SLUDGE COMPOST MARKETING AND DISTRIBUTION REGULATORY REQUIREMENTS IN THE UNITED STATES

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REGULATORY REQUIREMENTS IN THE UNITED STATES

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SLUDGE COMPOST REGULATORY REPORT

This report has been sponsored and reviewed by the U.S. Environmental Protection Agency (EPA) in cooperation with the Massachusetts Department of Environmental Quality Engineering (DEQE). Review of the contents of this report does not signify that the material necessarily reflects the views and policies of EPA or DEQE. It is important to note that EPA is currently developing comprehensive technical criteria for the use and disposal of sewage sludge pursuant to Section 405 of the Clean Water Act. EPA has also proposed state sludge program regulations that will require states to use these federal technical criteria as a minimum for managing sewage sludge use and disposal. However, states will be free to enact more stringent requirements based upon special factors or considerations.

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SLUDGE COMPOST MARKETING AND DISTRIBUTION REGULATORY REQUIREMENTS IN THE UNITED STATES

I. INTRODUCTION

A. Background and purpose

The Clean Water Act has set a national policy to encourage the recycling and beneficial reuse of municipal wastewater sludge. Composting, which is a biological process for stabilizing the sludge prior to use is considered a reuse process. Composting increases the acceptability of sludge for agricultural and related uses by converting organic waste into a humus-like material useful as a soil conditioner. The Massachusetts Executive Office of Environmental Affairs has selected sludge composting as the preferred method of sludge management for the wastewater treatment facilities serving the Boston metropolitan area. However, use of this compost may be limited because of its heavy metal content, which may exceed limits established by the Massachusetts Department of Environmental Quality Engineering (DEQE) in November 1983. The implementation of a large-scale composting program for the Boston metropolitan area may therefore be impeded by limitations on the marketing, distribution and ultimate use of the compost. Implementation of a successful composting program will either require a more effective pretreatment program by industries discharging to the metropolitan system, thereby reducing the metals discharged to the systems, or a review and possible revision of the regulatory limits governing the distribution and use of the sludge.

A primary purpose of this report is to provide an information base for the Massachusetts DEQE which will constitute the initial basis for the review and possible revision of the limits currently regulating the marketing, distribution and use of wastewater sludge compost. However, other New England states, as well as other states in the Northeast and other parts of the U.S., should find the information valuable. It is important to note that EPA is currently developing national comprehensive technical criteria for the use and disposal of sewage sludge pursuant to Section 405 of the Clean Water Act. These criteria will result in proposed regulations in early 1987. This report is intended to provide an updated interim information base which will be supplemented by the proposed EPA regulations.

Contents of this Report

This report is divided into three sections. Section I summarizes the background and purpose of the report. Section II is an extensive compilation of current state and federal sludge use regulations, and Section III describes the risks associated with sludge compost use and, where appropriate, recommends regulatory approaches and further study. Section II describes the main informational sources used to prepare state guidelines and regulations, and summarizes the overall trends and most common features in those regulations. The analysis of loading limits and maximum constituent limits concentrates on the northeast, where local conditions are most relevant to the problems faced in USEPA Region I. A more detailed summary of the information on which Section II is based is contained in Appendix A.

In Section III, separate discussions are presented on the three main agents of health risks in sludge: metals, organic compounds, and pathogens. Because an extensive study of these risks is currently being conducted by USEPA national headquarters, the present study concentrates on health risks and solutions of greatest importance to USEPA Region I.

II. SUMMARY OF STATE REGULATIONS AND GUIDELINES FOR SLUDGE LAND APPLICATION AND SALE/GIVEAWAY

A. Background and Summary

Approximately 40 states either have composting facilities in operation or under consideration (Goldstein, 1985). These states, as well as the District of Columbia and the Federal government, were contacted and a compilation made of relevant regulations or guidelines pertaining to the distribution/sale and reuse of sludge. Most states' regulations do not distinguish between the various forms of sludge such as dry compost, liquid sludge, cake, etc. Therefore, information was gathered on land application and reuse of sludge, with emphasis on dry compost as a category of sludge.

Discussions with representatives of the state and/or federal agencies administering the regulations, as well as a careful review of the regulations/guidelines, focused on several key parameters:

- degree of stabilization
- sludge quality (constituent levels)
- land application rate limits
- siting restrictions
- reporting requirements
- permit procedures
- use on dedicated sites

A summary was prepared of each state's regulations indicating the extent to which the state's regulations or guidelines addressed the above parameters. The individual state summaries are compiled in Appendix I. The information gathered is presented in the same format for each state, allowing direct comparison between states' regulations and guidelines, and facilitating evaluation of major similarities and differences. Although some states' regulations are lengthier than others, the information for each criterion can usually be found on the same page for each state. For example, information regarding the acceptability of sludge can usually be found on page 2 of each individual state summary.

Thirty-eight states have existing or proposed regulations/ guidelines which specifically address the land application of sludge to agricultural land, or to dedicated or reclaimed sites. Fifteen states also have specific regulations/guidelines addressing give-away or distribution programs.

Summary Tables 1, 2, and 3 were developed from the individual state summary tables in Appendix A. These summary tables indicate which states address the above listed key parameters in their land application or distribution programs.

A more detailed discussion of the different state programs and their regulations/guidelines as they relate to the key parameters follows. Although the degree of regulation, discretionary powers of the administrative agency, criteria for use, and required submittals for use approval vary from state to

TABLE 1.
REGULATIONS IN FORCE: LAND APPLICATION

	FED.	AK	AL	AR	AZ	CA	CO	CT*	DC	DE	FL I	FL II	GA	HI	IA EX.	IA NEX.	(ID)	IL
STATE CONTROL:																		
REGULATIONS	X	X	X				X	X		X	X	X		X	X	X		X
GUIDELINES					X	X		X					X					
ACCEPTABILITY OF SLUDGE:																		
PERMIT OR APPROVAL REQUIRED	X	X	X		X	X	X	X	X		X	X	X	X	X	X		X
SLUDGE SAMPLING REQUIRED					X	X	X	X			X	X	X		X	X		X
MAXIMUM SLUDGE CONSTITUENT CONCENTRATIONS:																		
NUTRIENTS															X			
METALS	X					X	X	X			X	X			X			
PCBS	X	X				X	X	X										
OTHER CONTAMINANTS								X										
LAND APPLICATION:																		
PERMIT OR APPROVAL REQUIRED		X	X			X	X	X			X	X			X	X		X
CRITERIA FOR USE:																		
DEGREE OF STABILIZATION:																		
STABILIZATION REQUIREMENT						X	X				X	X			X			X
PSRP	X		X		X	X	X	X					X					
PFRP	X	X	X		X	X	X				X	X	X					
SOIL SAMPLING		X			X		X	X			X	X	X			X		X
WATER QUALITY MONITORING		X			X		X	X			X	X	X			X		X
MAXIMUM SLUDGE LOADING LIMIT:																		
N(ANNUAL)					X	X	X	X			X	X	X		X			X
METALS	X	X			X	X	X	X				X	X					X
PCBS																		X
OTHER																		

TABLE 1.
REGULATIONS IN FORCE: LAND APPLICATION

	FED.	AK	AL	AR	AZ	CA	CO	CT*	DC	DE	FL I	FL II	GA	HI	IA EX.	IA NEX.	(ID)	IL
LAND USE RESTRICTIONS:																		
CROPS			X		X	X	X	X			X	X			X			X
GRAZING OR GREENCHOP	X	X	X		X		X	X			X	X	X		X	X		X
PUBLIC ACCESS	X	X	X		X						X	X	X		X	X		
pH OF SOIL	X				X	X	X	X			X	X	X		X	X		X
SITING RESTRICTIONS:																		
SOIL CONDITIONS		X					X	X					X		X			X
BUFFER REQUIREMENTS					X	X	X	X			X	X	X		X			X
GROUNDWATER PROTECTION	X	X	X		X		X	X			X	X	X		X			X
SURFACE WATER PROTECTION	X	X	X		X		X	X			X	X	X		X			X
RUNOFF AND EROSION CONTROL	X	X			X	X	X	X			X	X	X		X	X		X
MAXIMUM SLOPE LIMIT					X		X	X			X	X	X		X			X
STORAGE					X	X	X								X			X
TRANSPORTAION					X													X

* - NORTH EASTERN STATES
() - STATES NOT CONTACTED
F - SAME AS FEDERAL REGULATION
I,II,III - REFER TO SLUDGE
EX.,NEX. - EXEMPT, NONEXEMPT
GOV.-GOVERNMENT FACILITIES
PRIV.-PRIVATE SITES

TABLE 1.
REGULATIONS IN FORCE: LAND APPLICATION

	IN	KS	(KY)	(LA)	MA* I	MA* II,III	MD	ME*	MI	MN GOV.	MN PRIV.	(MO)	MS	MT	NC	(ND)	NE	NH*
STATE CONTROL:																		
REGULATIONS	X				X	X	X	X		X	X		X	X	X			X
GUIDELINES		X																X
ACCEPTABILITY OF SLUDGE:																		
PERMIT OR APPROVAL REQUIRED	X	X			X	X	X	X		X	X		X	X	X			X
SLUDGE SAMPLING REQUIRED		X			X	X	X	X		X	X		X					X
MAXIMUM SLUDGE CONSTITUENT CONCENTRATIONS:														F	F			
NUTRIENTS																		
METALS					X	X	X	X										X
PCBS					X	X	X	X		X	X							X
OTHER CONTAMINANTS								X										
LAND APPLICATION:																		
PERMIT OR APPROVAL REQUIRED	X	X					X			X	X		X	X	F			X
CRITERIA FOR USE:																		
DEGREE OF STABILIZATION:																		
STABILIZATION REQUIREMENT														X	F			
PSRP	X				X	X	X	X		X	X		X					X
PFRP	X				X	X	X	X		X	X							X
SOIL SAMPLING		X				X	X	X			X		X	X				X
WATER QUALITY MONITORING		X				X	X	X		X			X	X	X			X
MAXIMUM SLUDGE LOADING LIMIT:															F			
N(ANNUAL)	X	X			X	X	X	X		X	X		X					X
METALS	X					X	X	X		X	X		X					X
PCBS	X					X				X	X							
OTHER																		

TABLE 1.
REGULATIONS IN FORCE: LAND APPLICATION

	IN	KS	(KY)	(LA)	MA* I	MA* II,III	MD	ME*	MI	MN GOV.	MN PRIV.	(MO)	MS	MT	NC	(ND)	NE	NH*
LAND USE RESTRICTIONS:																		
CROPS		X			X	X	X	X		X	X		X					X
GRAZING OR GREENCHOP	X					X	X	X		X	X		X					X
PUBLIC ACCESS						X	X			X	X		X	X				F
pH OF SOIL	X	X				X	X	X			X		X					X
SITING RESTRICTIONS:																		
SOIL CONDITIONS	X	X				X		X			X		X	X				X
BUFFER REQUIREMENTS	X	X				X	X	X		X	X		X	X				X
GROUNDWATER PROTECTION	X	X				X	X	X		X	X		X	X				X
SURFACE WATER PROTECTION	X	X				X	X	X		X	X		X	X				X
RUNOFF AND EROSION CONTROL	X	X				X	X				X		X	X				X
MAXIMUM SLOPE LIMIT	X	X				X	X	X			X		X					X
STORAGE	X	X			X	X	X	X			X		X					X
TRANSPORTAION		X			X	X	X							X				X

* - NORTH EASTERN STATES
() - STATES NOT CONTACTED
F - SAME AS FEDERAL REGULATION
I,II,III - REFER TO SLUDGE
EX.,NEX. - EXEMPT, NONEXEMPT
GOV.-GOVERNMENT FACILITIES
PRIV.-PRIVATE SITES

TABLE 1.
REGULATIONS IN FORCE: LAND APPLICATION

	NJ*	(NM)	NV	NY* I,II	NY* III	OH	(OK)	OR	PA	RI*	SC	(SD)	TN	TX	UT	VA	VT*	WA
STATE CONTROL:																		
REGULATIONS	X		X	X	X	X		X	X	X				X	X	X	X	X
GUIDELINES	X			X	X	X			X		X		X				X	X
ACCEPTABILITY OF SLUDGE:																		
PERMIT OR APPROVAL REQUIRED	X		X	X	X	X		X	X	X			X	X	X	X	X	X
SLUDGE SAMPLING REQUIRED	X			X		X		X	X	X	X		X	X		X	X	X
MAXIMUM SLUDGE CONSTITUENT CONCENTRATIONS:																		
NUTRIENTS										X								
METALS	X			X	X			X	X	X				X			X	X
PCBS				X	X					X								X
OTHER CONTAMINANTS	X			X	X													
LAND APPLICATION:																		
PERMIT OR APPROVAL REQUIRED	X		X	X	X	X		X	X	X			X	X		X	X	X
CRITERIA FOR USE:																		
DEGREE OF STABILIZATION:																		
STABILIZATION REQUIREMENT				X	X	X			X	X			X		X			X
PSRP	X			X	X					X	X			X		X	X	
PFRP	X										X			X				
SOIL SAMPLING	X			X	X	X			X	X	X		X	X		X	X	X
WATER QUALITY MONITORING				X	X	X				X	X		X	X		X	X	
MAXIMUM SLUDGE LOADING LIMIT:																		
N(ANNUAL)	X			X		X		X	X	X	X		X	X		X	X	X
METALS	X			X	X	X		X	X	X	X		X	X		X	X	X
PCBS																		X
OTHER																		

TABLE 1.
REGULATIONS IN FORCE: LAND APPLICATION

	NJ*	(NM)	NV	NY* I,II	NY* III	OH	(OK)	OR	PA	RI*	SC	(SD)	TN	TX	UT	VA	VT*	WA
LAND USE RESTRICTIONS:																		
CROPS	X			X	X	X		X	X	X	X		X	X	X	X	X	X
GRAZING OR GREENCHOP	X			X	X	X		X	X	X	X		X	X		X	X	X
PUBLIC ACCESS				X	X			X		X	X			X		X	X	X
pH OF SOIL	X			X	X	X		X	X	X	X		X	X		X	X	X
SITING RESTRICTIONS:																		
SOIL CONDITIONS	X			X	X	X		X	X		X		X			X		
BUFFER REQUIREMENTS	X			X	X	X		X	X	X	X		X	X		X	X	
GROUNDWATER PROTECTION	X			X	X	X		X	X	X	X		X	X		X	X	
SURFACE WATER PROTECTION	X			X	X	X		X	X	X	X		X	X		X	X	
RUNOFF AND EROSION CONTROL	X			X	X	X		X	X	X	X		X	X		X	X	X
MAXIMUM SLOPE LIMIT	X			X	X	X		X	X	X	X		X	X		X	X	
STORAGE				X		X		X		X	X		X	X		X	X	X
TRANSPORTAION								X		X				X		X		X

* - NORTH EASTERN STATES
() - STATES NOT CONTACTED
F - SAME AS FEDERAL REGULATION
I,II,III - REFER TO SLUDGE
EX.,NEX. - EXEMPT, NONEXEMPT
GOV.-GOVERNMENT FACILITIES
PRIV.-PRIVATE SITES

TABLE 1.
REGULATIONS IN FORCE: LAND APPLICATION

	WI	(WV)	WY
STATE CONTROL:			
REGULATIONS	X		X
GUIDELINES			X
ACCEPTABILITY OF SLUDGE:			
PERMIT OR APPROVAL REQUIRED	X		X
SLUDGE SAMPLING REQUIRED	X		X
MAXIMUM SLUDGE CONSTITUENT CONCENTRATIONS:			
NUTRIENTS			
METALS	X		X
PCBS	X		
OTHER CONTAMINANTS			
LAND APPLICATION:			
PERMIT OR APPROVAL REQUIRED	X		X
CRITERIA FOR USE:			
DEGREE OF STABILIZATION:			
STABILIZATION REQUIREMENT	X		
PSRP			X
PFRP			X
SOIL SAMPLING	X		X
WATER QUALITY MONITORING			
MAXIMUM SLUDGE LOADING LIMIT:			
N(ANNUAL)	X		X
METALS	X		X
PCBS			X
OTHER			

TABLE 1.
REGULATIONS IN FORCE: LAND APPLICATION

	WI	(WV)	WY
LAND USE RESTRICTIONS:			
CROPS	X		X
GRAZING OR GREENCHOP	X		
PUBLIC ACCESS	X		X
pH OF SOIL	X		
SITING RESTRICTIONS:			
SOIL CONDITIONS			
BUFFER REQUIREMENTS	X		X
GROUNDWATER PROTECTION	X		
SURFACE WATER PROTECTION	X		X
RUNOFF AND EROSION CONTROL			X
MAXIMUM SLOPE LIMIT	X		X
STORAGE	X		
TRANSPORTAION			

* - NORTH EASTERN STATES
() - STATES NOT CONTACTED
F - SAME AS FEDERAL REGULATION
I,II,III - REFER TO SLUDGE
EX.,NEX. - EXEMPT, NONEXEMPT
GOV.-GOVERNMENT FACILITIES
PRIV.-PRIVATE SITES

TABLE 2.
REGULATIONS IN FORCE: GIVE AWAY, PUBLIC DISTRIBUTION, COMPOST MANAGEMENT

	AK	AL	AR	AZ	CA	CO	CT*	DC	DE	FL	GA	HI	IA	(ID)	IL	IN	KS	(KY)
STATE CONTROL:																		
REGULATIONS								X							X	X		
GUIDELINES					X													
ACCEPTABILITY OF SLUDGE:																		
PERMIT OR APPROVAL REQUIRED **					X			X							X	X		
SLUDGE SAMPLING PARAMETERS					X			X										
MAXIMUM SLUDGE CONSTITUENT CONCENTRATIONS:																		
NUTRIENTS								F										
METALS					X										X			
PCBS					X													
OTHER CONTAMINANTS																		
LAND APPLICATION:																		
PERMIT OR APPROVAL REQUIRED								X							X			
CRITERIA FOR USE:																		
DEGREE OF STABILIZATION:																		
STABILIZATION REQUIRED								X							X			
PSRP																X		
PFRP					X											X		
SOIL SAMPLING															X			
WATER QUALITY MONITORING															X			
MAXIMUM SLUDGE LOADING LIMIT:																		
N(ANNUAL)															X			
METALS								X							X			
PCBS															X			
OTHER																		

TABLE 2.
REGULATIONS IN FORCE: GIVE AWAY, PUBLIC DISTRIBUTION, COMPOST MANAGEMENT

	AK	AL	AR	AZ	CA	CO	CT*	DC	DE	FL	GA	HI	IA	(ID)	IL	IN	KS	(KY)
LAND USE RESTRICTIONS:																		
CROPS					X			X							X			
GRAZING OR GREENCROP															X			
PUBLIC ACCESS																		
pH OF SOIL															X			
SITING RESTRICTIONS:																		
SOIL CONDITIONS															X			
BUFFER REQUIREMENTS								X							X			
GROUNDWATER PROTECTION															X			
SURFACE WATER PROTECTION															X			
RUNOFF AND EROSION CONTROL								X							X			
MAXIMUM SLOPE LIMIT															X			
STORAGE								X							X			
TRANSPORTAION															X			

* - NORTH EASTERN STATES
** - SLUDGE MUST BE APPROVED BEFORE IT CAN BE DISTRIBUTED FOR USE
() - STATES NOT CONTACTED
F - SAME AS FEDERAL
C.M. - COMPOST MANAGEMENT
UC, CON. - UNCONTROLLED, CONTROLLED

TABLE 2.

	(LA)	MA* I	MD	ME*	MI	MN	(MO)	MS	MT	NC	(ND)	NE	NH*	NJ*	(NM)	NY*	OH	OH C.M.
STATE CONTROL:																		
REGULATIONS		X	X	X									X	X		X		
GUIDELINES													X	X		X	X	X
ACCEPTABILITY OF SLUDGE:																		
PERMIT OR APPROVAL REQUIRED **		X	X	X									X	X		X	X	X
SLUDGE SAMPLING PARAMETERS		X	X	X										X		X	X	X
MAXIMUM SLUDGE CONSTITUENT CONCENTRATIONS:																		
NUTRIENTS			X															
METALS		X	X	X									X			X	X	X
PCBS		X	X	X												X	X	X
OTHER CONTAMINANTS																		X
LAND APPLICATION:																		
PERMIT OR APPROVAL REQUIRED				X									X	X			X	
CRITERIA FOR USE:																		
DEGREE OF STABILIZATION:																		
STABILIZATION REQUIRED																X	X	X
PSRP		X																
PFRP		X	X	X									X	X		X		
SOIL SAMPLING																		
WATER QUALITY MONITORING																		
MAXIMUM SLUDGE LOADING LIMIT:																		
N(ANNUAL)		X												X			X	
METALS														X			X	
PCBS																		
OTHER																		

TABLE 2.

	(LA)	MA* I	MD	ME*	MI	MN	(MO)	MS	MT	NC	(ND)	NE	NH*	NJ*	(NM)	NY*	OH	OK C.M.
LAND USE RESTRICTIONS:																		
CROPS		X											X	X		X	X	X
GRAZING OR GREENCHOP																		
PUBLIC ACCESS													X					
pH OF SOIL													X					
SITING RESTRICTIONS:																		
SOIL CONDITIONS													X			X		
BUFFER REQUIREMENTS													X	X				
GROUNDWATER PROTECTION																		
SURFACE WATER PROTECTION													X	X				
RUNOFF AND EROSION CONTROL													X	X				X
MAXIMUM SLOPE LIMIT																		
STORAGE		X											X				X	
TRANSPORTAION		X																

TABLE 2.

	(OK)	OR	PA	RI*	SC	(SD)	TN	TX UC	TX CON.	UT	VA	VT*	WA	WI	(WV)	WY
STATE CONTROL:																
REGULATIONS			X					X	X		X			X		
GUIDELINES							X									
ACCEPTABILITY OF SLUDGE:																
PERMIT OR APPROVAL REQUIRED **			X				X		X		X			X		
SLUDGE SAMPLING PARAMETERS			X				X	X								
MAXIMUM SLUDGE CONSTITUENT CONCENTRATIONS:																
NUTRIENTS																
METALS								X	X					X		
PCBS								X	X							
OTHER CONTAMINANTS																
LAND APPLICATION:																
PERMIT OR APPROVAL REQUIRED							X				X					
CRITERIA FOR USE:																
DEGREE OF STABILIZATION:																
STABILIZATION REQUIRED							X	X								
PSRP									X							
PFRP								X			X			X		
SOIL SAMPLING																
WATER QUALITY MONITORING																
MAXIMUM SLUDGE LOADING LIMIT:																
N(ANNUAL)							X									
METALS							X	X	X							
PCBS																
OTHER																

TABLE 2.

