United States

US EPA – United States Environmental Protection Agency

USGS – United States Geological Survey

WPCF – Water Pollution Control Federation

WTP – water treatment plant

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