	(OK)	OR	PA	RI*	SC	(SD)	TN	TX UC	TX CON.	UT	VA	VT*	WA	WI	(WV)	WY
LAND USE RESTRICTIONS:																
CROPS							X	X	X		X			X		
GRAZING OR GREENCHOP							X		X							
PUBLIC ACCESS									X		X					
pH OF SOIL							X		X							
SITING RESTRICTIONS:																
SOIL CONDITIONS							X									
BUFFER REQUIREMENTS							X				X					
GROUNDWATER PROTECTION							X				X					
SURFACE WATER PROTECTION							X				X					
RUNOFF AND EROSION CONTROL											X					
MAXIMUM SLOPE LIMIT											X					
STORAGE							X									
TRANSPORTAION																

TABLE 3.

REGULATIONS IN FORCE: LAND RECLAMATION AND DEDICATED SITES

	AK	AL	AR	AZ	CA	CO	CT*	DC	DE	FL	GA	HI	IA	(ID)	IL	IN	KS	(KY)
STATE CONTROL:																		
REGULATIONS															X			
GUIDELINES																		
ACCEPTABILITY OF SLUDGE:																		
PERMIT OR APPROVAL REQUIRED															X			
SLUDGE SAMPLING PARAMETERS																		
MAXIMUM SLUDGE CONSTITUENT CONCENTRATIONS:																		
NUTRIENTS																		
METALS																		
PCBS																		
OTHER CONTAMINANTS																		
LAND APPLICATION:																		
PERMIT OR APPROVAL REQUIRED															X			
CRITERIA FOR USE:																		
DEGREE OF STABILIZATION:																		
STABILIZATION REQUIRED															X			
PSRP																		
PFRP																		
SOIL SAMPLING																		
WATER QUALITY MONITORING																		
MAXIMUM SLUDGE LOADING LIMIT:																		
N(ANNUAL)																		
METALS																		
PCBS																		
OTHER																		

TABLE 3.
REGULATIONS IN FORCE: LAND RECLAMATION AND DEDICATED SITES

	AK	AL	AR	AZ	CA	CO	CT*	DC	DE	FL	GA	HI	IA	(ID)	IL	IN	KS	(KY)
LAND USE RESTRICTIONS:																		
CROPS																		
GRAZING OR GREENCHOP																		
PUBLIC ACCESS																		
pH OF SOIL																		
SITING RESTRICTIONS:																		
SOIL CONDITIONS																		
BUFFER REQUIREMENTS																		
GROUNDWATER PROTECTION																		
SURFACE WATER PROTECTION																		
RUNOFF AND EROSION CONTROL																		
MAXIMUM SLOPE LIMIT																		
STORAGE															X			
TRANSPORTAION															X			

* - NORTH EASTERN STATES
() - STATES NOT CONTACTED
F - SAME AS FEDERAL
L.R. - LAND RECLAMATION
D.S. - DEDICATED SITES
(1) SEPARATELY REGULATED PROGRAMS ONLY

TABLE 3.

	(LA)	MA*	MD	ME*	MI	MN	(MO)	MS	MT	NC	(ND)	NE	NH* L.R.	NH* D.S.	NJ*	(NM)	NY*	OH
STATE CONTROL:																		
REGULATIONS			X										X	X	X		X	
GUIDELINES													X	X	X		X	
ACCEPTABILITY OF SLUDGE:																		
PERMIT OR APPROVAL REQUIRED			X										X	X	X		X	
SLUDGE SAMPLING PARAMETERS			X										X	X	X		X	
MAXIMUM SLUDGE CONSTITUENT CONCENTRATIONS:																		
NUTRIENTS																		
METALS																	X	
PCBS																	X	
OTHER CONTAMINANTS																		
LAND APPLICATION:																		
PERMIT OR APPROVAL REQUIRED			X										X	X	X		X	
CRITERIA FOR USE:																		
DEGREE OF STABILIZATION:																		
STABILIZATION REQUIRED			X														X	
PSRP			X												X		X	
PFRP			X												X		X	
SOIL SAMPLING			X										X	X	X		X	
WATER QUALITY MONITORING														X	X			
MAXIMUM SLUDGE LOADING LIMIT:																		
N(ANNUAL)																	X	
METALS			X										X	X	X		X	
PCBS																		
OTHER																		

TABLE 3.

	(LA)	MA*	MD	ME*	MI	MN	(MO)	MS	MT	NC	(ND)	NE	NH* L.R.	NH* D.S.	NJ*	(NM)	NY*	OH
LAND USE RESTRICTIONS:																		
CROPS			X										X				X	
GRAZING OR GREENCHOP			X															
PUBLIC ACCESS			X														X	
pH OF SOIL			X										X				X	
SITING RESTRICTIONS:																		
SOIL CONDITIONS													X	X	X		X	
BUFFER REQUIREMENTS			X												X		X	
GROUNDWATER PROTECTION			X										X	X	X		X	
SURFACE WATER PROTECTION													X	X	X		X	
RUNOFF AND EROSION CONTROL			X										X	X	X		X	
MAXIMUM SLOPE LIMIT													X	X	X			
STORAGE																		
TRANSPORTAION																		

* - NORTH EASTERN STATES
() - STATES NOT CONTACTED
F - SAME AS FEDERAL
L.R. - LAND RECLAMATION
D.S. - DEDICATED SITES
(1) SEPARATELY REGULATED

TABLE 3.

	(OK)	OR	PA	RI*	SC	(SD)	TN	TX	UT	VA	VT*	WA	WI	(WV)	WY
STATE CONTROL:															
REGULATIONS			X							X					
GUIDELINES			X				X								
ACCEPTABILITY OF SLUDGE:															
PERMIT OR APPROVAL REQUIRED			X							X					
SLUDGE SAMPLING PARAMETERS			X												
MAXIMUM SLUDGE CONSTITUENT CONCENTRATIONS:															
NUTRIENTS															
METALS															
PCBS															
OTHER CONTAMINANTS															
LAND APPLICATION:															
PERMIT OR APPROVAL REQUIRED			X				X			X					
CRITERIA FOR USE:															
DEGREE OF STABILIZATION:															
STABILIZATION REQUIRED															
PSRP															
PFRP															
SOIL SAMPLING			X												
WATER QUALITY MONITORING			X				X								
MAXIMUM SLUDGE LOADING LIMIT:															
N(ANNUAL)			X												
METALS			X							X					
PCBS															
OTHER															

TABLE 3.

	(OK)	OR	PA	RI*	SC	(SD)	TN	TX	UT	VA	VT*	WA	WI	(WV)	WY
LAND USE RESTRICTIONS:															
CROPS			X							X					
GRAZING OR GREENCHOP															
PUBLIC ACCESS															
pH OF SOIL			X							X					
SITING RESTRICTIONS:															
SOIL CONDITIONS															
BUFFER REQUIREMENTS			X												
GROUNDWATER PROTECTION			X												
SURFACE WATER PROTECTION			X												
RUNOFF AND EROSION CONTROL			X												
MAXIMUM SLOPE LIMIT			X												
STORAGE			X												
TRANSPORTAION															

* - NORTH EASTERN STATES
() - STATES NOT CONTACTED
F - SAME AS FEDERAL
L.R. - LAND RECLAMATION
D.S. - DEDICATED SITES
(1) SEPARATELY REGULATEC

state, the following general observations can be drawn from a review of the regulations.

- The degree of stabilization and permitted levels of sludge constituents depend upon the ultimate use (and sometimes user) of the product and whether the use can be controlled.

- Where the use cannot be easily controlled, as in public distribution, sludge quality is more carefully analyzed and monitored, the degree of required pathogen reduction is greater and permissible levels of heavy metals are lower. In most instances, the user does not have to obtain a permit or approval, although the producer is often required to maintain records of distribution and provide guidance and warnings to the final user.

- Where the use of the sludge product can be more controlled and public access can be restricted, as in the application of sludge to agricultural lands, the required degree of stabilization and pathogen reduction is lower, and the permissible levels of heavy metals are higher. However, restrictions on siting and methods of application are generally specified, and loading rates are controlled in order to limit metals accumulation, runoff and erosion, ground and surface water degradation, and food product contamination. Regulations and guidelines addressing application of sludge to reclaimed or dedicated sites may have the same restrictions on runoff, erosion, water quality, and siting, but may allow higher heavy metal loading rates.

- In preparing the regulations or guidelines, most states relied heavily on USEPA guidance. Among the USEPA publications most often referred to are USEPA (1979), USEPA (1983), and USEPA, USFDA, and USDA (1981). Several states, including Connecticut and Ohio, also rely on more recent research efforts to define sludge constituent levels and loading rates. The recent studies cited are Penn. State U. (1985) and Brown (1985).

B. Regulatory Treatment of Key Parameters

Regulations vary from state to state in regard to sludge disposal programs. The following paragraphs summarize how different states address the key parameters used to implement their sludge disposal programs.

Degree of Stabilization - Criteria for Use

Stabilization of sludge can be achieved through a variety of different means such as anaerobic digestion, aerobic digestion, lime stabilization, and composting. It reduces the potential for odors, reduces pathogen levels, and usually reduces volatile solids content. Almost all state regulations require that sludge be stabilized before application to land or distribution to the public. In addition, most states specify the level to which pathogens must be reduced. Pathogens are disease causing bacteria, viruses, protozoa, and ova (eggs) of parasitic worms which become concentrated in sludges during wastewater treatment.

The USEPA has defined processes by which pathogens can be reduced. These processes are categorized into two levels of treatment: Processes to Significantly Reduce Pathogens (PSRP) and Processes to Further Reduce Pathogens (PFRP). These processes are described in 40 CFR 257, Appendix II, Sections A and B. Bbecause of their importance in addressing the issues in this report, this reference is reprinted in Appendix II.

In almost all cases, states require PFRP when sludge is applied to agricultural land on which crops for direct human consumption are to be grown within a certain period of time, unless certain conditions are met. For example, Massachusetts, which classifies sludge into three categories based on heavy metals content, requires that Type II sludge undergo PFRP if it is to be applied to agricultural land on which crops for direct human consumption will be grown within 24 months, unless the sludge is incorporated into the soil. Maryland also requires PFRP for sludge for land application if crops for direct human consumption are to be grown within three years.

Most states also require PFRP when the use of the sludge cannot be carefully controlled, such as in public giveaway programs. Maryland has a giveaway program for composted sludge, and requires this product to meet PFRP criteria.

Some states require both PFRP and a warning that the sludge is not suitable for home vegetable gardens. For example, New Hampshire, New York, and New Jersey regulate composted sludge giveaway programs, but do not promote the use of compost on home vegetable gardens.

Sludge Quality (Limits for Constituents)

States can control the total amount of nutrients, heavy metals, or organic compounds applied to agricultural or other lands either by regulating the levels of nutrients and heavy metals in the sludge or by limiting the rate at which the sludge is applied. Some states address both with carefully regulated programs.

Approximately 60% of those states regulating land application programs establish constituent levels for nutrients and/or heavy metals. The only organic chemicals normally regulated are polychlorinated biphenyls (PCBs). Massachusetts, however, requires that there be no significant concentrations of organic chemicals for which drinking water standards exist if sludge is to be applied over an existing or potential groundwater public water supply. Other organic chemicals which may require regulation are currently being researched (see Section III of this report). Among those states regulating land application and distribution programs, heavy metals are more often regulated than nutrient and PCB levels. There is a variability among states regarding the maximum levels of heavy metals allowed in sludge, and often the levels are based upon type of crop grown or method of application. A summary of maximum sludge constituent concentrations for land application of sludge in the northeastern states (Table 4) indicates that permitted cadmium levels range from a low of 2 mg/kg in Massachusetts Type I sludge and New Hampshire sludge to a high of 25 mg/kg in several of the other states. The U.S. Environmental Protection Agency, the U.S. Food and Drug Administration, and the U.S. Department of Agriculture have developed an interagency policy statement on utilization of sewage sludge on cropland, defining a "high quality" sludge as containing less than 25 mg/kg cadmium (USEPA, USFDA, USDA, 1981). This policy may change as EPA proposes and subsequently promulgates comprehensive federal regulations for the use/disposal of sludge under Section 405(d) of the Clean Water Act. Constituent levels established by states outside the northeast can be compared by referring to the "maximum sludge constituent" section of each state summary in Appendix A.

TABLE 4.

SUMMARY OF MAXIMUM SLUDGE CONSTITUENT CONCENTRATIONS FOR LAND APPLICATION OF SLUDGE, NORTHEAST (NEW ENGLAND, NY, NJ)

	FED	CT	ME	MA TYPE I	MA TYPE II,III	NH	NJ	NY I,II
MAXIMUM SLUDGE CONSTITUENT CONCENTRATIONS								
CONDUCTIVITY (MMHOS/CM)			2 d				8 IN EXTRACT	
NUTRIENTS (%BY DRY WEIGHT)								
N								
P								
K								
METALS (MG/KG SLUDGE DRY WEIGHT)			e		g			
AS								
CD	<2 PPM a	25	10	2	25	2 (R) a 10 (G)	25 h	25
PB		1000	700	300	1000	700	1000 i	1000
NI		200	200	200	200	200		200
ZN		2500	2000	2500	2500	2000		2500
CU		1000	1000	1000	1000	1000		1000
CR		1000	1000	1000	1000	1000		1000
HG		10	10	10	10	10		10
MO				10	10			
B				300	300			
FE								
ORGANICS								
PCB	<10 PPM b	10 MG/KG	10	2 f	10	10		10
WATER								
OTHER CONTAMINANTS		c					j	c

---

a UNLESS ADJUSTED SOIL pH >6.5

b UNLESS INCORPORATED OR NOT INCORPORATED
IF: PCB IN FEED <.2 PPM, PCB IN MILK <1.5
FAT BASIS

c OTHER ELEMENTS OR COMPOUNDS CONSIDERED CASE BY CASE

d OTHERWISE SPECIAL REQUIREMENTS

e MAY SEEK 90 DAY VARIANCE IF ONLY ONE METAL LEVEL EXCEEDS LIMITS BY <25%

f 2 PPM FOR FERTILIZER, 1 PPM FOR SOIL CONDITIONER
2 PPM FOR USE ON PASTURE LAND

g TYPE III IF ANY LEVELS EXCEED

h FOR DAIRY AND SOME FOOD CROPS

i 1000 FOR DAIRY OR SOME FOOD CROPS

j PESTICIDES OR PERSISTANT ORGANICS NOT TO EXCEED RESIDUE LIMITS IN CROPS SET BY FED. REGS.

k NO SLUDGE TO BE APPLIED THAT EXCEEDS RI TOX. LIMITS FOR METALS

l OR 1% OF ZN LEVEL

TABLE 4.

	NY III	RI	VT
MAXIMUM SLUDGE CONSTITUENT CONCENTRATIONS			
CONDUCTIVITY (MMHOS/CM)			
NUTRIENTS (%BY DRY WEIGHT)			
N			
P			
K			
METALS (MG/KG SLUDGE DRY WEIGHT)		k	
AS			
CD	25	15 REC l	25
PB	1000	500 REC	1000
NI	200	200 REC	200
ZN	2500	2000 REC	2500
CU	1000	1000 REC	1000
CR	1000		1000
HG	10	5 MAN	10
MO			
B			
FE			
ORGANICS			
PCB	10	10 MG/KG MAN	
WATER			
OTHER CONTAMINANTS	c		

R-REGULATION
G-GUIDELINE
MAN-MANDATORY
REC-RECOMMENDED
I,II,III-REFER TO SLUDGE CLASSIFICATION

The level of lead permitted in sludge also varies. In Massachusetts, Type I sludge can have a maximum of 300 mg/kg lead, while Type II and III sludges can contain a maximum of 1,000 mg/kg. The Federal Government has suggested a maximum of 1,000 mg/kg lead concentration for "high quality" sludge (USEPA, USFDA, USDA, 1981).

Only ten states specify the levels of nutrients, heavy metals, or organics in the sludge to be distributed to the public. Table 5 summarizes the maximum sludge constituent concentrations for giveaway, public distribution, and compost management programs in the United States. The limits established for cadmium and lead are lower for distribution programs than for land application programs. These lower limits are due to the difficulty of controlling the loading rates of sludge in public distribution programs, compared to agricultural or dedicated site land application programs.

Land Application Rate Limits

As indicated above, one method of controlling the amount of nutrients, metals, and/or PCBs applied to agricultural or other lands is to limit the application rate. Over 75% of the states regulating land application have established maximum annual or cumulative loading rates. Montana and North Carolina, however, prefer to address each situation on a case-by-case basis.

TABLE 5.

SUMMARY OF MAXIMUM SLUDGE CONSTITUENT CONCENTRATIONS FOR GIVE AWAY, PUBLIC DISTRIBUTION, AND COMPOST MANAGEMENT PROGRAMS IN THE UNITED STATES.

	ME	MA 1	MD	NH	NY	CA	IL	OH	TX	WI
MAXIMUM SLUDGE CONSTITUENT CONCENTRATIONS										
CONDUCTIVITY (MMHOS/CM)										
NUTRIENTS (%BY DRY WEIGHT)										
N										
P										
K										
METALS (MG/KG SLUDGE DRY WEIGHT)				b						
AS										
CD	10	2	12.5		10	50	25	12.5	25	10 PPM
PB	700	300	500		250	500		500	500	250 PPM
NI	200	200	100		200			100	200	
ZN	2000	2500	1250		2500			1000	2000	
CU	1000	1000	500		1000			500	1000	
CR	1000	1000			1000					
HG	10	10	5		10					
MO		10								
B		300	40000							
FE										
ORGANICS										
PCB	10	2 a	5		1	2		5	2 PPM	2 PPM
WATER							ONLY DRIED SLUDGE CAN BE GIVEN AWAY (15% SOL.)			
OTHER CONTAMINANTS										

----

a 2 PPM FOR FERTILIZER, 1 PPM FOR SOIL CONDITIONER
  2 PPM FOR USE ON PASTURE LAND

b METALS LIMITS AS APPROVED

1-REFER TO SLUDGE CLASSIFICATION

Among those states establishing loading limits, the rates are based on the soil cation exchange capacity (CEC), which is the sum of the exchangeable cations a soil can adsorb. CEC is a measure of the soil's ability to immobilize metal cations and is related to the soil's clay type and content. In some states, such as Indiana and Wyoming, the loading rates are also dependent upon the soil pH. A soil with pH of 6.5 or higher immobilizes the metals. In a few other states, the loading rates are based in part upon organic matter content of the soil. In Rhode Island, the maximum cumulative application of cadmium is 3.37 kg/ha if the percent of soil organic carbon (SOC) content is less than 4.8, and 5.62 kg/ha if the percent of soil organic carbon content is greater than 4.8.

Limits for nutrients are less commonly established than those for heavy metals. In most cases, the nutrient levels are established by the nitrogen uptake requirements for a particular crop. Most states provide formulas for use in establishing the uptake requirements on individual crops grown on different soil types. Indiana provides formulas to calculate the amount of available nitrogen in the sludge, waste product, and/or wastewater.

States have generally established both annual and maximum cumulative loading rates for cadmium, but have specified only maximum cumulative rates for other metals. State agency representatives indicate that EPA guidelines (40 CFR 257) and other EPA publications (U.S. EPA 1983; and U.S. EPA, U.S. DA, U.S. FDA

1981) are the primary sources used to establish loading limits for metals. The loading limits listed in the referenced guidelines are given in kilograms per hectare (kg/ha). Some states, however, specify loading limits in pounds per acre (lb/ac), as in earlier EPA guidance documents. This difference in units accounts for small variation in some loading rates presented in the matrices in Appendix A and in the summary tables. For example, the State of Illinois established maximum metal loading limits based upon soil CEC for its public distribution program. The limits established for cadmium are expressed in pounds/acre, yet the figures are the same as the EPA limits in 40 CFR 257 expressed in kilograms/hectare. Therefore, when pounds/acre are converted to kilograms/hectare for comparison purposes as shown below, the Illinois limits for cadmium are slightly higher than the EPA guidelines.

	Illinois	EPA
if CEC <5:	5 lb/ac (5.5 kg/ha)	5 kg/ha
if 5<CEC<15:	10 lb/ac (11 kg/ha)	10 kg/ha
if CEC>15:	20 lb/ac (22 kg/ha)	20 kg/ha

(CEC measured in milliequivalents per 100 grams.)

Land application loading limits for the northeastern states (Table 6) reveal that there is some variation in heavy metal loading rates among states. The maximum cumulative loading rate for lead in Connecticut, which based its regulations on the 1985 Penn State study cannot exceed defined background levels by 337

TABLE 6.
SUMMARY OF LOADING LIMITS IN THE NORTHEAST FOR LAND APPLICATION OF SLUDGE

MAXIMUM SLUDGE LOADING LIMITS (KG/HA UNLESS OTHERWISE SPECIFIED)
(CEC IN MEQ/100G SOIL)
SLUDGE APPLICATION WILL BE LIMITED BY ANY OF THE FOLLOWING (ANNUAL OR CUMULATIVE)

SLUDGE	FEDERAL	CONNECTICUT
N (ANNUAL)		RECOMMENDED FERTILIZER N FOR CURRENT CROP, BASED ON: AVAILABLE N=AMMONIA N + ORGANIC N PERCENTAGE DETERMINED BY SLUDGE TYPE
METALS		
CD		
ANNUAL	<.5 KG/HA-TOBACCO, LEAFY VEGS, OR ROOTS FOR HUMAN CONSUMPTION <1.25 KG/HA-BEFORE 1/1/87 <.5 KG/HA-AFTER 1/1/87	.5 KG/HA
MAX. CUMULATIVE	<5 KG/HA-SOIL pH <6.5 <5 KG/HA-SOIL pH >6.5 AND CEC <5 <10 KG/HA-SOIL pH >6.5 AND 5<CEC<10 <20 KG/HA-SOIL pH >6.5 AND CEC >10 UNLIMITED IF: FOOD CHAIN CROPS ARE ANIMAL FEED pH >6.5 FOR FOOD CHAIN CROPS PLAN TO PREVENT HUMAN CONSUMPTION FUTURE OWNERS NOTIFIED BY DEED	(MAX. CUM. EXCLUDING SOIL BACKGR.) 3.37 KG/HA (3 LB/AC)
PB		(ANNUAL) 67.4 KG/HA (60 LB/AC) (MAX.CUM. EXCL. SOIL BACKGR.) 337 KG/HA (300 LB/AC)
ZN		(ANNUAL) 33.7 KG/HA (30 LB/AC) (MAX. CUM. EXCL. SOIL BACKGR.) 168 KG/HA (150 LB/AC)
CU		(ANNUAL) 16.8 KG/HA (15 LB/AC) (MAX. CUM. EXCL. SOIL BACKGR.) 85.2 KG/HA (75 LB/AC)

TABLE 6.
SUMMARY OF LOADING LIMITS IN THE NORTHEAST FOR LAND APPLICATION OF SLUDGE

	FEDERAL	CONNECTICUT
CR		(ANNUAL) 67.4 KG/HA (60 LB/AC) (MAX. CUM. EXCL. SOIL BACKGR.) 337 KG/HA (300 LB/AC)
NI		(ANNUAL) 6.7 KG/HA (6 LB/AC) (MAX. CUM. EXCL. SOIL BACKGR.) 33.7 KG/HA (30 LB/AC)
HG		
ORGANICS PCBS		

....

I,II,III-REFER TO SLUDGE CLASSIFICATION

TABLE 6.
SUMMARY OF LOADING LIMITS

	MAINE	MASSACHUSETTS TYPE I
SLUDGE		
N (ANNUAL)	AGRONOMIC RATES BASED ON INORGANIC + PERCENTAGES OF ORGANIC SURFACE APPLIED: UP TO 1.5 CROP NEEDS	SHOULD NOT EXCEED NITROGEN UPTAKE
METALS		
CD		
ANNUAL	.5 KG/HA IF USED FOR FOOD CHAIN CROPS	
MAX. CUMULATIVE	2.5 KG/HA IF CEC <5 5 KG/HA IF CEC >5	
PB	(MAX. CUMULATIVE) 500 KG/HA IF CEC <5 1000 KG/HA IF 5<CEC<15 2000 KG/HA IF CEC >15	
ZN	(MAX. CUMULATIVE) 250 KG/HA IF CEC <5 500 KG/HA IF 5<CEC<15 1000 KG/HA IF CEC>15	
CU	(MAX. CUMULATIVE) 125 KG/HA IF CEC <5 250 KG/HA IF 5<CEC<15 500 KG/HA IF CEC >15	

TABLE 6.
SUMMARY OF LOADING LIMITS

	MAINE	MASSACHUSETTS TYPE I
CR	(MAX. CUMULATIVE)	
	250 KG/HA IF CEC <5	
	500 KG/HA IF 5<CEC<15	
	1000 KG/HA IF CEC >15	
NI	(MAX. CUMULATIVE)	
	50 KG/HA IF CEC <5	
	100 KG/HA IF 5<CEC<15	
	200 KG/HA IF CEC >15	
HG		
ORGANICS		
PCBS		

TABLE 6.
SUMMARY OF LOADING LIMITS

	MASSACHUSETTS TYPE II,III	NEW HAMPSHIRE
SLUDGE		10 T/AC (DRY) AGRICULTURE 5 T/AC CLEAR CUT FOREST 15 T/AC LAND RECLAMATION
N (ANNUAL)	CROP NEEDS	CROP FERTILIZER RATE- SOME ALLOWANCE FOR NH4 VOLATILIZATION WHEN SURFACE APPLIED, N RELEASED DURING SLUDGE DECOMPOSITION, AND N PRESENT IN SOIL
METALS		
CD		.5 KG/HA (.45 LB/AC)
ANNUAL	.5 KG/HA (.45 LB/AC)	
MAX. CUMULATIVE	5 KG/HA (4.5LB/AC)(EXCLUDING SOIL BACKGROUND LEVELS)	2.5 KG/HA (2.2 LB/AC) IF CEC <5 5 KG/HA (4.5 LB/AC) IF 5<CEC<15 10 KG/HA (9 LB/AC) IF CEC >15 LAND REC: 4.5 LB/AC
PB	(MAX. ANNUAL, INCLUDING SOIL BACKGROUND LEVELS) 499 KG/HA (445 LB/AC) IF CEC <5 673 KG/HA (600 LB/AC) IF CEC >5 UP TO 802 KG/HA (715 LB/AC) IF APPR.	(MAX. CUMULATIVE) 562 KG/HA (500 LB/AC) IF CEC <5 1123 KG/HA (1000 LB/AC) IF 5<CEC<15 2246 KG/HA (2000 LB/AC) IF CEC >15 LAND REC.: 1000 LB/AC
ZN	(MAX. CUMULATIVE, EXCLUDING SOIL BACKGROUND LEVELS) 280 KG/HA (250 LB/AC) IF CEC <5 561 KG/HA (500 LB/AC) IF CEC >5	(MAX. CUMULATIVE) 281 KG/HA (250 LB/AC) IF CEC <5 562 KG/HA (500 LB/AC) IF 5<CEC<15 1123 KG/HA (1000 LA/AC) IF CEC >15 LAND REC.: 500 LB/AC
CU	(MAX. CUMULATIVE, EXCLUDING SOIL BACKGROUND LEVELS) 140 KG/HA (125 LB/AC) IF CEC <5 280 KG/HA (250 LB/AC) IF CEC >5	(MAX. CUMULATIVE) 140 KG/HA (125 LB/AC) IF CEC <5 281 KG/HA (250 LB/AC) IF 5<CEC<15 562 KG/HA (500 LB/AC) IF CEC >15 LAND REC.: 250 LB/AC

TABLE 6.
SUMMARY OF LOADING LIMITS

	MASSACHUSETTS TYPE II,III	NEW HAMPSHIRE
CR		(MAX. CUMULATIVE) 140 KG/HA (125 LB/AC) IF CEC <5 281 KG/HA (250 LB/AC) IF 5<CEC<15 562 KG/HA (500 LB/AC) IF CEC >15 LAND REC.: 250 LB/AC
NI	(MAX. CUMULATIVE, EXCLUDING SOIL BACKGROUND LEVELS) 56 KG/HA (50 LB/AC) IF CEC <5 112 KG/HA (100 LB/AC) IF CEC >5	(MAX. CUMULATIVE) 56.2 KG/HA (50 LB/AC) IF CEC <5 112 KG/HA (100 LB/AC) IF 5<CEC<15 225 KG/HA (200 LB/AC) IF CEC >15 LAND REC.: 100 LB/AC
HG		(MAX. CUMULATIVE) .6 KG/HA (.5 LB/AC) IF CEC <5 1.1 KG/HA (1 LB/AC) IF 5<CEC<15 2.2 KG/HA (2 LB/AC) IF CEC >15 LAND REC.: 1.0 LB/AC
ORGANICS		
PCBS	(MAX. CUMULATIVE, INCLUDING SOIL BACKGROUND LEVELS) 2.5 KG/HA (2 LB/AC), MAX. 2 PPM ON PASTURE LAND	

TABLE 6.
SUMMARY OF LOADING LIMITS

	NEW JERSEY	NEW YORK CATEGORY I,II
SLUDGE	LIQUID: 25000 GAL/ACRE/APP., COARSE SOIL 15000 GAL/ACRE/APP., MEDIUM SOIL 1000 GAL/ACRE/APP., FINE SOIL OR 30 T/ACRE/YR DRY COMPOST	CATEGORY I: 1-3 T/YR BASED ON P NEEDS CATEGORY II: 5-12 T/YR BASED ON N NEEDS
N (ANNUAL)	CROP REQUIREMENT, DEPENDING IN CONTENT OF ORGANIC AND INORG. N (MUST USE FERTILIZER TO SUPPLY P & K IF NECESSARY) BASED ON CROP AND SOIL PRODUCTIVITY CLASS	CROP REQUIREMENTS
METALS		
CD		
ANNUAL	1.25 KG/HA	1.25 KG/HA-BEFORE 1/1/87 .5 KG/HA-AFTER 1/1/87
MAX. CUMULATIVE	<5 KG/HA-CEC <5 <10 KG/HA- 5<CEC<10 <20 KG/HA-CEC >10	11 KG/HA (DEDICATED SITES) 3.4 KG/HA: SOIL GROUPS 1,2,3 5 KG/HA
PB	(ANNUAL) 112 LB/AC (MAX. CUMULATIVE) 560 KG/HA IF CEC <5 1120 KG/HA IF 5<CEC<15 2240 IF CEC >15	1123 KG/HA (DEDICATED SITES) 337 KG/HA: SOIL GROUPS 1,2,3
ZN	(MAX. CUMULATIVE) 280 IF CEC <5 560 OF 5<CEC<15 1120 IF CEC >15	561 KG/HA (DEDICATED SITES) 168 KG/HA: SOIL GROUPS 1,2,3
CU	(MAX. CUMULATIVE) 140 IF CEC <5 280 IF 5<CEC<15 560 IF CEC >15	281 KG/HA (DEDICATED SITES) 84 KG/HA: SOIL GROUPS 1,2,3

TABLE 6.
SUMMARY OF LOADING LIMITS

	NEW JERSEY	NEW YORK CATEGORY I,II
CR		TO BE EVALUATED 337 KG/HA: SOIL GROUPS 1,2,3
NI	(MAX. CUMULATIVE) 140 IF CEC <5 280 IF 5<CEC<15 560 OF CEC >15	168 KG/HA (DEDICATED SITES) 34 KG/HA: SOIL GROUPS 1,2,3
HG		TO BE EVALUATED
ORGANICS PCBS		

TABLE 6.
SUMMARY OF LOADING LIMITS

	NEW YORK CATEGORY III	RHODE ISLAND
SLUDGE	UP TO 50 T/AC BASED ON MAXIMUM LOADING LIMITS FOR METALS	10 T/AC DRY
N (ANNUAL)		FOUR TIMES CROP NEEDS
METALS		
CD		
ANNUAL		
MAX. CUMULATIVE	5 KG/HA	(MAX. CUMULATIVE) 1.1 KG/HA (1 LB/AC) IF CEC <5 OR SOC <1.6 3.37 KG/HA (3 LB/AC) IF 5<CEC<15 OR 1.6<SOC<4.8 5.62 KG/HA (5 LB/AC) IF CEC >15 OR SOC >4.8
PB	500 KG/HA	(MAX. CUMULATIVE) 561 KG/HA IF CEC <5 OR SOC <1.6 1123 KG/HA IF 5<CEC<15 OR 1.6<SOC<4. 2242 KG/HA IF CEC >15 OR SOC >4.8 (500,1000,2000 LB/AC, RESP.)
ZN	250 KG/HA	(MAX. CUMULATIVE) 281 KG/HA IF CEC <5 OR SOC <1.6 561 KG/HA IF 5<CEC<15 OR 1.6<SOC<4.8 1123 KG/HA IF CEC >15 OR SOC >4.8 (250,500,1000 LB/AC, RESP.)
CU	125 KG/HA	(MAX. CUMULATIVE) 140 KG/HA IF CEC <5 OR SOC <1.6 281 KG/HA IF 5<CEC<15 OR 1.6<SOC<4.8 562 KG/HA IF CEC >15 OR SOC >4.8 (125,250,500 LB/AC, RESP.)

TABLE 6.
SUMMARY OF LOADING LIMITS

	NEW YORK CATEGORY III	RHODE ISLAND
CR	TO BE EVALUATED	
NI	50 KG/HA	(MAX. CUMULATIVE) 56.1 KG/HA IF CEC <5 OR SOC <1.6 112 KG/HA IF 5<CÊC<15 OR 1.6<SOC<4.8 225 KG/HA IF CEC >15 OR SOC >4.8 (50,100,200 LB/AC, RESP.)
HG	TO BE EVALUATED	
ORGANICS PCBS		

TABLE 6.
SUMMARY OF LOADING LIMITS

VERMONT

SLUDGE	
N (ANNUAL)	CROP REQUIREMENT BASE ON AVAIL. INORGANIC AND ORG. N
METALS	
CD	
ANNUAL	.5 KG/HA (0.45 LB/AC) ON LAND USED FOR LEAFY VEG., TOBACCO OR ROOT CROPS FOR HUMAN CONS. FOR ALL OTHER FOOD DRAIN CROPS: TIL 12/86-1.25 KG/HA (1.1 LB/AC) AFTER 1/87 0.5 KG/HA
MAX. CUMULATIVE	5.62 KG/HA (5 LB/AC) FOR LOAMY SAND AND SANDY LOAM 11.2 KG/HA (10 LB/AC) FOR FINE SANDY LOAM, LOAM, SILT LOAM 22.5 KG/HA (20 LB/AC) FOR CLAY LOAM SILTY CLAY AND CLAY
PB	(MAX. CUM.) 200 KG/HA (178 LB/AC) FOR LS,SL 400 KG/HA (356 LB/AC) FOR FSL, L, SiL
ZN	(MAX. CUM.) 281 KG/HA (250 LB/AC) FOR LS,SL 562 KG/HA (500 LB/AC) FOR FSL, L, Si 1123 KG/HA (1000 LB/AC) FOR CL, SiC,C
CU	(MAX. CUM.) 140 KG/HA (125 LB/AC) FOR LS, SL 281 KG/HA (250 LB/AC) FOR FSL,L,SiL 562 KG/HA (500 LB/AC) FOR CL,SiC,C

TABLE 6.
SUMMARY OF LOADING LIMITS

	VERMONT
CR	(MAX. CUM) 140 KG/HA (125 LB/AC) FOR LS, SL 281 KG/HA (250 LB/AC) FOR FSL,L,SiL 562 KG/HA (500 LB/AC) FOR CL,SiC,C
NI	(MAX. CUM.) 56.2 KG/HA (50 LB/AC) FOR LS,SL 112 KG/HA (100 LB/AC) FOR FSL, L, SiL 224 KG/HA (200 LB/AC) FOR CL, SiC,C
HG	(MAX. CUM.) 5.6 KG/HA (5 LB/AC) FOR LS,SL 11.2 KG/HA (10 LB/AC) FOR FSL, L,SiL 22.5 KG/HA (20 LB/AC) FOR CL,SiS,C FSL-FINE SANY LOAM, L-LOAM, SiL,SILT
ORGANICS	LOAM, CL-CLAY LOAM, SC-SILTY CLAY
PCBS	

kg/ha, while Maine has established a maximum lead cumulative loading rate of 50 to 2000 kg/ha, depending upon CEC.

Cadmium levels for almost all states follow USEPA guidelines in 40 CFR 257 (1979), although some states, such as Maine, have established a more conservative rate. Maine allows only 2.5 kg/ha if CEC is less than five milliequivalents per 100 grams (meq/100g) or 5 kg/ha if CEC is greater than five meq/100g. Connecticut, in its land application program, allows only 3.37 kg/ha maximum cumulative loading excluding soil background.

Eight states with public distribution or giveaway programs have regulatory criteria for maximum sludge loading limits as part of these programs. These are controlled public distribution programs, and notification is given to the users regarding safe metals application rates. The users may be required to maintain records indicating their compliance with application rates. (See Reporting Requirements).

A summary of loading limits in give-away, public distribution, and compost management projects in the Northeast is presented in Table 7. New Jersey is the only state which addresses annual or cumulative loading rates. These rates are similar to those established for the land application of sludge.

Siting Restrictions

Almost all of the states have established siting restrictions in their land application programs. These restrictions include buffer requirements (distance to water supplies, distance to residences), ground and surface water protection measures, and

TABLE 7.

SUMMARY OF LOADING LIMITS IN THE NORTHEAST FOR GIVE AWAY, PUBLIC DISTRIBUTION AND COMPOST MANAGEMENT

MAXIMUM SLUDGE LOADING LIMITS (KG/HA UNLESS OTHERWISE SPECIFIED)
(CEC IN MEQ/100G SOIL)
SLUDGE APPLICATION WILL BE LIMITED BY ANY OF THE FOLLOWING (ANNUAL OR CUMULATIVE)

	MASSACHUSETTS TYPE I	NEW JERSEY	RHODE ISLAND
SLUDGE		30 T/AC/YR DRY MAY BE GREATER WITH APPROVAL	10 T/AC DRY
N (ANNUAL)	SHOULD NOT EXCEED NITROGEN UPTAKE	CROP REQUIREMENTS	
METALS			
CD			
ANNUAL			
MAX. CUMULATIVE		<5 KG/HA-CEC <5 <10 KG/HA- 5<CEC<10 <20 KG/HA-CEC >10	
PB		(ANNUAL) 100 LB/AC (MAX. CUMULATIVE) 560 KG/HA IF CEC <5 1120 KG/HA IF 5<CEC<15 2240 IF CEC >15	
ZN		(MAX. CUMULATIVE) 280 IF CEC <5 560 OF 5<CEC<15 1120 IF CEC >15	
CU		(MAX. CUMULATIVE) 140 IF CEC <5 280 IF 5<CEC<15 560 IF CEC >15	
CR			
NI		(MAX. CUMULATIVE) 56 IF CEC <5 112 IF 5<CEC<15 224 OF CEC >15	
HG			
ORGANICS			
PCBS			

* NO LOADING LIMITS FOR MAINE, NEW HAMPSHIRE, AND NEW YORK

erosion control measures. In some states, counties may have local bylaws which establish additional buffer requirements. Some counties in Maryland have established zoning bylaws, which specifically address compost operations.

The buffer requirements vary substantially between states. For example, the required distance to a private well is 1000 feet in Rhode Island, but only 150 feet in Illinois. Often, the buffer requirements are based upon the method of application. Incorporation of sludge into the soil enables application to be made closer to residences, while surface or spray application requires a greater buffer. The State of Georgia requires a buffer of 300 feet to residences if the sludge is injected or incorporated into the soil, and a buffer of 2000 feet if the sludge is applied through high pressure spraying.

Most states require measures be taken to preserve ground and surface water supplies. These measures include siting restrictions such as depth to mean annual high groundwater, depth to bedrock, and distance to streams and seasonal stream beds. The method and time of application often affect the specific siting requirements.

Approximately eight states with public distribution or giveaway programs have some siting restrictions. Again, these are controlled distribution programs in which the sludge producer is responsible for notifying the user of certain siting requirements. In New Hampshire's distribution/composted sludge giveaway program, the producer must provide the user with information regarding use restrictions, and the user must sign a form acknowledging an awareness of these restrictions. The state's control of the user is essentially limited to maintaining records of these forms.

Reporting Requirements

There is no consistent policy among states regarding reporting requirements. Some states are very specific about recordkeeping and reporting requirements (including type of information to be obtained and frequency of submittal), while other states do not address reporting at all, or only indicate that reporting requirements will be established through permitting procedures.

Vermont requires only that records of sludge quantity and location of application sites be kept. Massachusetts requires an annual report and records detailing the location of application, date applied, method of application, crop or animal information, transportation modes, amount of sludge authorized to apply, the amount spread, and the annual and cumulative loading rates. New Hampshire requires only that records and reports be prepared as determined on an individual basis.

Permit Procedure

Approvals or permits are required by most states for sludge land application and public distribution programs. Approvals can either be part of the wastewater treatment facility's NPDES permit if done under state authority, or can be part of a separate permit application. In some states, separate approvals are required for the acceptability and for the use of the sludge. For example, Massachusetts requires that sludge producers submit detailed applications to the Department of Environmental Quality Engineering to obtain approval and classification of sludge if the sludge is applied to agricultural land. In addition, a separate land application certificate, renewable annually, must be obtained through submittal of a detailed application form. Other states, such as Maine, require only one approval regarding sludge acceptability and the suitability of the land application site and operation.

Approvals are also required for sludge distribution and giveaway programs. In some states, the producer acquires approval for sludge quality and distribution operations, and the user is required to sign off on a notification form or information sheet. In New Jersey, under the controlled compost distribution program, the producer must obtain approval of the sludge and must guarantee that the compost will be used in accordance with the New Jersey Department of Environmental Protection's provisions. In addition, a compost application site form must be submitted indicating the amount of compost required, the location, owner, type of land uses in the vicinity, and general site conditions.

In New Jersey's uncontrolled compost distribution program, which is limited to public agencies or general contractors, the receiver of compost must sign a form acknowledging conditions for use of the compost.

Dedicated Sites

Dedicated sites are publicly owned and controlled sites which are set aside for a specific use, such as parks, forests, and highway mediums and buffer strips. Reclaimed sites are those in which disturbed areas such as landfills, strip mines, and gravel pits are restored to where they can support vegetation.

Only eight states (Illinois, Maryland, New Hampshire, New Jersey, New York, Pennsylvania, Tennessee, and Virginia) regulate specific land application programs on dedicated or reclaimed sites. Information on states having distinct programs is summarized in Appendix A. Other states may briefly mention dedicated site or land reclamation programs in their agricultural land application regulations, but do not specify separate program regulations. For example, Florida regulates application to dedicated sites, such as highway shoulders and medians, with the same regulations they apply to agricultural land.

Other states' agricultural land application regulations permit sludge application to dedicated sites and establish loading rates that can be increased with approval. New Jersey's regulations for land application to privately-owned agricultural land indicate that sludge application rates for dedicated sites may be increased, upon approval, as long as monitoring and public access requirements are maintained.

Table 3 indicates which states regulate distinct land reclamation or dedicated site programs, and the criteria that their programs address.

Of the states that specifically address sludge application to reclaimed or dedicated sites, only a few specify sludge constituent levels or loading rates. Tables 8 and 9 summarize the maximum sludge constituent concentrations and loading rates for northeastern state programs, respectively. As seen, New York is the only northeastern state which addresses sludge consituent levels for application to dedicated or reclaimed sites. These levels, which are for the application of composted sludge, are the same as for application of sludge to agricultural land.

Several states address loading limits for application to reclaimed and dedicated sites. New Hampshire allows greater amounts of sludge to be applied to reclaimed land than to dedicated sites, but the permitted maximum cumulative loading rates are less. Both New Hampshire's land reclamation and dedicated site programs allow higher loading rates than does New York's controlled compost distribution program to dedicated sites. However, the New York guidelines for application of Category I and II sludge to agricultural land allow for higher loading levels to dedicated sites.

Before a determination can be made regarding the adequacy of state regulations and guidelines for the use and distribution of sludge, an understanding of safe threshold levels and human exposure limits must be obtained. The following chapters address quality standards and environmental risks associated with the use and distribution of sludge.

TABLE 8.
SUMMARY OF MAXIMUM SLUDGE CONSTITUENT CONCENTRATIONS FOR LAND RECLAMATION AND DEDICATED SITE PROGRAMS, NORTHEAST 1

MAXIMUM SLUDGE CONSTITUENT CONCENTRATIONS	NH LR	NH DS	NJ DS	NY DS *
	NO LIMITS	NO LIMITS	NO LIMITS	
CONDUCTIVITY (MMHOS/CM)				
NUTRIENTS (%BY DRY WEIGHT)				
N				
P				
K				
METALS (MG/KG SLUDGE DRY WEIGHT)				
AS				
CD				25
PB				1000
NI				200
ZN				2500
CU				1000
CR				1000
HG				10
MO				
B				
FE				
ORGANICS				
PCB				10
WATER				
OTHER CONTAMINANTS				

LR- LAND RECLAMATION
DS- DEDICATED SITES

*- COMPOSTED SLUDGE ONLY
1- SEPARATELY REGULATED PROGRAMS

TABLE 9.
SUMMARY OF LOADING LIMITS IN THE NORTHEAST FOR LAND RECLAMATION AND DEDICATED SITES

	NEW HAMPSHIRE LAND RECLAMATION	NEW HAMPSHIRE HIGHWAYS/DEDICATED
MAXIMUM SLUDGE LOADING LIMITS (KG/HA UNLESS OTHERWISE SPECIFIED) (CEC IN MEQ/100G SOIL)		
SLUDGE APPLICATION WILL BE LIMITED BY ANY OF THE FOLLOWING (ANNUAL OR CUMULATIVE)		
SLUDGE	15 T/AC(DRY)	5 T/AC
N (ANNUAL)		
METALS		
CD ANNUAL	.5 KG/HA (.45 LB/AC)	.5 KG/HA (.45 LB/AC)
MAX. CUMULATIVE	5 KG/HA (4.5 LB/AC)	10 KG/HA (9 LB/AC)
PB	(MAX. CUMULATIVE) 1123 KG/HA (1000 LB/AC)	(MAX. CUMULATIVE) 2246 KG/HA (2000 LB/AC)
ZN	(MAX. CUMULATIVE) 562 KG/HA (500 LB/AC)	(MAX. CUMULATIVE) 1123 KG/HA (1000 LB/AC)
CU	(MAX. CUMULATIVE) 281 KG/HA (250 LB/AC)	(MAX. CUMULATIVE) 562 KG/HA (500 LB/AC)
CR	(MAX. CUMULATIVE) 281 KG/HA (250 LB/AC)	(MAX. CUMULATIVE) 562 KG/HA (500 LB/AC)
NI	(MAX. CUMULATIVE) 112 KG/HA (100 LB/AC)	(MAX. CUMULATIVE) 225 KG/HA (200 LB/AC)
HG	(MAX. CUMULATIVE) 1.1 KG/HA (1 LB/AC)	(MAX. CUMULATIVE) 2.2 KG/HA (2 LB/AC)
ORGANICS		
PCBS		

(1) SEPARATELY REGULATED PROGRAMS ONLY

*- COMPOSTED SLUDGE ONLY. NEW YORK ALLOWS HIGHER LOADING LTS. FOR APPLIC. OF SLUDGE TO DED. SITES.

TABLE 9.

	NEW JERSEY	NEW YORK CASE II *
MAXIMUM SLUDGE LOADING LIMITS (CEC IN MEQ/100G SOIL)		
SLUDGE APPLICATION WILL BE LIM		
SLUDGE	LIQUID: 25000 GAL/ACRE/APP., COARSE SOIL 15000 GAL/ACRE/APP., MEDIUM SOIL 1000 GAL/ACRE/APP., FINE SOIL DRY COMPOST APP.25 TO 100 T/AC/YR	
N (ANNUAL)	CONSISTANT WITH PLANT UPTAKE MAY BE LIMITED BY P	CROP REQUIREMENTS
METALS	METAL LOADING LIMITED TO PREVENT	
CD	IMPAIRMENT OF FUTURE SITE	
ANNUAL	USEFULNESS	1.25 KG/HA-BEFORE 1/1/87 .5 KG/HA-AFTER 1/1/87
MAX. CUMULATIVE		5 KG/HA
PB		500 KG/HA
ZN		250 KG/HA
CU		125 KG/HA
CR		TO BE EVALUATED
NI		50 KG/HA
HG		TO BE EVALUATED
ORGANICS		
PCBS		

III. RISKS ASSOCIATED WITH SLUDGE COMPOST USE: SURVEY AND RECOMMENDATIONS

A. Introduction

The debate over acceptable levels of toxic chemicals and pathogenic organisms in sludges intended for land application has been active for over a decade, and is far from over. This section of the report examines the factors governing land application of sludges containing heavy metals, organic chemicals, and pathogens in the northeast region of the United States. The objective of the section is to assess the basis and need for regulations governing the use of composted sludge. In particular, this section examines the public health and environmental basis for:

- Maximum quality limits
- Application rates (annual and max. cummulative)
- Siting restrictions
- Stabilization requirements (for pathogens)

The differences in these requirements that might be permitted for sale/give away programs versus more controlled uses are also discussed.

The scope of this project has necessitated focus on only two of the several metals identified in sludge. Cadmium and lead were selected for evaluation because of cadmium's strong tendency to bioaccumulate and lead's association with adverse human health effects at low level environmental exposures. Zinc, copper and nickel also warrant careful consideration (USEPA, USFDA, USDA, 1981). EPA currently is evaluating cadmium, lead, chromium, selenium, iron, mercury, arsenic, and molybdenum for potential deelopment of criteria for land application.

This section has six parts. The first part assesses existing ongoing federal guidelines and standards development. The second part assesses the soil chemistry and site conditions typical of the northeast which can play a limiting role in the land application of sludges. The next three parts focus in turn on the scientific basis for regulation of metals, organic chemicals, and pathogens in composted sludges applied to land. The final part discusses the implications of the report's findings for state and federal agency policy on land application of composted sludges.

It is important to note that the USEPA in Washington is nearing completion of a massive four-year program designed to look at the same questions raised in this report. Draft risk assessment methodologies for the evaluation of public health risks from land application of municipal sludges have been completed by the Environmental Criteria and Assessment Office (ECAO) in Cincinnati. These methodologies have been used to support development of comprehensive technical regulations for use and disposal of sewage sludge under Section 405(d) of the

Clean Water Act, and will be available for public comment and review at the time the regulations are proposed for public comment in early 1987. They are ultimately intended for use by federal and state environmental agencies in standard setting. Final drafts of these methodologies are not expected to appear until late 1987.

This report does not intend to duplicate the efforts of the federal program. It attempts to provide a basis for the critical review of the federal program results so that they can be applied judiciously to the development of land application regulations appropriate for the New England states. The report relies as much as possible on recent field and epidemiologic studies to characterize the complex and often poorly understood relationships governing availability, uptake, and exposure to inorganic, organic, and pathogenic constituents of municipal sludges.

B. Federal Regulations and Guidelines

The federal regulations governing land application of municipal sludges are relatively limited. The 1979 EPA regulations focused only on annual and maximum cumulative application rates for cadmium, maximum PCB content of sludges, and stabilization requirements for pathogen control. The problems potentially resulting from unregulated sale or give away programs for composted sludge were not specifically addressed.

Because of the limited scope of the 1979 regulations, many questions remained about the safety of and recommended limits for land application of sludges which contain several other potentially toxic inorganic and organic chemical constituents. Recognizing these concerns, the USEPA, USFDA, and USDA published "Land Application of Municipal Sewage Sludge for the Production of Fruits and Vegetables; a Statement of Federal Policy and Guidance" in 1981. This guidance further explained the 1979 regulations but in addition provided a definition of 'high quality' sludge that has formed the basis for the quality limits imposed on sludges by several states. They recommended that, for fruit and vegetable production only, sludges intended for land application contain no more than 25 mg/kg cadmium, 1000 mg/kg lead, and 10 mg/kg PCBs on a dry weight basis (USEPA, USFDA, USDA, 1981). Several northeastern states were contacted as part of the present study and most cited this 1981 guidance as the basis for their regulations or guidelines on quality limits for sludges (see Appendix C for state representatives contacted and regulatory bases cited). A 1977 paper by R. Chaney and P. Giordano has been cited by other investigators as the source of recommended quality limits for zinc (2500 mg/kg), copper (1000 mg/kg), chromium (1000 mg/kg), nickel (200 mg/kg), and mercury (10 mg/kg) (Penn. State, 1985).

Since the publication of the 1981 guidelines, the USEPA Office of Water Regulations and Standards has begun a far more comprehensive review of the toxic constituents of municipal sludges and the need for further regulations. Section 405 of the Clean Water Act requires that the USEPA develop and issue regulations which: "(1) identify uses for sludges including disposal; (2) specify factors to be taken into account in determining the measures and practices applicable for each use or disposal (including costs); and (3) identify concentrations of pollutants which interfere with each use or disposal." (USEPA, 1985). The previously published 1979 regulations did not meet these statutory requirements.

The USEPA's approach to meeting their obligations under the Clean Water Act has been (1) to identify the potential pollutants of concern for landfilling, ocean dumping, incineration, and land application of municipal sludges, (2) to determine the environmental pathways of concern for each pollutant and method of disposal, and (3) to assess the degree of hazard potentially associated with each pollutant and pathway of concern (USEPA, 1985). In practice, this approach has evolved in the last four years into three distinct phases of regulation development: identification and screening of initial pollutants of concern; detailed review of the pollutants of concern and development of methodologies for assessing the risks to public health and the environment; and use of the methodologies to promulgate criteria or regulations on sludge quality, application rates and land management practices.

The first two phases of this program are nearly complete as of this writing (Lomnitz, 1986 personal communication). Expert committees convened by USEPA identified 50 potential pollutants of concern to undergo preliminary hazard evaluation (see Table 10). These pollutants were then screened to

TABLE 10. SLUDGE POLLUTANTS EVALUATED BY U.S. EPA

*Aldrin/Dieldrin	*Selenium
Arsenic	TCDD
Benzene	TCDF
Benzidine	Tetrachloroethylene
Benzo(a)anthracene	*Toxaphene
*Benzo(a)pyrene	Trichloroethylene
Beryllium	2,4,6-Trichlorophenol
Bis(2-ethylhexyl)phthalate	Tricresyl phosphate
*Cadmium	Vinyl chloride
Carbon tetrachloride	Zinc
*Chloride	
Chloroform	
*Chromium	
*Cobalt	
*Copper	
Cyanide	
*DDT/DDE/DDD	
3,3-Dichlorobenzidine	
Dichloromethane	
2,4-Dichlorophenoxyacetic acid	
Dimethyl nitrosamine	
Endrin	
*Fluoride	
*Heptachlor	
*Hexachlorobenzene	
*Hexachlorobutadiene	
*Iron	
*Lead	
*Lindane	
MOCA	
Malathion	
*Mercury	
Methyl ethyl ketone	
*Molybdenum	
*Nickel	
*PCB's	
Pentachlorophenol	
Phenanthrene	
Phenol	

SOURCE: U.S. EPA, 1985
* Identified for detail risk evaluation.

identify those compounds which warranted more detailed assessment and, potentially, regulatory action. The screening process involved developing environmental profiles or data bases to characterize the chemical/physical properties and major environmental pathways for each contaminant. Simple worst case exposure models were then developed to estimate potential exposures to both human and environmental receptors under conditions of sludge use. Hazard indices were then developed by calculating the ratio of the predicted exposure to an 'acceptable' level. For example, projected human daily intake of non-carcinogenic chemicals for given exposure scenarios were compared to the respective acceptable daily intakes (ADI) for those chemicals. Contaminants with a ratio or hazard index less than one were considered to pose sufficiently low hazard to be eliminated from further detailed investigation.

For land application/distribution and marketing, 32 contaminants were evaluated for 13 separate environmental pathways including:

- toxicity to soil biota
- toxicity to predators of soil biota
- phytotoxicity
- plant uptake
- toxicity to animals resulting from plant consumption
- toxicity to animals from soil/sludge consumption
- human toxicity from plant ingestion

- human toxicity from ingestion of contaminated animal products
- direct soil ingestion by humans.

Contamination of groundwater or surface water supplies was not evaluated for the land application disposal option at this stage of rulemaking (pollutant identification), but these pathways will be evaluated for certain pollutants in subsequent steps of rulemaking (criteria generation) (USEPA, 1985).

This screening process identified 22 contaminants which warranted detailed evaluation for at least one of the exposure pathways considered (USEPA, 1985). Table 10 identifies the contaminants that were considered and eliminated from detailed evaluation. A full discussion of these results is included in the USEPA summary report (1985).

The USEPA has currently completed the first drafts of the risk assessment methodologies that will be used in the detailed assessments and ultimately in the promulgation of regulations. These draft methodologies are not available at this time however (Lomnitz, 1986, personal communication). The Office of Water Regulations and Standards expects to propose draft regulations using these methodologies in the spring of 1987. Careful review of the applicability of methodologies and regulations to the needs of the northeast is advisable at that time.

C. New England Conditions Affecting Land Applications Of Sludges

One of the primary objectives of this project is to evaluate the impacts of land application of municipal sludges in light of soil or other conditions characteristic of the northeast. This section of the report describes briefly the principal factors affecting or limiting land application of sludges in the northeast, and provides a basis for evaluating the adequacy of existing or proposed state and federal regulations.

There are two broad factors which can play a critical role in the nature and magnitude of impact that land-applied sludges have on public health and the environment: soil chemistry and the physical characteristics of the site. The pH, cation exchange capacity (CEC), and background concentrations of soil constituents can each influence the mobility, bioavailability, and uptake of toxic constituents of sewage sludges, particularly of heavy metals. The slope, drainage, and proximity to ground and surface water sources can also prevent contamination of water supplies by metals, organic chemicals and pathogens.

Soil Chemistry

The pH of soils has long been recognized as an important factor in the soluble metal concentration and bioavailability of most metals. In general, lower pH or greater acidity increases metal bioavailability through hydrolysis of hydroxide species, by a reduction in the adsorption of metals to pH-dependent adsorption sites on mineral surfaces, and by lowering the CEC of soil organic matter (Logan and Chaney, 1983). Plant uptake of heavy metals is significantly reduced at soil pH values greater than 6.5. Molybdenum and selenium are exceptions to this rule as they tend to increase in availability with increasing pH. Uptake of lead does not typically increase with decreasing pH since lead is not significantly translocated into plant tissues.

Background soil pH can influence metal availability over long periods of time. Studies of sludge application to unlimed soils at rates of 2-10 metric tons/hectare, dry weight (Mt/ha DW) by investigators at Ohio State University indicate that application of sludge results in an initial increase in soil pH which then drops over time. For soils with pH less than 6.0, investigators saw a significant increase in extractable cadmium on unlimed soil 85 days after sludge application (Brown, 1985).

Controlling pH over time can effectively prevent the increasing availability and uptake of metals by plants. Logan and Chaney (1983) reported on a 1980 review of the available data on the residual availability of cadmium and zinc to crops after termination of sludge application. The review indicated that soluble metal concentrations increased as pH decreased, but that if pH were maintained at a constant level, soluble metal concentrations remained constant or decreased. No increase over time of the soluble metal concentrations in soils maintained at constant pH was observed. These results indicate the importance of careful land management practices well after applications of sludges to the land have ended (Logan and Chaney, 1983).

Cation exchange capacity (CEC) is also commonly cited in the scientific literature as an important factor in the soluble metal concentration, bioavailability, and uptake of metals cation. In general, the higher the CEC of the soil, the lower the availability of cations. Logan and Chaney (1983) caution that CEC "is best viewed as a general, but imperfect indicator of soil composition that limits the solubility of cadmium and zinc." It is not clear that CEC is a good indicator for other metal cations although it is used in both federal and state regulations to determine allowable application rates for several metals.

New England soils are typically low in both pH and CEC. A recent review of the literature published by Pennsylvania State University (1985) reports that the dominant soil types of the northeast are the Spodosols and Inceptasols, both of which have moderately to strongly acidic pH levels and low CEC levels. Table 11, taken from the Penn. State study (1985), summarizes the findings of soil pH studies throughout the northeast. The results of these studies indicate roughly 80% of the northeast soils sampled fell below the pH 6.5 recommended for lands receiving sewage sludges and would therefore require long term soil pH treatment.

Physical Site Characteristics

An other factor affecting the land application of sludge in the northeast is the availability of cropland meeting the necessary physical requirements to receive sludge safely.

TABLE 11. SOIL pH IN THE EAST - NORTHEAST

State	Crop or use	Duration	Ave pH	Percent in each pH range			
				<5.5	5.6-6.0	6.0-6.6	>6.6
Connecticut	Corn	1980-81	6.2	12	25	38	25
Connecticut	Other field crops	1980-81	6.0	24	30	30	16
Maine	All	1945-55	5.4	62	28	8	2
Maine	All	1945-55	5.5	62	21	13	4
Maine	All	1965-75	5.4	62	23	12	1
Maine	All	1975-80	5.8	39	30	19	12
Maryland	Field	1967-71	6.1	16	25	35	24
Maryland	Field	1972-76	6.2	15	24	34	27
Maryland	Field	1977-81	6.3	15	24	34	27
Maryland	Lawn & garden	1967-71	6.0	26	22	25	27
Maryland	Lawn & garden	1972-76	6.0	25	22	25	29
Maryland	Lawn & garden	1977-81	6.3	22	20	23	35
New York	Alfalfa	1978-79	6.1	18	26	35	19
New York	All	1978-79	6.0	25	29	32	15
New York	Corn grain	1978-79	6.0	22	28	32	15
New York	Corn silage	1978-79	6.0	20	30	31	14
New York	Pasture	1978-79	5.8	38	27	25	10
Pennsylvania	Agronomic	1966-79	6.4	--	--	--	--
Pennsylvania	Agronomic	1980	6.4	7	15	50	28
Vermont	All farm	1980	5.8	--	--	--	--
West Virginia	All	1976-81	5.8	35	21	18	26
West Virginia	Forage	1977-81	5.9	38	23	18	21

Source: Penn. State (1985)

Careful selection of sites for land application is essential for protection of ground water and surface water supplies from contamination by inorganic and organic chemicals as well as by pathogenic organisms. A recent review of soil classification of the northeast indicates that a large percentage of cropland in New England is characterized as unsuitable for land application of sludges (Penn. State, 1985). These results underscore the need for judicious land management (eg. siting) restrictions in land application regulations.

Investigators cited in the Penn. State (1985) study defined several criteria limiting cropland for the receiving sludges:

- Excessively well-drained soils
- Poorly drained soils
- Soils with seasonably high water tables
- Soils subject to flooding
- Soils or slopes permitting rapid runoff
- Soils with low available water capacity

Soils or sites meeting these criteria are associated with a higher probability of contaminating ground water and/or surface water.

Table 12 provides a breakdown of soil classification of New England crop land and the associated limitations for sludge application based on the Soil Conservation Service Classification system (Penn. State, 1985). As the table indicates, a large proportion of cropland in New England falls into categories

TABLE 12. SOIL CONSERVATION SERVICE CLASSIFICATION OF SOILS IN THE NORTHEAST

Class	Limitations for Cultivation	Percentage (%) of Total Land in New England	Percentage (%) of Crops Land in New England(1)
I	Slight	1	5
II	Moderate limitations which restrict choice of crops or necessitate corrective procedures	15	42
III	Severe limitations restricting crop choices or requiring corrective practices	19	36
IV	Very severe limitations for cultivation	10	12
V, VI, VII, VIII	Generally unsuited for cultivation	55	6

Source: Penn. State, 1985

1. Cropland defined as percentage (approx. 17%) of rural, non-federal land.

which, on the basis of the criteria defined above, would be unsuitable to receive sewage sludges. Taken together, a minimum of 30-40% (approx. 37-50 million acres) of New England cropland should be restricted from land application of sludges (Penn. State, 1985).

Despite these restrictions, the acreage available for land application of sludges is still considerable. As far as could be determined, the Penn. State (1985) study included only agricultural land in its calculations leaving the availability of forest lands open for further consideration. Nonetheless, the large percentage of cropland alone that should be restricted from sludge application in order to prevent possible ground or surface water contamination indicates the importance of siting and other land management regulations in protecting human health and the environment.

Subsequent sections of this report will evaluate how well existing regulations address the particular conditions of northeast soils. The discussion will focus on the issues surrounding heavy metal limits and application rates for naturally acidic, low CEC soils rather than on siting restrictions.

D. Metals in Municipal Sludges

Several metals have been detected in municipal sludges raising concerns about possible reduction in crop productivity and hazards to human and animal health resulting from land application of sludges. Table 13 provides a summary of the metals detected in municipal sludge, their mean and 95th percentile concentrations. The values reported in the table are those identified by the USEPA for detailed risk assessment in their initial screening evaluation of toxic constituents of municipal sludge (USEPA, 1985).

The variability in the quality of sludges is substantial and depends on a variety of factors including the nature and level of industrial discharge to the facility. The values reported in the table are derived from national studies; no data has been

TABLE 13. INORGANIC CONTAMINANTS IN SLUDGE EVALUATED BY U.S. EPA (1985)

Identified for Detailed Evaluation	Concentration (mg/kg DW) Mean	95%
Arsenic	4.6	20.8
Cadmium	8.2	88.1
Chromium	230.1	1500
Cobalt	11.6	40
Copper	409	1430
Fluoride	86.4	739
Iron	28,000	78,700
Lead	248	1071
Mercury	1.5	5.8
Nickel	44.7	663
Selenium	1.11	4.85
Zinc	677	4580

compiled to reflect the concentrations typical of New England states. The variability, however, shows that difference must be expected and that monitoring is essential to determine the suitability of any given sludge for land application.

This study has focused on the public health and environmental implications of cadmium and lead in sludges applied to land. Because of cadmium's tendency to bioaccumulate and its association with both phytotoxicity and human toxicity, and lead's neurotoxicity at low levels of human exposure, the acceptable limits set for these metals are typically low. Cadmium and lead therefore tend to be controlling factors in the acceptability of any sludge for land application, particularly for distribution and marketing programs. This emphasis on cadmium and lead does not indicate that other metals do not warrant the same level of evaluation; however, the emphasis reflects the disproportionate level of attention given cadmium and lead in the scientific literature. With the studies being completed by the USEPA, the hazards posed by other toxic metals will likely come into clearer focus.

The following discussions of cadmium and lead attempt to shed light on the scientific basis for their regulation under existing land application regulations and guidelines, the adequacy of that basis, and the applicability of these regulations for the soil conditions in the northeast. For example, what routes of exposure or exposure scenarios were evaluated? What other routes of exposure should have been considered? What does recent research indicate about the level of protection provided by existing regulations? How were conditions like soil pH taken into account?

Cadmium

Cadmium is among the most well studied of metals in sludges largely because of its demonstrated uptake in plants and the widely reported incident of human poisoning (itai-itai disease) from environmental cadmium contamination which occurred in Japan in the late 1970's. Although the factors influencing human exposure to cadmium (uptake in plants, influence of soil pH, effect of dietary deficiencies on human uptake, etc.) are better understood than for most metals, many questions remain. Cadmium in sludges is still an area for active research. This section examines the basis for early cadmium regulations (USEPA, 1979) and guidelines (USEPA, USFDA, USDA, 1981), their adequacy in light of recent research, and their relevance to the northeast.

Logan and Chaney described the original basis for the 1979 USEPA cadmium regulations in a recent review (1983). Their review indicates that the early regulations already accounted for the influence of low soil pH on cadmium uptake and on potential human exposure and toxicity. While the federal regulations on annual and maximum cumulative application rates for cadmium were intended for controlled use of sludges on agricultural and other lands, they were derived from what was considered to be a worst case exposure scenario -- the case of sludges applied to personal 'acid gardens' (Logan and Chaney, 1983).

The assumptions incorporated into that scenario are important in understanding the applicability of the early regulations to northeast soil conditions and are listed here:

- The soil contains the maximum allowed cumulative cadmium application 5 kg/ha.
- The soil is continuously acidic (pH 5.5)
- The gardener obtains 50% of his annual supply of garden vegetables from the sludge amended, acidic soils (potatoes, leafy, root and legume vegetable, and garden fruits-tomatoes)
- The gardener eats from this garden for 50 years
- The individual is part of the sensitive-to-cadmium population
- The individual has a dietary intake of 39 ug/day (based on the teen-age male food intake).

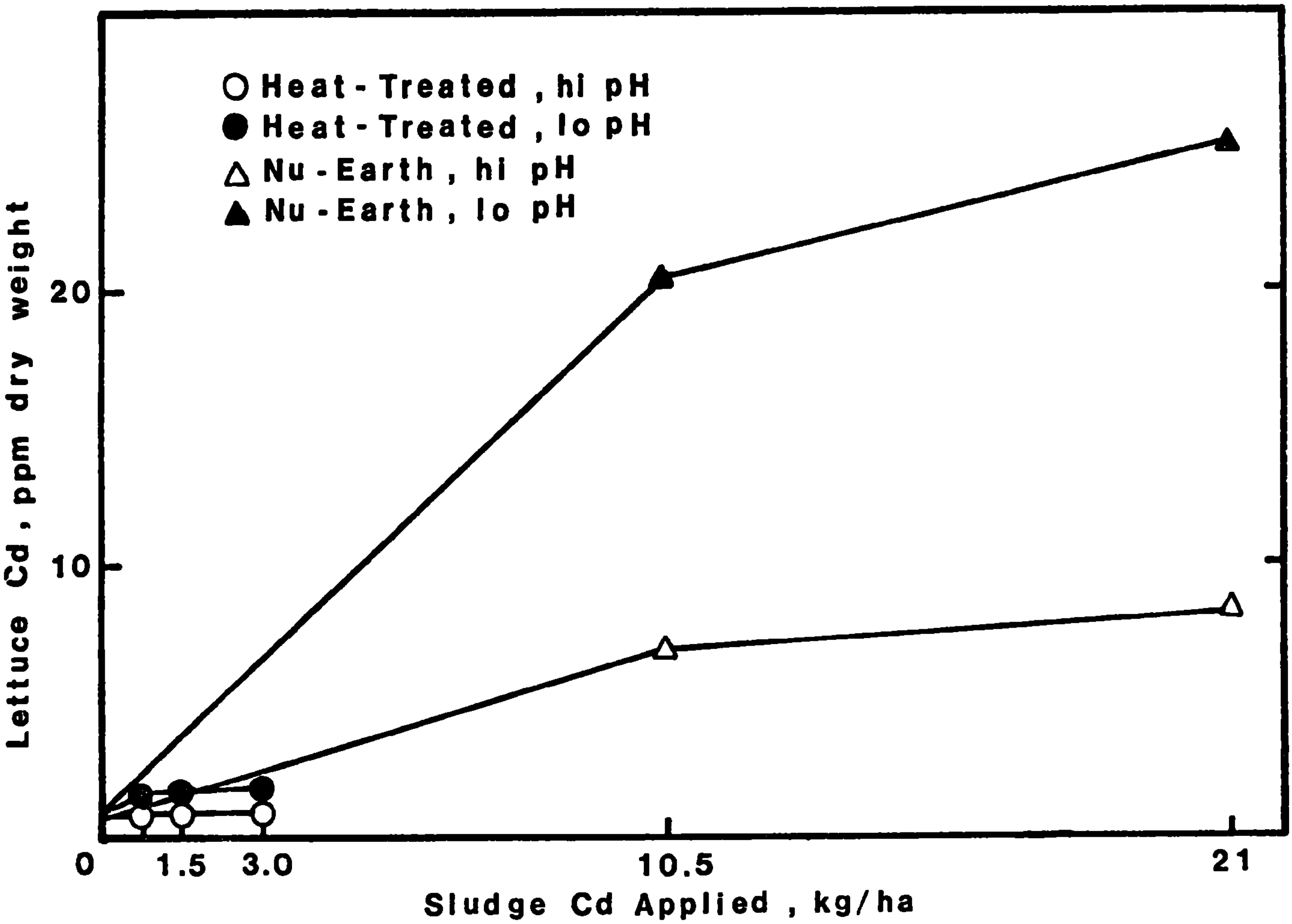
Logan and Chaney (1983) assert that these assumptions are each very conservative and therefore provide multiple factors of safety. They contend that most gardeners growing 50% of their vegetables are likely to be educated about the importance of pH control in maintaining crop productivity and are therefore unlikely to maintain their garden at a pH of 5.5. While their criticism is debatable, Table 11 indicates that (with the exception of Maine soils) the largest percentage of soils are at pH 5.6 or above so the assumption is still conservative. Vegetables also supply the micronutrients (zinc, iron, and calcium) the deficiencies in which define the cadmium-sensitive individual; i.e. individuals with deficiencies in these elements are more susceptible to the uptake and toxic effects of cadmium. Third, increased cadmium in sludge grown vegetables (chard and lettuce -- both 'high uptake' species USEPA, USFDA, USDA, 1981) does not necessarily lead to the theoretically projected increase in kidney cadmium (Logan and Chaney, 1983). Logan and Chaney (1983) cite a study by Ryan et al. (1982) that concludes that in the U.S., sensitive individuals can safely take in up to 150 ug cadmium/day which is higher than the acceptable daily intake used in the scenario. Fourth, the teenage male's dietary intake of cadmium is typically much higher than that of other age and sex groups and therefore is not representative of the general population. More recent versions of this exposure scenario recommend use of the average adult daily intake (Chaney et al, 1986).

One of the most important pieces of research to emerge in recent years is work done by Chaney et al. (1982) which demonstrates in controlled field studies that the cadmium in "low level" cadmium sludges (<25 ppm dry weight as defined by Chaney) is less available for uptake than previously believed at the time of the 1979 regulations. The research indicates that low and high cadmium sludges applied to land will not result in the same level of plant uptake of cadmium even if the total amount of cadmium applied is the same. The uptake rate for cadmium in sludges is not the linear function of cadmium concentration predicted by studies where cadmium is applied as cadmium salts

(Chaney, Sterret, Morella, and Lloyd, 1982). Lower amounts of cadmium appear in plant tissues following sludge application than would be predicted from studies with cadmium salts, particularly for low cadmium sludges. This relationship holds at both low (<6.5) and high (>6.5) pH soils. A new model introduced in 1980 to explain cadmium bioavailability suggests that sludges have intrinsic sorption capacity for cadmium which, with high cadmium sludges, begin to be saturated leaving more cadmium available for uptake. It is this cadmium adsorption capacity, rather than cadmium precipitation as an inorganic compound that regulates cadmium bioavailability (Logan and Chaney, 1983).

Figure 1, taken from the Chaney et al. (1982) study illustrates this relationship. There is a greater uptake of cadmium in lettuce receiving the higher cadmium sludges, showing the importance of initial sludge cadmium concentrations in determining cadmium uptake. The figure also shows that the leaf cadmium concentrations level out at increasing application rates instead of increasing linearly as has been seen in experiments with cadmium salts. This leveling off occurs at both low and high pH levels. The figure also demonstrates the influence of soil pH on cadmium uptake; much higher levels of leaf cadmium are observed in lettuce grown on soil at pH 5.6 than at pH 6.6. Very little difference in cadmium uptake is seen between low and high pH for lettuce grown on soils amended with low cadmium sludge (13.4 mg/kg) but a large difference is apparent for the high cadmium sludge (210 mg/kg). These results, in part, provided

FIGURE 1 The Effect of Sludge Cd, Soil pH, and Sludge Applied Cd on Cd in Romaine Lettuce



Source: Chaney R.L., S.B. Sterrett, M.C. Morella, and CA Lloyd, 1982

Heat-Treated Sludge: Cadimium: 13.4 mg/kg dry weight
Cadmium/Zinc Ratio: 1.01
Lo pH - 5.4
Hi pH - 6.2

Nu-Earth: Cadmium: 210 mg/kg dry weight
Cadmium/Zinc Ratio: 5.07
Lo pH - 5.6
Hi pH - 6.6

support for the 1981 policy guidelines published by the USEPA, USFDA, and the USDA.

The findings illustrated in these experiments have also been demonstrated for copper, zinc, and nickel indicating that the plant uptake of these metals is also more strongly determined by initial sludge metal concentration than by application rate (Logan and Chaney, 1983).

On the basis of these and other findings, a recent USDA bulletin published guidelines defining acceptable levels of several metals in sludge (see Table 14). Sludges meeting these requirements are considered low metal sludges (Hornick et al., 1984). They are essentially the same levels recommended in earlier quidelines (USEPA, USFDA, USDA, 1981) and in the recent Penn State (1985) review.

In addition to research reported above, several investigators noted both in their writings and personal communications that there is another factor of safety in existing guidelines and regulations of cadmium that is frequently overlooked. The factor of safety lies in the recommendation that sludges be applied on agricultural land at agronomic rates; that is, at rates which primarily provide soil conditioning and, secondarily, which help meet the nitrogen and phosphorus requirements of the crop to be grown. (Hornick et al., 1984, personal communication; Brown 1985; Logan, 1986, Personal communication). Agronomic rates are likely to be much lower than the rates theoretically allowable by applying the maximum sludge

TABLE 14. MAXIMUM RECOMMENDED LIMITS FOR METALS IN SLUDGES ACCEPTABLE FOR COMPOSTING

Element	"Maximum domestic Sludge" (mg/kg sludge dry weight)
Arsenic (As)	---
Cadmium (Cd)	25.0
Chromium (Cr)	1,000.0
Cobalt (Co)	200.0
Copper (Cu)	1,000.0
Fluorine (F)	1,000.0
Iron (Fe)	4.0
Lead (Pb)	1,000.0
Manganese (Mn)	---
Mercury (Hg)	10.0
Molybdenum (Mo)	25.0
Nickel (Nj)	200.0
Selenium (Se)	---
Tin (Sn)	2,500.0
Cadmium:zinc (Cd:Zn)	1.5

Source: Hornick et al., 1984

cadmium. For example, investigators at Ohio State studying the effect of land application of municipal sludges on human health, animal health, and crop yield applied sludges in the range of 2 to 10 metric tons per hectare (Mt/ha). A recent USDA bulletin on the utilization of low metal sewage sludge compost strongly recommends application rates of 10 to 20 Mt/ha - rates which substantially improve the physical properties of the soil but which do not necessarily meet the nitrogen requirements of the crop (Hornick et al., 1984). Assuming a sludge cadmium content of 25 mg/kg dry weight and the current maximum allowable annual application rate for cadmium, 1.25 kg/ha (USEPA, 1979), 50 Mt/ha of sludge could be applied. This amount is several times the agronomic rate recommended by the Ohio State study or by USDA. Some investigators argue that it is a physically impractical and expensive volume of sludge for farmers to handle; a combination of sludge application and commercial fertilizers is likely to meet the soil conditioning and mineral requirements of a crop more economically (Hornick et al., 1984). However, assuming a maximum acceptable sludge cadmium content of 25 mg/kg, the total amount of sludge that can be applied will approach agronomic rates when the 0.5 kg/ha maximum annual loading rate for cadmium comes into effect in January of 1987 (USEPA, 1979). At that time, the maximum sludge application rate will be 20 Mt/ha for sludges containing 25 mg/kg cadmium.

Both the unexpectedly low rates of cadmium uptake from 'low' cadmium sludges and use of sludges at agronomic rates appear to provide adequate protection of human health from excessive intake of cadmium from commercial crops or personal vegetables grown on sludge amended soils. However, the 1979 USEPA regulations and later guidelines on sludge application (USEPA, USFDA, USDA, 1981; Hornick et. al., 1984) do not explicitly address some of the other routes of human exposure to cadmium and other toxic constitutents of sludge that could also influence the selection of quality limits or land management practices for land application of sludge.

The USEPA (1985) program currently under direction of the Office of Water Regulations and Standards attempts to address that oversight. As discussed earlier, the USEPA screened several routes of transport and potential human and environmental exposure to identify those routes which presented the most concern. For cadmium, the routes of potential human exposure that are being evaluated in greater detail include:

- ingestion of plants that have accumulated cadmium
- consumption of animal products from animals fed on cadmium contaminated plants
- consumption of animal products from animals which have inadvertently ingested sludge directly
- direct ingestion of sludge (eg. by children).

Draft risk assessment methodologies have been developed to evaluate the impact of these possible exposures by the USEPA Environmental Criteria and Effects Office in Cincinnati but they are not yet available for general public or agency use (Lomnitz, 1986, personal communication).

The current USEPA approach considers possible contamination of groundwater or surface water by heavy metals as a result of land application of sludges. Groundwater contamination is also being evaluated for landfilling of sludges.

Because the USEPA risk assessment methodologies were not available for review, a search was conducted of the recent scientific literature (1980-1986) for studies that could begin to address some of the questions raised about the importance of other routes of exposure. Some evidence is available which suggests that direct domestic animal consumption of sludge adhered to forages or directly from soils while grazing can be an important route of cadmium transport into the human food chain (Logan and Chaney, 1983; Chaney et al., 1986; Reddy et al., 1985). Professor Logan of the Agronomy department at Ohio State University has reviewed some early results of the USEPA's risk assessments which indicate that direct animal ingestion of sludge appears to be a significant route of human exposure (Logan, 1986, personal communication). Direct ingestion effectively bypasses the "soil-plant barrier" created by soil pH control, phytotoxicity of the contaminant, or by the contaminant's inability to be translocated into plant tissues (Logan and Chaney, 1983). Fortunately, the importance of this route of exposure appears to be greater for "metal-rich" sludges than for the recommended "low metal" (<25 ppm Cd) sludges. As in the case of plant uptake, metals in "low metal" sludges are reported to be less bioavailable than in "high metal" sludges (Chaney, Smith, Baker et al., 1986).

Sludge adherence to forages is one of the primary ways in which domestic animals can ingest sludges (Chaney, Smith, Baker et al., 1986). Several factors affect the amount of sludge that adheres to forages: the higher the application rate (within practical rates), the greater the amount of sludge adherence; the higher the percent solids, the greater amount of adherence; and if sludges are allowed to dry on forages (as opposed to being injected or otherwise incorporated), they will adhere strongly even during subsequent rainfall. Forages can reach up to 15-30% sludge (dry weight basis) following application, but other investigators report that "in practical grazing management" (undefined), 2 to 3% is more likely (Chaney, Smith, Baker, et al., 1986). Applying sludge to a recently mowed field and waiting for the crop to grow can keep the sludge content of forage to 3 to 5% by dry weight (Logan & Chaney, 1983).

Direct ingestion of sludges in soils is also a route of exposure, although its significance is difficult to separate from that of sludge contaminated forages. Chaney, Smith, Baker, et al., (1986) cited studies showing that animals ingested 1 to 3% sludge in their diet even when no detectable sludge adhered to forages. Other studies showed ingestion of up to 8% sludge in the diet of animals grazing from pastures (Chaney, Smith, Baker, et al., 1986).

Chaney, Smith, and Baker (1986) report that sludge-borne microelements do not appear to be very bioavailable; they do not necessarily cause the health effects seen in toxicologic studies based on use of metal salt in the diet. They cite studies in which cattle, sheep and swine were fed "low metal" sludges and no increased tissue concentrations of cadmium, zinc, or lead were observed. When the animals were fed "high" cadmium sludges, increased concentrations of cadmium were observed in the liver and kidney, the primary target organs for cadmium.

Metal uptake by cattle was recently evaluated in a major field study conducted by Ohio State University. Reddy et al., (1985) compared the metal uptake in calves and cows grazed on sludge-amended pastures to levels in animals grazed on unamended control pastures. The sludge-amended pastures received sludges at a rate of 2 to 10 Mt/ha. The sludges contained on average, 78 mg/kg DW cadmium, 557 mg/kg DW lead, 5223 mg/kg DW zinc and therefore would be considered "high" metal sludges in light of federal guidelines. Metal uptake was measured by fecal and tissue metal levels.

The study contained several important findings. First, fecal cadmium levels fell to pre-sludge application levels 3-8 months after grazing began on the pastures, indicating the importance of a delay between application and grazing. Second, the study found a significant increase of cadmium and lead in the kidney cortex in sludge exposed calves compared to control calves but found no differences among the cows. No significant differences in zinc or copper uptake were observed in either calves or cows. The study also detected a tendency (not significant) for lead to accumulate in the bones of calves and a statistically significant ($p<.05$) increase in blood lead of exposed cows versus that of controls. Despite the appearance of lead in blood, there was no evidence of metals accumulation in muscle tissues. The authors concluded that the biological significance of the metal uptake was therefore minimized since metals did not appear to accumulate in the primary edible tissue of the animals (Reddy, et al., 1985). No discussion of metal content of dairy products was discussed.

Reddy (1985) also evaluated exposures of farm families to sludge-borne cadmium compared to control farms but found no significant differences. The study monitored fecal cadmium in an attempt to evaluate cadmium exposures from a variety of potential sources: inhalation of cadmium laden dust while working in the fields, ingestion of cadmium from ground water draining the fields, or ingestion of meat products from animals grazing on sludge amended soils. Families were not permitted to grow vegetables on sludge-amended gardens. The primary limitations of this study were the relatively small sample size and the absence of any data to indicate what real exposures might have been (eg. via air or ground water). The latter problem in particular makes it difficult to determine whether farm families are at no greater risk of exposure to metals in sludges applied at 2 to 10 Mt/ha or that the exposures encountered have any biological significance.

Contamination of ground and surface water supplies have often been cited as an area of concern but they have not been studied much to date. The preliminary indications from available data are that leaching of metals appears to be less of a concern than runoff (Logan and Chaney, 1983). Each route of transport will be discussed briefly.

Metal cations do not leach readily from soil. However when sludge is heavily applied to a soil with low pH, metals can move up to several meters. Some of the examples cited by Logan and

Chaney include a case where chromium, copper, and zinc were detected 2 meters below a sludge drying bed and nickel and cadmium were detected at 3.5 meters below the bed. Cadmium was detected 45 centimeters beneath agricultural land receiving 135-148 Mt/ha. In both cases, the volumes of sludges were much higher than agronomists recommend for agricultural uses of sludge. (The initial metal content of the sludges was not specified). Logan and Chaney (1983) suggested that application rates below 15 Mt/ha should pose no threat to groundwater supplies.

Even less information is available in the literature reviewed on the potential impact of land application of metal containing sludges on surface water. Logan and Chaney (1983) noted that runoff is a potentially greater problem but felt that "proper site selection and sludge application management should be adequate to protect water resources from metal contamination from surface water runoff and erosion."

Lead

Although lead is not as well studied as cadmium in the context of land application of municipal sludges, it has received considerable attention as an environmental contaminant because of its adverse effects on the nervous system associated with even low levels of exposure. The absence of federal regulations governing sludge quality limits or land application rates for lead has been rectified in part by subsequent federal guidelines (USEPA, USFDA, USDA, 1981) and several state regulations.

Unlike the case of cadmium, the basis for these guidelines and regulations (i.e. the scenarios or assumptions used) are not clear. Lead is not phytotoxic and its limited uptake by plants is not strongly affected by pH and other characteristics of soil that are important for cadmium uptake. As for cadmium, though, the USEPA is in the process of developing risk assessment methodologies with which to evaluate the public health impact of lead in sludges applied to land. Since those methodologies are not yet available, this section of the report evaluates some of the recent scientific evidence on the importance of various routes of exposure to lead in municipal sludges. This evaluation can then serve as a basis for the critical assessment of the methodologies and their use in regulation development.

In its screening of the potential public health and environmental impacts from land application of municipal sludges, the USEPA evaluated the same routes of human exposure to lead as were considered for cadmium and the other contaminants; uptake from plants, consumption of animal products from animals fed on plants which had taken up lead, consumption of animal products from animals which directly ingested sludge or sludge-amended soils, and direct human ingestion of sludge or sludge-amended soils (USEPA, 1985).

The results of the screening were that the only routes of exposure identified for detailed evaluation in the second phase of the USEPA program were consumption of contaminated plants and direct ingestion of sludges or sludge amended soils. These results are partly at odds with conclusions reached in the review of scientific literature during this study. It is not clear that the USEPA will rely solely on the results of the screening process to dictate the routes of exposure to be considered in detail. A discussion with Professor Logan of Ohio State University indicated that direct consumption of sludges by animals and subsequent human ingestion of animal products appeared to be an important route of exposure to sludge contaminants on the basis of detailed risk assessments completed by USEPA (Logan, 1986, personal communication).

The USEPA screening evaluation indicated that consumption of plants grown on sludge amended soils warranted further evaluation as a route of exposure to lead. This result is surprising in light of scientific research findings. The USEPA screening model considered only the uptake of a contaminant into plant tissues. Lead is a non-essential element for plants as well as animals. Chaney (1983) (cited in Logan and Chaney, 1983) reported that plants do not have a tendency to incorporate lead unless the lead content is "very high", such as the levels associated with land treatment of hazardous wastes or under conditions where the phosphate levels in soil are very low. Low phosphate levels in soil appear to promote lead translocation into plant tissues (Penn. State, 1985). In fact, as for cadmium, application of lead in low metal sludges appears to decrease plant-available lead even though the concentration of lead in the soil is increasing. This phenomenon was observed in all crops studied including grains, fruits, tubers, edible roots, and leafy vegetables (Logan and Chaney, 1983). The mechanism for limiting the availability of lead may be similar to the sludge sorption capacity reported for cadmium.

Concern about exposure to lead from plants grown on sludge amended soils might better be focused on surface contamination of root crops (Penn. State, 1985). Plant lead is usually much higher in roots than in the tops. Report correlated with the lead levels in soils indicating that adherence of particulate lead to plant surfaces may be an important mechanism for lead contamination of plants (Penn. State, 1985). This finding argues strongly for limitations on the maximum cumulative levels of lead that can be added to soils by land application of sludges, particularly because the addition of lead is essentially "permanent and irreversible" (Penn. State, 1985). Monitoring for background levels of lead in soils receiving sludges would also be advisable given the demonstrated and ongoing contribution of lead in gasoline to soil lead levels.

The USEPA, USFDA, USDA (1981) guidelines recommend a maximum cumulative lead application of 800 kg/hectare. They further recommend that "crops grown on sludge - or compost - amended soils particularly root crops and low growing fresh fruits and vegetables, be processed in accordance with established industry practices".

Direct ingestion of sludges or sludge amended soils is a potentially important route of exposure to lead for young children or infants who intentionally ingest small quantities of soil (a condition known as pica) or inadvertently ingest soil from soiled hands or toys. Exposures to low levels of lead create concern because of studies which suggest that neurological impairment (defined by lower IQ, school achievement, and other problems in classroom behavior) is associated with increased levels of lead in deciduous (baby) teeth (Needleman, 1979, 1980; Winneke et al., 1981). Lead levels in deciduous teeth indicate lead exposures at a young age.

Despite these concerns, the consensus in the literature reviewed for this report is that further research is needed on the effect of low lead sludges on infants and children. Logan and Chaney (1983) cite several studies indicating that individuals may absorb "excessive" amounts of lead by ingesting soils "rich in lead", 500-1000 mg/kg. The relevance of these findings to lead exposures in children versus that in adults is not clear. The detailed evaluations of this route of exposure currently underway by the USEPA should provide valuable assistance in answering this question. The ultimate importance of this route should provide a basis for setting more stringent lead limits in sludges intended for use in private gardens or other locations where young children may play.

The USEPA's apparent elimination of direct animal ingestion of sludges as a route of human exposure to lead may be an important oversight. As in the case of cadmium, although plant uptake of lead is minimal under normal conditions, this "soil plant" barrier can be bypassed effectively by animals ingesting sludge directly. The section on cadmium discussed in detail how animals can take in sludges adhered to forages or directly from soils while grazing. The scientific debate revolves around the biological and toxicological significance of this route of exposure.

Logan and Chaney (1983) concluded that "domestic" or "low" metal sludges as defined in the USEPA, USFDA, and USDA policy guidelines (1981) and in recent USDA (Hornick et a., 1984) guidance (Table 14) pose no risk to livestock or human adults through plant uptake or soil ingestion by animals. While plant uptake of lead may not be significant, investigators at Ohio State University have recently completed field studies of the uptake of metal contaminants in sludge by grazing animals that indicate that animal uptake of metals does occur via direct ingestion. The study, discussed in more detail in the cadmium section, looked at differences in fecal and tissue lead levels between calves and cows grazing on sludge-amended pastures and animals grazing on control pastures. Pastures received sludges at application rates of 2-10 Mt/ha and with average lead concentrations of approximately 557 mg/kg dry weight (Reddy et al., 1985). The average lead concentrations therefore appeared to be within the commonly recommended levels (1000 mg/kg).

The study did find some association between grazing on sludge-amended pastures and tissue lead levels, although the significance of those levels for human health was not discussed. Lead concentrations were higher in the kidney cortex of exposed calves compared to control calves but not in cows. The study found a significant ($p<.05$) increase in lead in cow blood and a tendency (not significant) for lead to accumulate in calf bones. There was no evidence of lead or other metal accumulation in muscle tissue, the predominant source of meat for human intake. Although it is not clear how the tissue analysis was conducted, it appears possible that human exposure to lead in muscle tissue could still occur as a result of the blood lead observed in the study. Risk evaluation of the lead levels observed would be necessary and advisable to determine if the calves' lead exposure was excessive.

Despite these equivocal finding, Professor Logan at Ohio State University noted recently that from his review of the USEPA's draft risk assessments, direct animal consumption of sludges appeared to be a significant route of human exposure and one which might well provide a driving force behind new federal regulations, particularly those governing land management practices (Logan, 1986, personal communication). Lead was not mentioned specifically in this conversation so the USEPA's risk assessment methodologies should be carefully evaluated in light of the findings of the field studies discussed above. Studies like that completed by investigators at Ohio State University are uncommon and provide an important touchstone for the more theoretical risk assessment models.

E. Organic Chemicals in Municipal Sludges

Until recently, organic chemical contaminants of municipal sludge have not received the research or regulatory attention accorded their inorganic counterparts. Polychlorinated biphenyls (PCBs) are the only class of organic chemicals currently covered in federal and state land application regulations. Organic priority pollutants have also been detected in studies evaluating the quality of sludges from wastewater treatment facilities. The ultimate fate of these compounds, in subsequent composting or other stabilization processes and once they have been applied to the land, has not been well characterized. The USEPA is currently evaluating the public health and environmental risks posed by various organic contaminants of municipal sludge. Other investigators, both at EPA and at universities, are evaluating aspects of the fate and impact of specific organic chemicals in municipal sludges. In the words of one investigator, however, " the detailed research and field investigations necessary to document the land treatment behavior of specific organics has only just begun " (Overcash, 1983).

This section reviews the initial basis for the PCB regulations, the work to date on organic chemicals in municipal sludge, and the relevance of the recent work to concerns of the northeast. Despite the limited amount of research available on the fate, public health , and evironmental impact of organic chemicals in composted sludges applied to land, some conclusions can be made. The more persistant, less biodegradable chemicals pose the greatest potential hazards to public health and the environment largely because they survive the treatment and any subsequent stabilization processes in greater concentrations than volatile or more readily degradable compounds.

A summary of the organic priority pollutants that have been identified in municipal sludges appears in Table 15 (USEPA, 1985). These are the constituents that the USEPA selected to screen initially for potential public health and environmental impacts. The screening process ultimately identified 10 compounds, principally pesticides, for further detailed risk assessment. Those compounds, their mean and 95th percentile concentrations (mg/kg dry weight) are reported in Table 16. The detailed risk assessments to be completed this year by the USEPA will ultimately help determine whether these compounds warrant regulatory action.

It is not clear that either the initial chemicals screened or those identified for detailed assessment are representative of significant contaminants of sludges in the northeast. Several of the 10 compounds are pesticides which have been banned or severely restricted for use in the United States (aldrin/dieldrin, chlordane, heptachlor, and DDT, in particular) in recent years. Data on a wide range of organic chemicals are generally not available on a regional basis and do not easily

TABLE 15. ORGANIC CONTAMINANTS OF MUNICIPAL SLUDGE EVALUATED BY USEPA (1)

Identified for Detailed Evaluation	Eliminated from Detailed Evaluation
Aldrin/dieldrin	Benzene
Benzo(a)pyrene	Benzidine
Chloroane	bis(2-ethyl hexyl) phthalate
DDT/DDE/DDD	Benzo(a)anthracene
Heptachlor	Carbon tetrachloride
Hexachlorobenzene	Chloroform
Hexachlorobutadiene	3,3-Dichlorobenzidine
Lindane	Dichloromethane
PCBs	2,4-Dichlorophenoxy acetic acid
Toxaphene	Dimethyl nitrosamine
	Endrin
	Malathion
	Methyl ethyl ketone (2)
	Pentachlorophenol
	Phenanthrene
	Phenol
	TCDD (2)
	TCDF (2)
	Tetrachloroethylene
	Trichloroethylene
	2,4,6-Trichlorophenol
	Tricresyl phosphate
	Vinyl chloride

(1) Source: U.S. EPA, 1985
(2) Insufficient data to evaluate

TABLE 16. MEAN AND 95TH PERCENTILE SLUDGE POLLUTANT CONCENTRATIONS (1)

	Mean	95%(2)
	mg/kg DW	
Aldrin/dieldrin	0.07	0.81
Benzo(a)pyrene	0.14	1.94
Chlordane	3.2	12
DDT/DDE/DDD	0.28	0.93
Heptachlor	0.07	0.09
Hexachlorobenzene	0.38	2.18
Hexachlorobutadiene	0.3	8
Lindane	0.11	0.22
PCBs	0.99	2.9
Toxaphene	7.88	10.79

(1) Source: U.S. EPA, 1985.
(2) 95% of observations are at or below this level.

permit comparisons between domestic and more industrial sludges (Overcash, 1983).

Analytical data for effluents and/or sludges from 12 Massachusetts cities and towns, primarily located in the eastern half of the state, were reviewed during this study. The purpose of the review was to make a preliminary determination about the presence of the 10 compounds listed in Table 16 in New England sludges. Unfortunately, no determination could be made on the basis of the data supplied. Of the 12 plants, only one analyzed its sludge for organic priority pollutants. Three plants analyzed for and reported detectable concentrations of lindane and toxaphene but the analysis conducted was for EP Toxicity, a measure of the leachability, rather than for total concentration of each compound in sludge. Therefore, the results are not comparable to the values reported for USEPA. No analyses were conducted for any of the other organic compounds identified by the USEPA for detailed consideration.

The limitations of the data illustrate the difficulties involved in assessing the regional need for regulation of specific organic contaminants based on the results of national sludge quality surveys. Since monitoring for the organic priority pollutants is not required for all sewage treatment plants, the necessary data are not available. Monitoring for non-priority pollutants that may be of concern locally is even less common. A prudent initial approach would be to review carefully the results of the USEPA's detailed risk assessment, identify those compounds that pose the greatest health risks, evaluate the likelihood that these compounds would appear in local or regional sludges, and where necessary, conduct a carefully targeted sampling program.

The only organic chemicals currently included in regulations governing land application of sewage sludges are the polychlorinated biphenyls. The reason for the limited coverage of the regulations was not clear from review of regulations and scientific literature or from conversations with state and federal regulators.

As with inorganic contaminants, there are several known and theoretical routes of human exposure to organic contaminants in sludges applied to land. The USEPA identified four routes of exposure to evaluate for the 10 chemicals: human consumption of plants, human consumption of animal products contaminated either by animal ingestion of plants or direct animal ingestion of sludge, and direct human ingestion of sludge (eg. by infants or children) (USEPA, 1985). Some recent research findings on the significance of these routes follow.

Factors governing the uptake of organic chemicals by plants are not very well understood. Overcash (1981,1983) has conducted extensive reviews of the scientific literature on the fate of organic chemials applied to land. In his 1983 paper he concluded that, although a number of studies have been conducted on individual chemicals, no good mechanisms for predicting the level of chemical uptake in plants currently exist. The relationship is highly soil-, chemical-, and plant-specific.

Investigators at the USEPA in Cinncinati are currently evaluating plant uptake of organic chemicals in sludge applied to land. They are evaluating the compounds that are most frequently detected in the highest concentrations in sludges such as the phthalate acid esters (di-n-butyl and bis-2-ethylhexyl phthalates) and polycyclic aromatic hydrocarbons (eg. anthracene, benzo(a)pyrene), p-dichlorobenzene, etc. (Ryan, 1986, personal communication). Although some of these compounds were included in the original list of chemicals to undergo screening, none of them appeared in the list selected for detailed risk assessment. Nonetheless, they are chemicals which are also relatively persistant and difficult to biodegrade.

Some of the preliminary conclusions reached by the investigators at the USEPA are that most organic chemicals do not partition into plant tissues with the exception of some pesticides. Furthermore, the chemicals must typically be applied in concentrations orders of magnitudes higher than concentrations normally detected in sludges (Ryan, 1986, personal communication). These findings appear to support the preliminary screening results published by the USEPA (1985).

As for metals found in sludges, direct ingestion of sludge by animals appears to be one of the most important ways in which organic contaminants of sludges can be transmitted via the food chain to humans. Sludges on forages can contribute 15-30% of the total weight on a dry weight basis immediately following application. This sludge content may be reduced to 2 to 5% where waiting periods are imposed before harvest. Animals have been reported to ingest from 1 to 8% sludge in their diet when grazing from pastures (Chaney, Smith, Baker, et. al. (1986).

The current USEPA regulations for PCBs reflect concern about the importance of direct ingestion of sludge on forages as a route of human exposure. While it is unclear how the 10 mg/kg limit was derived, the regulations require that " solid waste containing concentrations of PCBs equal to or greater that 10 mg/kg (dry weight) is incorporated into the soil when applied to land used for producing animal feed, including pasture crops for animals raised for milk" (USEPA, 1979). The 10 mg/kg limit appears to be based on the final anticipated concentrations of

PCBs in animal feed or in milk since the requirement can be waived if the concentrations in feed and milk do not exceed 0.2 mg/kg (actual weight) and 1.5 mg/kg (fat basis) respectively. However, Hornick _et al_. (1984) state that the 10 mg/kg of PCBs is based on an assumption that "carrots receive appropriate processing, including scrubbing and peeling".

The USEPA is evaluating ground and surface water contamination as routes of human exposure to organic chemicals from sludges. Little research has been done in this area. However, two investigators have indicated that leaching does not appear to be a major concern. Overcash (1983) wrote that leaching of organics is "insignificant if;

1. the municipal effluent or sludge land treatment occurs at normal [undefined] application rates,
2. a reasonable drainage and cyclic establishment of sustained aerobic soil conditions occur, and
3. groundwater remains deeper than 1-2 feet from the soil surface."

Leaching has not been reported for such "reasonable " conditions.

The exceptions to these general observations might be sandy or gravel conditions which allow rapid infiltration or conditions which allow rapid runoff (Overcash, 1983). Ryan (1986, personal communication) noted that the solubility and thus leachability of organics is positively correlated with the ability to be biodegraded. Since concentrations of organic chemicals typically found in sludge are relatively low, biodegradation can successfully compete with leaching for the fate of some chemicals applied to land in municipal sludges.

Several research objectives need to be met in order to understand better the possible impact of the land application of organic chemicals in sludges on human health (Overcash, 1983) These objectives include:

- the relationship between the level of a contaminant in vegetation and the annual human intake it represents must be established to estimate human health impact
- the rates of decomposition of organic chemical occurring in sludges must be understood better to verify or correct data collected on pure compounds
- non-priority pollutants detected in sewage sludges need to be evaluated in terms of their potential human or enviromental impact and added to the priority pollutant list if appropriate.

The first of these objectives may begin to be met by the detailed risk assessment methodologies currently under development, but the latter two are areas for ongoing research.

F. Pathogens in Municipal Sludge

The purpose of this section is to assess the public health and environmental risks associated with land application of compost that has undergone processes to significantly reduce pathogens (PSRP) and processes to further reduce pathogens (PFRP). The review provides a basis for assessing the likelihood of surface or ground water contamination from runoff or leachate of compost-amended soils, and the likelihood of animal or human infection from applications of sludge between hay crops that has undergone only PSRP. The scope of this project limited the assessment to composting as the only form of PSRP or PFRP evaluated.

The approach taken to assess the environmental and health risks associated with compost-amended soils included:

- Identification of pathogens of most concern in primary and secondary treated municipal wastewater sludge, their densities, animal or human hosts

- Assessment of the effectiveness of composting by PSRP and PFRP. What pathogens found during and after composting are a problem?

- Evaluation of the environmental fate of surviving pathogens in compost applied to land. How long will they survive in soil, water, and on plants?

- Identification of the routes of animal and human exposure to pathogens in compost amended soils--direct ingestion, skin contact, and food and water contamination. How likely is infection via these routes? What do epidemologic studies addressing the health risks of compost-amended soils indicate about the risks associated with land application programs?

The following sections will address each issue.

Pathogens in Sewage Sludge: Overview

This section will discuss the pathogens of most concern in primary and secondary treated municipal wastewater sludge. It reviews the occurrence, abundance, and significance of pathogens in sewage sludge before evaluating the effectiveness of composting and residual risk associated with land application of composted sludge.

Pathogens found in sewage sludge can be divided into three groups: bacteria, viruses, and parasites. A fourth group of pathogens, fungi, proliferate during the composting process. The significant pathogens from each group are discussed below.

Bacteria. There appears to be a general concensus among contributors to the literature that the bacterial pathogens of most concern to human health are those listed in Table 17 (Venosa, 1985). Many have important non-human reservoirs as well. The most important bacteria are the enteric bacteria, which originate in the human intestine and are discharged to wastewater through urine and feces of infected individuals. These pathogens have an affinity for the solid component of wastewater that comprises sludge.

Table 18 summarizes the average densities of indicator organisms and pathogens in primary and secondary treated wastewater sludge. The densities reported for fecal indicator bacteria range from 10^6 to 10^8 per gram dry weight and for pathogenic bacteria 10^1 to 10^4 per gram dry weight. Salmonella and Shigella spp., are the most common bacterial pathogens in municipal wastewater (Venosa, 1985).

TABLE 17. BACTERIAL PATHOGENS IN SLUDGE AND THEIR ASSOCIATED DISEASES

Organism	Disease
Campylobacter jejuni	Gastroenteritis
Escherichia coli (enteropathogenic strains)	Gastroenteritis
Leptospira sp.	Leptospirosis, infectious jaundice
Salmonella spp.	Gastroenteritis, enteric fever
Shigella spp.	Acute dysentery
Vibrio cholerae	Cholera
Yersinia spp.	Yersiniosis, gastroenteritis

Source: Venosa, 1985.

TABLE 18.
DENSITY OF BACTERIA IN RAW SLUDGES (AVERAGE GEOMETRIC MEAN OF ORGANISMS PER GRAM DRY WEIGHT)

Organism	Primary	Secondary
Total coliforms	1×10^8	7×10^8
Fecal coliforms	2×10^7	8×10^6
Fecal Streptococci	9×10^5	2×10^6
Salmonella spp.	4×10^2	9×10^2
Pseudomonas aeruginosa	3×10^3	1×10^4

Source: Venosa, 1985.

Variability in literature values of pathogen densities in sludge is high. The concentrations of these pathogens in wastewater vary with the incidence of disease in the community and, for some organisms, with fluctuations in climate. Fecal coliforms and fecal streptococci tend to be more constant than other pathogens in sludge because they are inherent organisms of the general population.

Another factor is the variability in methodologies used to quantify the bacteria levels. Standardization of the quantitive and qualitive techniques for analyses of bacteria will help reduce the variability of data and ensure better interpretation of the meaning of the results (Venosa 1985).

Viruses. More than 110 different virus types may be present in raw sewage. Table 19 lists those that are generally of greatest concern. These are viruses which infect either the respiratory or gastorintestinal tracts of humans, which are excreted in the feces of infected individuals, and/or which are stable in the adverse environment found in wastewater treatment and transport (Moore et. al., 1985).

Like bacteria, viruses are most concentrated in sludge because of their affinity for solids. Literature values for the concentration of viruses in primary sludge range from 2.1 to

TABLE 19. VIRUSES IN SEWAGE SLUDGE

Virus	Associated Disease
Enteroviruses	Gastroenteritis, heart anomalies, meningitis
Rotaviruses	Gastroenteritis
Parvovirus-like agents	Gastroenteritis
Adenoviruses	Respiratory disease, conjunctivitis
Hepatitis A virus	Infectious hepatitis
Poliovirus	Polio

Source: Taffel, 1978.

1,429 plaque forming units per gram of total suspended solids. Moore *et al.* (1985) reported anaerobically digested sludge which contained a range of viruses from <0.1 to 148 plaque forming units per gram of total suspended solids. Variability in concentrations are dependent on population and climate as well as on difficulties with available analytical methods.

Although enteroviruses appear to best define the relative degree of viral contamination of sludges, problems with analytical methods can mean that viruses of important public health concern go unreported. Hepatitis A virus and rotavirus require elaborate assay procedures, while others such as Norwalk virus have not been grown outside the human host (Moore et. al., 1985).

Parasites. Several parasitic organisms have been detected in municipal sludges (Table 20). The parasites most commonly found in domestic sludges are the ova (eggs) of *Ascaris*, *Trichuris* and *Toxocara* species. Table 21 lists the percentage of treatment plants in northern states which detected ova of these parasites and the average number of ova found per kilogram of dry weight of sludges destined for disposal.

Ascaris ova are considered to be the most resistant form of any sewage pathogen (Little, 1985). Most wastewater treatment processes are not effective in killing them (Little, 1985).

TABLE 20 PARASITES IN SEWAGE SLUDGE

Pathogen	Disease
Protozoa	
Entamoeba histolytica	Amoebic dysentery, amebiasis
Giardia lamblia	Giardiasis
Balantidium coli	Balantidiasis
Naegleria fowleri	Meningoencephalitis
Acanthamoeba	Meningoencephalitis
Helminths	
NEMATODES	
Ascaris lumbricoides	Ascariasis
Ancylostoma duodenale	Ancylostomiasis, hookworm infection
Necator americanus	Necatoriasis, hookworm infection
Ancylostoma braziliense (cat hookworm)	Cutaneous larva magrans
Ancylostoma caninum (dog hookworm)	Cutaneous larva migrans
Enterobius vermicularis (pin worm)	Enterobiasis
Strongyloides stercoralis (threadworm)	Strongyloidiasis
Toxocara cati (cat roundworm)	Visceral larva migrans
Toxocara canis (dog roundworm)	Viscera larva migrans
Trichuris trichura (whipworm)	Trichuriasis
CESTODES	
Taenia saginata (beef tapeworm)	Taeniasis
Taenia solium (pork tapeworm)	Taeniasis
Hymenolepis Nana (dwarf tapeworm)	Taeniasis
Echinococcus Granulosus	Unilocular enchinococcosis
Echinococcus Multilocularis	Alveolar hydatid disease

Source: Taffel, 1978.

TABLE 21 PERCENTAGE OF FINAL SLUDGE SAMPLES NORTHERN STATES VIABLE EGGS OF *ASCARIS*, *TRICHURIS*, *TRICHIURA*, *T. VULPIS* AND *TOXACARA*, AND MEAN NUMBERS OF EGGS FOUND

Parasite Eggs	% of Samples Containing Eggs	Northern States N = 143 Mean No. Eggs/ Kg Dry Wt.
Ascaris	48%	782
T. trichiura	22%	107
T. vulpis	38%	170
Toxocara	5%	143

Source: Little, 1985

Cysts of protozoa are occasionally recovered from untreated sludges, however, they are rarely found in treated sludges. Due to their low specific gravity, they do not settle rapidly and primarily end up in the effluent discharge (Little, 1985).

The detection of parasites in sludge presents several problems which make it difficult to determine the level of parasite contamination of sludge. The developmental stages of parasites (principally ova) do not multiply in cultures and are typically present in low densities. Each cyst or egg has to be identified morphologically by a microscope, a time consuming procedure requiring a highly trained technician.

Pathogen Kill Effectiveness of PSRP/PFRP Standards

The purpose of this section is to compare the pathogen kill effectiveness of composting by processes to significantly reduce pathogens and further reduce pathogens (PSRP/PFRP) in order to evaluate the health or environmental risks from pathogens that may be associated with land application of composted sludge. Within the limits of this research, no study was found specifically comparing PSRP and PRFP pathogen kill effectiveness. In most of the studies reviewed (i.e., Venosa (1985), Passman (1978), Reimers et al. (1985), Little (1985), Moore et al. (1985)), where composting was mentioned, no distinction was made between PSRP and PFRP conditions. The only study where it was clear that PFRP conditions were met was in the two step windrow system described by Hay et al. (1985).

Destruction of viruses, protozan cysts and helminth ova means irreversible elimination of these public health risks unless more viruses, cysts, or eggs are introduced to the finished compost. In contrast, a small number of surviving bacteria can proliferate in the rich organic matrix of finished compost if post-composting conditions favor regrowth. Also, composting itself promotes proliferation of many thermophilic fungi such as Aspergillus fumigatus, actinomycetes, and mucorales.

The definitions of composting for PSRP and PFRP are given in Appendix B in Volume II of this report. The key difference between the two levels of pathogen reduction are temperature and time.

Processes to significantly reduce pathogens including the in-vessel, static aerated pile, or windrow composting methods, require the sludge to be maintained at minimum operating conditions of 40°C for five days. For only four hours during this period, the temperature must exceed 55°C.

Processes to further reduce pathogens require periods at higher temperatures. Using the in-vessel or the static aerated pile composting methods, the sludge must be maintained at operating conditions of 55°C or greater for three days. When windrow composting method is used, the sludge must attain a temperature of 55°C or greater for at least 15 days during the composting period.

For a sludge treatment process to qualify as a process to significantly reduce pathogens, it must produce a reduction in pathogens at least equivalent to that obtained by good anaerobic digestion (Venosa, 1985). This definition is based on the observation that agricultural use of anaerobically digested sludge as a fertilizer has been practiced for many years with no evidence that the practice has caused illness, (Venosa, 1985). The scientific information related to the survival and transport of pathogens in sludge-amended soils was not incorporated.

None of the papers reviewed for this report defined the basis for PFRP requirements, although it appears that they were developed in recognition of the limited pathogen kill effectiveness of PSRP.

Several factors affect pathogen survival during treatment and their final concentration in composted sludge: temperature, shielding by organic matter, and regrowth. Fungi present a separate problem since they can proliferate during as well as after the composting process.

In composting, heat is the primary factor contributing to pathogen inactivation (Passman, 1978), but the heat resistance of organisms is highly variable. The D-values listed in Table 22, the time at given temperature required for a 10-fold reduction in population, illustrates this variability. Some organisms, such as bacteriophages, require several times longer periods at 55°C to be inactivated than other organisms. The time for bacteriophage, 4 hours and 27 minutes, is slightly longer than the 4 hours at which sludge would be held at 55°C in PSRP. These D-values are only a rough indicator of resistance since they were obtained from pure cultures in liquid media under laboratory

TABLE 22. TIME REQUIRED FOR A 10-FOLD POPULATION REDUCTION OF VARIOUS MICROORGANISMS BY HEAT, D-VALUE.

ORGANISM	D-Value at 55°C	D-Value at 60°C
	Minutes	
Adenovirus, 12	11.0	0.17
Ascaris ova	--[b]	1.3
Poliovirus, type 1	32.0	19.0
Hystolytica cysts	44.0	25.0
Salmonella	80.0	7.5
Coliforms	---	2.0
Staphlococci	---	3.3
Streptococci	---	15.0
Bacteriophage, f2	267.0	47.0

Sources: Hornick *et al.*, 1984 and Burge *et al.*, 1977

(a) D-Value: time necesary at a given temperature to cause a 10-fold reduction in the number of organisms.
(b) ---- Dash indicates no value reported.

conditions. Naturally occurring populations tend to be hardier and more likely to persist under treatment conditions (Passman 1978).

Despite their limitations, the D-values reported here can be used to illustrate the relative effectiveness of PSRP and PFRP. Table 23 presents the reduction factors for various microorganism calculated on the basis of their D-values and the time required at 55°C for PSRP and PFRP. Table 24 presents the density of organisms (per gram dry weight) in sludge estimated by multiplying the reduction factors by reported initial concentrations of various microorganisms in primary and secondary sludge. As Table 24 indicates, PFRP reduce organisms by a much greater factor than PSRP. PSRP (55°C at 240 minutes or 4 hours) only reduces the number of bacteriophage to 1×10^4 organism/gdw whereas PFRP (55°C at 4320 minutes or 3 days) reduces the number of bacteriophage to 1.3×10^{-11} per gdw.

In practice, a number of factors besides heat influence the overall effectiveness of PSRP and PFRP at pathogen reduction. Studies evaluating the effectiveness of composting and the factors influencing survival for bacteria, viruses, parasites, and fungi are discussed below.

Bacteria. Several authors have demonstrated that pathogenic bacteria can be virtually eliminated during composting if aerobic conditions and temperatures above 60°C can be maintained for prolonged periods (Hay *et al.*, 1985; Venosa, 1985). However, even when populations are reduced to undetectable levels a

TABLE 23. PATHOGEN REDUCTION FACTORS FOR PSRP AND PFRP USING D-VALUES @ 55° C

Organism	D-Value @ 55°C	PSRP 240 min (4 hours)	PFRP 4320 min (3 days)
Adenovirus	11.0	$1x10^{-22}$	$1x10^{-340}$
Poliovirus type 1	32.0	$1x10^{-8}$	$1x10^{-130}$
Hystolytica cysts	44.0	$1x10^{-6}$	$1x10^{-98}$
Salmonella	80.0	$1x10^{-3}$	$1x10^{-54}$
Bacteriophage f2	267.0	$1x10^{-.9}$	$1x10^{-16}$

Sources: Hornick et al., 1984 and Burge et al., 1977.

(a) D-Value: Time necessary at given temperature to cause a 10-fold reduction in the number of organisms.

TABLE 24. ESTIMATED REDUCTION IN PATHOGENS POPULATION AFTER COMPOSTING BY PSRP AND PFRP USING D-VALUES @ 55°C

Organism	Initial Density in Raw Sludge (per gram dry weight[a])	Projected Density in Compost following:[b] PSRP	PFRP
Adenovirus PFU	3.9×10^{2} PFU[c]	3.9×10^{-20} PFU	3.9×10^{-391}
Poliovirus type 1	3.9×10^{2} PFU	3.9×10^{-6} PFU	3.9×10^{-132} PFU
Hystolytica cysts agm	2.1×10^{2} agm[d]	2.10×10^{-4} agm	2.10×10^{-96}
Salmonella	$8.8 \times 10-^{2}$ agm	0.88 agm	8.8×10^{-52} agm
Bacteriophage f2	1.3×10^{5} agm	1.0×10^{4} agm	1.3×10^{-11} agm

(a) Source: Hornick *et al.*, 1984; Burge *et al.*, 1977; Grasso *et al.*, 1985; and Ahlsrom *et al.*, 1985.
(b) Calculated using reduction factors presented in table 23.
(c) PFU - Plaque forming units.
(d) agm - Average geometric mean.

sufficient residual population may persist to repopulate the composted sludge once temperatures return to ambient levels if the moisture content remains sufficiently high.

Hay et al., (1985) studied bacteria reduction in a two step windrow composting system which met PFRP requirements. He demonstrated a reduction of Salmonella sp. from 1.4 x 10^4 most probable number per gram dry weight (MPN gdw) at the start of step 1 to <.2 MPN/gdw at the end of Step 2. The recommended limit for Salmonella sp. in finished compost is < 1 MPN/gdw (Hay et al, 1985).

Results from studies reported by Hay et al. (1985) suggest that bacterial regrowth is minimal or non-existant in finished compost that has been properly composted. One study monitored regrowth of finished compost in 41 plastic bags stored at 35°C and in 41 flower pots containing a mixture of compost and soil that were stored out doors over 4 week periods. Most of the compost samples that were well composted initially contained no detectable Salmonella sp. and showed no regrowth.

Regrowth can occur if sufficient numbers of bacteria remain after composting or are reintroduced. Venosa (1985) reported a study where composted sludge was inoculated with Salmonella enteritidis. After two days of incubation, the bacterial counts were greater than 10^9/g. Hay et al, (1985) cites evidence that under certain conditions, Salmonella sp. regrowth can be very rapid so that ingestion of a small amount of compost may result in an infective dose.

Factors which increase the likelihood of regrowth include cross-contamination by airborne particulates from untreated sludge entering the treatment plant, by contaminated equipment (especially in small systems with limited equipment), or by naturally occuring sources. The characteristics of the compost can also play a factor in bacterial regrowth. Reimers et al. (1985) reported that biological activity of Salmonella sp. is fostered at a pH between 5.5 to 9, temperature between 10°C to 40°C, and a moisture content greater than 20%. Proper storage of composted materials is extremely important to avoid recontamination or regrowth. Monitoring for regrowth before distribution to the public is also strongly advised.

Viruses. Limited data were available on the survival of viruses in composting. Two studies reviewed indicated that well managed compost systems can be effective at inactivating viruses. According to Hay et al. (1985), typical density values of viruses in a well managed windrow operation are less than .05 IU per gram dry weight. The recommended concentration of viruses is .1 IU [IU not defined] per gram dry weight. (Hay et at., 1985).

Passman (1978) reported a study where polio virus type I was added at a concentration of 580 TCID (tissue culture in dose) per 10 grams of sludge to an active compost pile (temperature 55°C to 60°C). Within one hour, virions could no longer be detected. Passman (1978) reported a second study where sludge was seeded with the bacteriophage f-2 at an initial concentration of 10^6 plaque forming units (PFU) per gram dry weight. The f-2 bacteriophages persisted for greater than 70 days in compost windrows, but were inactivated within 14 days in forced aeration compost piles (Passman, 1978).

Adsorption of viruses onto particles may afford some protection against virus inactivation. Other factors contributing to the survival of a virus include: relative humidity, ionic conditions, pH and particle aggregation. For example, at low relative humidity, poliovirus I inactivation is greatly accelerated.

Parasites. Most research and monitoring efforts have depended on *Ascaris lumbricoides* persistance as the indicator of protozoans and helminth survival during sewage treatment. The general concensus is that *A. lumbricoides* is the most resistant parasite in this group. Protozoan cysts probably do not survive composting (Passman, 1978) although very little data are available to support this conclusion. Field experiments must be performed to demonstrate that this conclusion is, in fact, valid.

Temperature is the primary factor affecting survival of helminths. *Ascaris lumbricoides* are much more resistant to low temperature inactivation than high temperature. Passman (1978) cited the threshold temperature for helminth ova destruction to be 51°C. Below this threshold, ova may survive long periods of time. PSRP for composting require temperatures of 55° for only four hours.

The two step windrow process (PFRP) studied by Hay et al. (1985) reduced the concentration of ova from 0.8 ova per gram dry weight before Step 1 to <0.4 ova per gram dry weight at the end of Step 2. Hay et al. (1985) reports the recommended limit of ova in compost to be 0.2-0.5 ova per gram dry weight. Thus, even if PFRP conditions are achieved, there is a possibility that helminth ova may be introduced into the soil in small numbers.

Fungi. Fungi pose a different type of problem than other pathogens because they are common in nature and thrive under some of the composting conditions intended to destroy their bacterial, viral and, parasitic counterparts.

The fungi found in compost are ubiquitous in nature (Passman, 1978). Passman (1978) reported the following thermophilic species to predominate in a municipal waste compost system in Gainsville, Florida; *Asperigillus fumigatus*, *Chaetomlum Thermophile*, *Humicola lanuginosa*, *Mucor pusillus*, *Thermoascus aurantious*, and *Torula thermophile*. Some of these species have also been isolated from self-heated industrial woodchip piles and sunheated soils.

A. fumigatus is one of the most prevalent fungi in municipal sludge compost during the period when compost temperatures range from 50 to 60°C (Passman, 1978). The fungus thrives in a variety of substrates, including stored hay or grain, decaying vegetation and, soil (Clark et al. 1984). Passman (1978) reported a study where compost produced from a forced aeration facility was monitored for *A. fumigatus*. He noted that *A. fumigatus* in sludge, wood chips and compost were comparable to concentrations in potting soils, manures and mulches. However, the concentration of *A. fumigatus* in air surrounding the compost facility was several orders of magnitude higher than that surrounding a control site.

Hay et al. (1985) reported that the two step windrow compost system designed to inhibit enteric pathogens should also inactivate A. fumigatus. However, they reported that limited research had been conducted on the survival of A. fumigatus during composting. Taken together, these studies indicate that A. fumigatus and possibly other thermophilic organisms may be a problem both during and after composting. Further evaluation of the public health impact of these organisms in composted sludge applied to land is necessary.

Fate of Pathogens in Compost Once Applied to Land

The previous section showed that pathogens are likely to remain in compost in some number after PSRP. Compost which has undergone PFRP is more likely to be pathogens-free but PFRP is not routinely required or used.

This section will attempt to assess the fate of bacteria, viruses, parasites, and fungi in the environment if they survive the composting process, or if regrowth or recontamination occurs. The purpose of this analysis is to determine how well pathogens survive once applied to soils in order to assess the risks to domestic animal and public health.

Table 25 presents survival times of pathogens on plants and soils. Many pathogens have been reported to survive for longer than 1 month in soil and on plants. Salmonella have been reported to survive up to 280 days on soil and 42 days on grass. Ascaris ova has been reported to survive up to 7 years in soil and 35 days on vegetables and fruits.

TABLE 25. SURVIVAL OF PATHOGENS ON PLANTS AND IN SOIL

ORGANISM		SURVIVAL TIME PLANT SURFACE	SURVIVAL TIME SOIL SURFACE
Coliforms	grass and clover vegetables	6-34 days 35 days	38 days
Streptococci			35-63 days
Fecal streptococci			26-77 days
Salmonellae	grass and clover vegetables & fruits	12-42 days 3-49 days	15-280 days
Salmonella typhi	vegetables	1-68 days	1-120 days
Shigellae	on grass (raw sewage) vegetables	42 days 2-10 days	
Mycobacterium		10-49 days	90-450 days
Tubercle bacilli	grass		180 days
Vibrio cholerae	vegetables & fruits	1-29 days	
Erysipelothrix			21 days
Leptospira			15-43 days
Entamoebia histolytica cysts	vegetables	1-3 days	6-8 days
Enteroviruses	vegetables	4-6 days	8 days
Poliovirus			
Ascaris ova	vegetables & fruits	27-35 days	up to 7 years
Hookworm larvae			42 days
Liver fluke cysts	in dry hay in improperly dried hay	few weeks over a year	

Source: Burge et al., 1978; Hunt, 1985 and Taffel 1978.

Bacteria. Many factors affect the survival of bacteria in soil. They include: genetic and physiological characteristics of the bacterium, the physiochemical characteristics of the soil, atmospheric conditions (i.e., moisture, temperature, and exposure to sunlight), the mode of application to the soil, biological interactions among microbes in the compost and compost-soil environments, and host-parasite relationships. Survival times of bacteria increase with greater moisture, moisture capacity of the soil and organic matter. Survival times decrease with greater exposure to sunlight, lower pH, increased competition, antagonism and predation. Venosa (1985) remarked that enteric bacteria applied to sterilized soil survive longer than those applied to unsterilized soil.

Passman (1978) reported moisture to be the primary factor controlling *Salmonella typhi* survival in soils. He also reported a study stating that pathogen survival was directly related to the organic matter in soils. No study was found addressing the question of pathogen persistance in compost-amended soil.

Except during heavy rain or snowmelt, bacteria tend to adsorb to and be entrained in the upper few centimeters of the soil. Once in the soil, pathogenic bacteria may persist for periods ranging from hours to years depending on the various environmental factors listed above.

Virus. Temperature and moisture content are probably the most important factors limiting virus survival in soils. Bitton *et al*. (1984) observed that viruses could survive up to 170 days in soil at 3° to 10°C and that survival was higher at 3° to 10°C than at 18° to 23°C. Viruses survived no more than 15 to 25 days in air-dried soil compared to 60 to 90 days in samples with 10 percent moisture (Bitton and Gerba et al. 1984). Sunlight at the soil surface is detrimental but its role is minor in comparison to other environmental factors.

The characteristics of soil also influence the survival of viruses. A study reported by Bitton and Gerba (1984) showed that virus survival correlated with the extent of virus adsorption to soil, soil saturation, pH, and exchangeable aluminum. Biological factors may also play a role in virus inactivation in soil, but no clear trend emerged from the literature.

Helminths. Since most of the processes used for PSRP will not adequately reduce the number of viable helminth ova (Little, 1985) some ova inevitably make it into compost-amended soils. The ova of Ascaris are considered to be the most resistant form of any sewage pathogen. Under some conditions these eggs may survive in soil for several years. Little (1985) reported a study where eggs of Ascaris that were still infective for animals were recovered on experimental soil plots after 14 years. Another study reported Ascaris eggs to be infective in garden soil in Germany for 5 to 7 years.

Once applied to land, solar irradiation becomes a significant factor operating against ovum persistance. Exposure to sunlight and dessication account for reduced helminth ova survival time on vegetable surfaces compared to those in feces or in soil. However, survival on crops such as lettuce, which have short growing seasons, might be sufficient to allow persistence through harvest (Passman, 1978).

The persistence of some parasite ova calls into question some of EPA's regulations governing grazing of animals on lands which have received sludges treated by PSRP. The USEPA (1979) requires only 1 month between application of sludges which have undergone PSRP and grazing of food chain animals. Little (1985) cited a study where grass land was treated with sludge containing ova of *T. saginata*. Calves which were allowed to graze on pastures 9 to 10 weeks after sludge was applied became infected with *T. saginata*. However, when tested 17 to 18 weeks after sludge application, the pasture was no longer infective to calves.

Fungi. A. *fumigatus* and other fungi are natural soil microbes. No specific studies indicating fate of fungi in compost amended soil were found.

Routes of Animal and Human Exposure to Pathogens in Sludge-Amended Soils

This section integrates the findings of earlier sections into an assessment of the possible routes of human and animal exposure to various pathogens and the likelihood of infection and disease. The assessment attempts to account for the original pathogen content of the compost and for the ability of the pathogens to survive, proliferate, and be transported in the environment. Epidemologic studies of human exposure to composted sludge either in compost facilities or on farms receiving composted sludges are reviewed.

Comparisons of PSRP to PFRP are by necessity largely theoretical. Processes to further reduce pathogens are not widely used. Therefore, this study has relied on the theoretical D-value discussed earlier to illustrate theoretical differences in the pathogen-kill effectiveness of PSRP and PFRP. All the caveats appied to the earlier discussion apply to this risk evaluation as well.

As elsewhere, theory and practice do not always agree. In theory, much higher concentrations of pathogens remain after PSRP than PFRP. However, field studies and epidemologic studies have not detected the level of infection and disease that might be expected despite years of land application of sludges that have undergone only PSRP. These factors have led some investigators to comment that PFRP are unnecessary for general agricultural use of sludge and that proper management practices -- loading rates, grazing restrictions, slopes, buffer zones, etc. -- provide adequate level of protection (Logan, 1986, personal communication). PFRP is probably still advisable for sale/give away programs to the general public where children may be at risk of ingesting small quantities of compost (Chaney, 1986, personal communication).

Several potential routes of exposure are discussed below: inhalation, skin contact/penetration, direct ingestion (human and animal), and ingestion of water contaminated by runoff or leachate.

Inhalation. Very little information was found on inhalation exposures to pathogens except for _aspergillus fumigatus_ exposures to compost facility workers. General population exposures to airborne pathogens resulting from land application of compost was addressed only indirectly in one epidemologic study reviewed.

The transmission of pathogenic fungi via inhalation is considered to represent a potentially serious health threat particularly to compost workers. _Asperigillus fumigatus_ is the fungus of greatest concern, although thermophilic mucorales and actinomycetes are also known to be present in compost (Taffel, 1978). _A. fumigatus_ spores can produce severe asthmatic reactions in atopic (sensitized or allergic) individuals (Taffel, 1978). Individuals with pre-existent lung desease are susceptible to colonizing aspergilli, which form fungus balls in the lung, a condition known as aspergillosis. The small percentage of immuno-suppressed individuals in the general population are at greater risk of aspergillosis.

Clark _et al_. (1984) has suggested that fungal spores at the compost site could have caused such disorders as burning eyes, skin irritation, abnormal ear and nose conditions, and upper respiratory tract colonization in exposed compost workers.

Clark _et al_. conducted an epidemiological study of wastewater sludge composting facilities from 1979-1981. All facilities studied were thermophilic aerated pile processes and produced from 15 to 125 dry tons per day. The study included 388 compost and control workers divided into three exposure groups: Group I - workers directly involved in composting; Group II -

workers occasionally involved in composting or whose job locations are within 100 meters of a composting facility; Group III - workers not involved in composting and whose job locations are greater than 100 meters from a facility. Health monitoring included: physical exams and chest x-rays; nasal and throat cultures; antibody testing to fungi, Legionella, histoplasma and endotoxin; immunochemical testing; and routine blood analysis. Clinical specimens (nose and throat cultures and sera) and health questionnaires were collected eight times during the study.

Clark et al., 1984 reported that non-respiratory symptoms were more prevalent among the compost (Group I) and control workers than intermediate (Group II) workers in November 1980 at one plant. Symptoms of burning eyes occurred more in Group II and Group I workers than in control groups for several plants combined in November 1980. Skin irritation was somewhat higher among Group I and Group II for combined worker groups in September 1978, September 1980 and February 1981 (Clark et al., 1984)

Acute and chronic eyes and nose inflammation, possibly compost related, was found in 19% of Group I workers, 20% of Group II workers and 5% in control workers. Abnormal skin conditions occurred in 12% of the Group I workers, 21% of the Group II workers and 0% in the control individuals. The percentage of workers with positive cultures for A. fumigatus were directly related to exposure: Group I workers (70%), Group II (intermediate exposure) (20%), and controls (5%).

Skin Contact/Penetration. Skin contact and penetration are not a major route of animal or human exposure. Only a few of the pathogens potentially found in composted sludge are able to cause an infection by penetrating the skin. These include the human, dog and cat hookworm and the human threadworm. However, neither the human or dog and cat hookworm are very common in the U.S. and the human threadworm is seldom detected in sewage sludges. Furthermore, Taffel (1978) states there is no evidence to suggest that the ova of these parasites are hardy enough to survive the composting process and subsequently mature to the infective stage.

Ingestion. The most direct route of human or animal exposure is through ingestion of the compost. For both humans and animals, ingestion or compost of compost-amended soil could occur directly or through contamination of food products and forages.

Active infection depends on the concentration of pathogen in the compost and the dose required to cause infection in the exposed individual (infective dose). Table 26 lists infective doses for a few pathogens and the amount of compost that would have to be ingested to achieve an infective dose. This table suggests that a large amount of compost and even greater amounts of compost-amended soil would theoretically need to be ingested to cause an illness. For example, Taffel (1978) reported the infective dose of Salmonella for a 9 month old to be 44 organisms. Under PSRP conditions (assuming no regrowth) and

TABLE 26. AMOUNT OF COMPOST CONTAINING INFECTIVE DOSE VIA INGESTION

Organism	Infective Dose[a]	Amount of Ingested Compost Required to Cause an Infection[b]	
		PSRP	PFRP
Salmonellae	44 organisms in 9 mo. old.	50 gdw [c]	5.0×10^{52} gdw
	10^5-10^6 Healthy males.	1.1×10^6 gdw	1.1×10^{56} gdw
Poliovirus	1 PFU [d] in infants	2.6×10^5 gdw	2.6×10^{131} gdw
	2 PFU in adults	5.2×10^5 gdw	5.2×10^{131} gdw
Entomoeba histolytica	10^1-10^4 organisms produced infection without illness	4.8×10^3 gdw	4.8×10^{95} gdw

[a] Source: Taffel, 1978
[b] gdw - gram dry weight
[c] Based on concentrations of organisms estimated in Table 24.
[d] PFU - plaque forming units

using the D-value to calculate the final density of Salmonella in compost, a baby would have to eat the equivalent of 50 gdw of compost to become infected. A healthy male would have to eat 1.1 x 10^6 gdw or 1100 kg (over a ton) of compost to become infected, an unrealistic amount.

In cases where composting is insufficient or regrowth occurs, the potential for infection increases. Apparent regrowth of coliform and Salmonella bacteria has been observed by a number of investigators (Taffel, 1978). Bacteria can exist below detectable levels in compost but at sufficient levels to regrow. The fact that compost is a nutritive medium, free of competition, makes it ideal for possible regrowth. Finished compost should be monitored for regrowth before distribution.

Contamination of human food products grown in compost-amended soils is a legitimate concern. As Table 25 indicates, several types of pathogens can survive in plant surfaces and in soils for long periods of time. Taffel (1978) reported a study where radishes grown in soil fertilized with typhoid-infected stools contained typhoid bacteria after 37 days. Also, he stated that bacteria were not observed to penetrate vegetable skins, but were able to enter decaying or injured parts of vegetables, and stay viable to up to 42 days. Entamoeba histolytica cysts have been observed to last only three days in dry weather on lettuce and tomatoes. If composting has not been effective, regrowth has occurred, or inadequate time has elapsed between application of compost and growth of produce for human consumption, the risk of infection increases. No studies were found that evaluated the presence and persistance of pathogens in soils or produce where compost that had undergone PSRP or PFRP was applied.

As has been previously discussed for toxic inorganic and organic constituents of sludge, available evidence suggests that direct domestic animal consumption of sludge adhered to forages or directly from soils while grazing can be an important route of exposure to pathogens.

While animal ingestion of sludges adhered to forages and mixed in soils is clearly possible, few studies have examined the actual risk of infection. A study recently completed by investigators at Ohio State University has evaluated the incidence of domestic animal infection related to land application of sludges which had undergone PSRP (digestion). The study, discussed in greater detail at the end of this section, found no evidence of increased animal infection.

Water supply contamination from leachate and runoff. Contamination of ground and surface water supplies is a potential problem associated with land application of composted sludges. It is a problem that can be mitigated by requiring a high degree of pathogen destruction (i.e., PSRP), by proper siting and application restrictions, or both. It is not clear from the brief review of the literature conducted for this report that sludges must undergo PFRP to ensure the safety of ground and surface water supplies. Stabilization by PSRP combined with sound land management practices should provide comparable protection. An exception to this general conclusion may be found for distribution and marketing or sale/giveaway programs where application restrictions are harder to control or enforce.

As discussed in the section on the environmental fate of pathogens, several pathogenic organisms can survive for several months in soils depending on site-specific conditions. However, in order for infection to occur, the following conditions must be met:

- the organisms must be able to move freely either over or through the soil to the receiving water body
- the organisms must survive both in soil and in water and maintain virulence
- the organism must survive any treatment applied to the water to make it fit for drinking
- the organisms must be present in large enough numbers to infect an individual when the water is ingested.

Taffel (1978) concluded that the likelihood that pathogenic organisms already at low levels in compost will pass through soil and water to arrive in drinking water supplies in sufficient quantities to initiate an infection is exceedingly small.

In the literature reviewed, incidences of ground water contamination by various pathogens was most frequently reported but usually in the context of application of sewage effluents, not stabilized sludges. Gerba (1983) cited two studies which concluded that land disposal of digested sludge has shown little impact on bacterial contamination of groundwater unless the ground water table is too high and/or the soil is not well drained. Gerba cited other studies with sludge-amended soil which indicated that viruses are not easily elutriated even after rainfall events and pose minimal threat to groundwater. Both bacteria and viruses tend to be bound by sludge organic matter which then limits their movement in soils. By contrast, bacterial and viral movement in soils following land application of sewage effluents can be substantial.

Protozoans and helminth ova pose no threat to groundwater primarily because their relatively large size restricts their movement through soil (Gerba, 1983).

Transport of pathogens by runoff to surface water supplies is theoretically of greater concern. Bacteria, viruses, and parasites applied in composted sludges are likely to remain in the top layers of soil. If erosion occurs as a result of poor site selection and/or heavy rainfall, pathogenic organisms can be washed along with particles into surface water. They can pose a threat to water supplies used for swimming as well as for drinking.

The likelihood of human infection via contamination of public drinking water is quite low if the water supplies are treated prior to distribution. Human infection is more likely when the water supply or the swimming area goes untreated. Similarly, animal infection is possible if animals receive water from contaminated surface water supplies such as farm ponds.

Despite the probability of pathogen transport in runoff, no studies were reported in the literature reviewed for this report that found evidence of surface water contamination and subsequent human infection. This gap does not necessarily indicate that such contamination has never occurred but may suggest that it is less of a problem than theory predicts.

Ohio Farm Study. A three year prospective epidemologic study was conducted on 47 farms receiving sludge annually and 46 control farms in three locations in Ohio (Brown, 1985). The objectives of this study were to evaluate the health risks to rural residents and their livestock resulting from sludge applied to cropland and to define and demonstrate management practices for application of sludge to farmlands. This study provides a basis for evaluating the aggregate risk from all routes of exposure discussed above.

Annual surface applications of liquid or dewatered anaerobically or aerobically digested sludge were applied at 2 to 10 dry metric tons per hectare. Although not specifically stated, the digestion process is believed to have met PSRP requirements (Logan, 1986, Personal communication). Corn, soybeans, hay, and wheat were the principal crops grown.

One hundred and sixty-four individuals participated from farms receiving sludge and 130 individuals from control farms. Monthly questionnaires on illness symptoms for individuals and their animals were distributed to all families. Baseline blood samples were taken before the first application of sludge and every four months thereafter. Stool samples were collected every four months and analyzed for bacteria, viruses and parasites. Tuberculin testing was performed annually. Fecal samples from cattle were examined for bacteria and parasites. Slaughtered calves were tested for tuberculin and forage samples were collected over a one month period for parasite analysis.

There were no major differences in digestive or respiratory illnesses reported between families from control farms and farms which received sludge. It was concluded that exposure to sludge did not increase the antibody titer. There were no positive tests for tuberculin and hepatitis A. There was no significant difference in the frequency with which viruses or parasites were found in stool specimens. Salmonella was isolated from three individuals on sludge farms and one on control farm.

There were no differences in the health of domestic animals on control and sludge farms. Four control and two sludge farm animals were positive for salmonellae. Tuberculin tests were found negative on the slaughtered calves.

Ova of toxocara were found in five of 52 sludge samples examined for parasites (Jakubowski, 1985) and one ascarid ovum was detected in a forage sample collected 14 days after the application of sludge.

There was no evidence of human or animal health effects resulting from the application of sludge to farmland at the rates applied (2 to 10 Mt/ha). However, other authors have noted that the exposure of most of the participants on the sludge farm was probably very low and that caution should be used when applying these results to higher sludge application rates (Jakubowski, 1985).

The negative results of the studies reported to date and the lack of outbreaks associated with wastewater and sludge treatment and disposal activities may indicate that there is little or no problem with infectious disease from this exposure However, the low exposure and small populations in the reported studies may account for the lack of effect found (Jakubowski 1985).

One problem associated with prospective epidemiological studies such as the one discussed above is that symptoms are usually grouped into broad categories--respiratory, gastrointestinal, etc., that are not necessarily specific to sewage sludge. For example, influenza is not a sewage-borne organism but can cause similar symptoms (fever, headache, etc.) as some of the sludge-borne pathogens. Also, transmission of the sludge pathogens is not limited to sludge as the sole exposure source, since pathogens can be transmitted from person to person in food and in water. Furthermore, Jakubowski (1985) states that reporting of such subjective symptoms may be subject to recall bias. Individuals can tend to under-report symptoms if sufficient time elapses between onset and reporting of symptoms or may over or under report symptoms in an erroneous effort to assist the study. This could account for the lack of differences seen between sludge and control farms.

A second problem is the difficulty in quantifying the exposure received by the individuals. In the Ohio Farm Study, the highest sludge exposure was estimated to be only 1.5 hours per week and could account for the lack of health effects observed. However, the limited time spent in contact with or exposed to sludge is in itself an important result.

The recommendations of experts on epidemiological studies has been changing over the past 12 years. In 1973, at a workshop held in Champaign, Illinois, a panel of public health experts agreed that more studies should be conducted relating to land application of sludge. In 1979, a World Health Organization report indicated that current epidemiological techniques are not sensitive enough to detect low-level transmission of viruses through water (Jakubowski, 1985). A conference sponsored by Commission of European Communities in May 1985 concluded that prospective epidemiology studies of sludge exposed populations should not now be conducted because of design, interpretation and expense considerations (Jakubowski, 1985). Instead, the members concluded that monitoring programs should be developed and implemented and that more information on the health effects of composted sludge products is needed.

Jakubowski (1985) therefore concluded that prospective studies will not be the approach to assessing and quantifying health risks related to sludge disposal due to a number of reasons including: identification of exposed individuals, quantifying the exposure rates, and extrapolating one site to another for use in guidelines. This last factor is a problem because there are different conditions affecting pathogen transport and survival for each site.

Another approach to risk assessment is by mathematical modeling. This approach is theoretically attractive because it can be site specific but is hampered by the complexity of data necessary to calculate risks with a reasonable degree of certainty. No specific model-based risk assessments were found within the scope of this research. Jakubowski (1985) reported that two models for health risk assessment of sludge disposal were under development but no details were given.

G. Conclusions and Recommendations

This review of the scientific basis for the limits on toxic and pathogenic constituents of municipal sludge supports several conclusions about acceptable limits for inorganic and organic contaminants of sludge, reasonable annual and cumulative maximum application rates, and acceptable levels of stabilization among others. Some conclusions emerged regarding the differences in regulatory requirements that may be appropriate for general public use in sale/give-away programs versus those acceptable for more highly regulated uses on agricultural or dedicated lands. The conclusions are presented in the same three broad groups defined in the body of the report: inorganic contaminants (cadmium and lead), organic chemical contaminants, and pathogenic organisms.

The conclusions do not address all the issues confronting land application of municipal sludges. They focus on the primary issues raised in the scope of work. For example, the conclusions address acceptable limits and application rates for specific constituents but do not address site selection and land management practices except in general terms. The recommendations, like the body of the report, focus on factors which most influence human exposure rather than animal exposures to toxic or pathogenic constituents in sludges.

An overriding recommendation from this report is that any new regulatory initiatives regarding land application of sludges in the northeast should incorporate a careful review of the risk assessment methodologies and recommendations approaching completion by the U.S. EPA, Office of Water Regulations and Standards. While this study found strong scientific support for some existing standards and guidelines, primarily those for cadmium, the scientific bases for regulation of other metals and organic compounds are generally incomplete. Studies of sludge contaminant uptake by plants, the effect of soil chemistry or other physical site characteristics on exposures to animals and humans, and of other routes of animal or human exposure that should be taken into account in setting regulations have not been conducted for all of the contaminants that may ultimately warrant regulation. The federal study attempts to bridge some of these scientific gaps using risk assessment techniques and may ultimately play a key role in the development of new regulations for several other chemical contaminants besides those currently regulated by federal and state agencies. This report did not attempt to duplicate the federal effort and therefore recommends that the results of the federal study be evaluated carefully for use in regulation development for northeast states.

Recommendations for Cadmium, Lead, and Organic Chemicals

Use of composted sludge by the general public. Table 27 summarizes two basic recommendations for regulation of cadmium and lead: one governs acceptable limits and the other addresses general labeling requirements.

This report recommends that the maximum allowable concentration for cadmium in sludges or sludge products to be applied to land should be 13 mg/kg dry weight. Although several investigators and review papers commonly endorse 25 mg/kg DW cadmium as an appropriate maximum level in "domestic" sludges (USEPA, USFDA, USDA, 1981; Hornick et al., 1984; Penn. State, 1985), the scientific basis underlying this number was never clearly stated.

Some of the most convincing recent evidence supporting the safety of low metal sludges comes from work by Chaney et al. (1982) which studied cadmium uptake in lettuce leaves from plots receiving sludge. Lettuce has a strong tendency to accumulate cadmium as do several other plants such as spinach, chard, turnip and beet greens, and carrots (USEPA, USFDA, USDA, 1981). Plots receiving sludges with 13.4 mg/kg cadmium showed no demonstrable increase in lettuce leaf cadmium concentrations at application rates up to 3 kg cadmium/ha. The difference in lettuce leaf cadmium levels between lettuce grown on soils at pH 5.6 and 6.4 was negligible indicating that the bioavailability of cadmium is restricted even at the low pH levels more typical of northeast soils. Chaney et al. (1982) and Logan and Chaney (1983) suggest but do not state that the bioavailability of cadmium at concentrations of 25 mg/kg would be similarly low.

Chaney's work is particularly important because it appears that previous arguments for lower maximum acceptable levels of cadmium in sludge were based on studies using cadmium salts added to soils. Such studies predicted a linear increase in plant cadmium content with increasing cumulative application rate regardless of initial sludge concentration. Chaney's work with cadmium applied in sludges indicates that this relationship does not hold. Other investigators suggest that chemical factors in the sludge, expressed generally as the "sludge-specific cadmium adsorption capacity", limit cadmium's bioavailability (Logan and Chaney, 1983). Only at high cadmium level -- levels beyond 25 mg/kg -- is the sorption capacity of the sludge apparently exceeded. The initial concentration of cadmium is subsequently a strong predictor of available cadmium for long periods beyond the initial sludge application.

TABLE 27. RECOMMENDATIONS FOR CADMIUM AND LEAD IN SLUDGE: USE BY GENERAL PUBLIC

	Cadmium	Lead
Maximum Acceptable Levels	13-25 mg/kg DW	500 mg/kg DW

Labeling Requirements

1. Maximum acceptable level of sludge contaminant.
2. Recommended sludge application rate based on soil conditioning requirements 10-20 Mt/ha - 50-100 lbs/250 sq ft.
3. Recommend washing of all fruits and vegetables grown on sludge-amended soils.

Two factors argue for setting cadmium limits below 25 mg/kg DW. One is that if pH levels are not maintained at pH 6.5, cadmium bioavailability increases slowly over time. If soils are not treated, pH levels tend to revert to background levels which in the northeast are considerably below 6.5. Very few studies, if any, have been able to evaluate cadmium mobilization over long periods of time (e.g. 10 to 20 years). The second factor is that disposal of municipal sludges will continue to be a problem for the forseeable future. However, if maximum cadmium levels in soils are adhered to by the general public as well as by commercial agricultural users land application of sludges is a finite disposal option. The lower concentration extends the useful and safe life of land application as a disposal option for municipal sludges. Despite the widespread support for 25 mg/kg DW cadmium, support for a lower limit is growing. Chaney suggested recently that a workgroup on metals in sludge are likely to recommend 12.5 mg/kg DW cadmium.

There is much evidence, however, to suggest that the 2 mg/kg cadmium specified in Federal and Massachusetts regulations is unnecessarily stringent even for sludge used in giveaway programs. The USEPA, USFDA, and USDA (1981), for instance, give evidence that, depending on soil CEC, it would take 50 to 200 years to reach cumulative Cd limits when sludge containing 25 mg/Kg Cd was applied at agronomic rates. Hornick et al. (1984) define a good quality sludge as containing no more than 25 mg/Kg cadmium. With the addition of bulking agents, this concentration may be diluted in the compost. Hornick et al.

document that even without control over soil pH, it is difficult to exceed the maximum recommended application rate with a good quality sludge because the amounts of sludge materials needed would be enormous and economically impractical. Logan and Chaney (1983) indicate that the bioavailability of cadmium in crops grown on sludge-amended soil is considerably less than in crops grown on soil with cadmium from non-sludge sources, because other materials present in sludge interact with the cadmium to reduce the amounts absorbed and retained by animals and humans. This property of sludges suggests that severe cadmium problems in humans such as itai-itai disease may not be possible with crops grown with sludge amended soils.

Logan and Chaney (1983), as has been discussed in the section on cadmium risks, listed the extremely conservative assumptions used to set the 1979 USEPA standard of 2 mg/kg. Since these regulations were promulgated, newer research findings cited by Logan and Chaney (1983) and by Page, et al. (1986) give strong indications that a limit of 2 mg/kg is unnecessarily restrictive. Page et al. have shown that sludges containing up to 15 mg/kg Cd do not result in appreciable cadmium uptake even by the most sensitive crops, regardless of the amount applied, and even in acidic soils. In addition, the danger to health from eating crops that may have been contaminated with cadmium was probably overestimated in the past. This assessment is based on improved dietary analysis, consideration of the portion of the diet that a person would eat from sludge-amended soils, and new research on populations that have consumed high-cadmium foods for long periods of time.

Page et al. (1986) concluded that even under the worst-case assumption that one third of the human diet would be from crops grown on sludge-amended soils over a 50-year period, there would be no adverse impacts on human health even if the soil pH was as low as 5.7, the sludge cadmium level was as high as 200 mg/kg, and 100 metric tons of sludge was applied per hectare. With a sludge Cd level of 25 to 50 mg/kg, there would be no adverse dietary impact even if over 220 metric tons per hectare of sludge were applied, and the soil pH were as low as 5.0.

Finally, an unfavorable soil pH may be adjusted upward simultaneously with sludge compost addition by requiring the incorporation of calcuim carbonate to the compost. The State of Maryland has proposed regulations which permit unlimited distribution to the public of compost containing up to 12.5 mg/kg cadmium and 10% calcium carbonate equivalent.

The basis for a maximum acceptable level of lead in sludges is more uncertain. Logan and Chaney (1983) cited several studies which collectively indicated that "individuals may absorb excessive lead" from soils containing over 500 to 1000 mg/kg DW. The maximum level of lead recommended by most studies is 1000 mg/kg although the public health basis for that number was never explained. The USEPA, USFDA, and USDA (1981) recommended a maximum final concentration of lead in soils to be 800 mg/kg. Again, the public health basis for their recommendation was not given.

This report recommends that 500 mg/kg DW lead be the maximum acceptable level for lead in sludges or sludge compost destined for sale/give-away programs. This recommendation is based on the assumption that children could ingest small amounts of sludge containing lead at these levels and based on the studies cited by Logan and Chaney (1983), could therefore, take in unacceptably high levels of lead. In reality, sludges used in the home are likely to be mixed in garden soils or potting soil thereby reducing the overall level of lead in soils that a child may have access to. This factor appears to add an additional margin of safety to the 500 mg/kg lead recommended. However, there was no opportunity to review the studies from which the 500 to 1000 mg/kg values were derived for this study, so definitive support for the applicability of the values to sludge regulations cannot be established at this time.

The US EPA is developing a risk assessment methodology to evaluate direct human ingestion of sludges as a route of exposure to lead. Their evaluation of that route of exposure, as well as their evaluation of direct animal ingestion of sludges and subsequent human exposure, should provide valuable insight into the level of protection provided by current guidelines and recommendations for lead. For this study, the decision was made not to conduct the same risk assessment independently and to evaluate the peer-reviewed US EPA's methodology when it becomes available.

Insufficient data were available to evaluate the public health basis for limits on organic chemicals in municipal sludges intended for general public use. As discussed in the organic chemicals section of the report, only 10 chemicals were identified for detailed risk evaluation by the U.S. EPA (1985). Of those, most are pesticides whose prevalence in northeast sludges could not be determined on the basis of data available at the completion of this report. Even if present, their public health or environmental significance needs more evaluation before levels in sludge can be recommended.

PCBs are a possible exception although reports on the basis for the 10 mg/kg PCBs recommended in U.S. EPA's 1979 regulations are inconsistent and unclear. Hornick et al. (1984) suggest that the PCB limits are based on the levels remaining on carrots grown in sludge-amended soils following washing and peeling. The 1979 regulations, however, cite contamination of milk as the basis for the limits. Until further risk analysis becomes available, the 3 mg/kg PCBs recommended by the USEPA, USFDA, and USDA (1981) for sludges applied to surface soils should be used as a limit for PCBs in sludges for general public use.

Sludges packaged or otherwise designated for general public use should clearly state the maximum metal and organic chemical concentrations permitted and those detected in the sludge so that individuals know the characteristics of the material they choose to use.

As an additional factor of safety, it is recommended that sludges packaged or otherwise designated for general public use carry recommendations that sludges be applied at what most investigators describe as agronomic rates, 10 to 20 mt/ha. For general public information, this translates into 50 to 100 lbs of sludge (dry weight basis) for every 250 square feet of garden. These are rates which provide good soil conditioning but do not necessarily meet all the nitrogen or phosphate requirements of the crops grown, assuming typical levels of 1.5 percent N and 1.5 percent P in sludge compost (Hornick _et al._, 1984). Application of sludges at these rates help assure that even if the sludge contains 25 mg/kg cadmium DW, the annual cumulative cadmium application rate will not exceed 0.5 kg/ha, the maximum level allowed for growing leafy vegetables (U.S. EPA, 1979).

Finally, it is recommended that any packaging or instructions provided with sludge carry recommendations that any vegetables grown in sludge-amended soils be carefully washed before eating.

Controlled Land Application of Sludges

Recommendations for regulation of cadmium, lead, and organic chemicals (PCBs) in sludges are summarized in Table 28. Brief explanations for the basis for these recommendations appear below.

Acceptable Limits. For reasons given in the section on general public use of composted sludges, 25 mg/kg cadmium in sludge provides an adequate level of public health protection from cadmium taken up in vegetable tissues. The level of

TABLE 28. RECOMMENDATIONS FOR CADMIUM AND LEAD CONTROLLED APPLICATION

Regulations	Cadmium	Lead	PCBs
Acceptable Limits	25 mg/kg DW	500 mg/kg DW	10 mg/kg injected 3 mg/kg surface
Application Rates	a. Use federal rates for cadmium to establish upper limit. b. Incorporate strong recommendations that sludge be used only at agronomic rates 10-20 Mt/ha for most agricultural uses.		
Maximum Cumulative Concentrations	Same as current federal regulations	500 kg/ha	
Application Restrictions			
1. General	Never to growing crops - for direct human consumption (i.e., only to soil). Injection or incorporation recommended even for forage crops to be harvested for animals intended for human consumption.		
2. Crops	Never for growing tobacco	--	--
3. Grazing Restrictions	a. Three months minimum should be required between application and grazing by animals intended for human consumption. Otherwise, one month or b. One month minimum. Use of animal products (meat or dairy) restricted for 3 to 8 months from onset of grazing.		
Background Metal Monitoring at Soil Required	Yes a. Annual basis if sludge applied more than once/year. b. Before application otherwise.	Yes	--

protection is particularly safe if soils are maintained at the required pH 6.5 and other siting restrictions are met. As explained in the body of the report, the primary route of exposure considered is uptake in plants which then become part of the human diet. Other limits for cadmium may be justifiable if risk analyses of other routes of exposure (i.e., direct animal ingestion of sludge or direct human ingestion of sludge) appear to contribute significantly to human dietary intake of cadmium.

For lead, 500 mg/kg-DW/1000 mg/kg is recommended as a maximum acceptable level in sludge. The public health basis for allowing 1000 mg/kg lead, the value recommended in several guidelines is not clear (USEPA, USFDA, USDA, 1981; Hornick et al., 1984; Penn. State, 1985). Nor does it seem to be necessary on the basis of reported mean concentrations of lead in sludge (see Table 13). The recommended maximum concentration of lead in sludge needs to be evaluated in light of the comprehensive risk analysis under way by the U.S. EPA (1985).

Application Rates. The pH and CEC dependent cadmium application rates provide protection of public health with an adequate margin of safety. As discussed in the section on cadmium, these rates were in part based on the "acid garden" scenario, a conservative, worst case scenario. Therefore, although the federal cadmium application rates are directed primarily to large-scale agricultural users, they were designed to protect against conditions of low pH in private gardens where individuals grow a large percentage of their vegetables. Given the assumptions incorporated into the "acid garden" scenario, the federal regulations provide adequate protection of public health for the soil conditions more typically associated with the northeast. One caveat is that the regulations address only plant uptake as a route of human exposure; they may warrant revision or modification if other routes of exposure to cadmium are also significant.

New regulations should strongly recommend or possibly require the use of sludges at agronomic rates (10 to 20 Mt/ha) rather than on the basis of nitrogen requirements which can lead to application of 2 to 10 times the volume of sludge (Hornick et al., 1984). The recommendation should apply particularly to food chain crops and exceptions would be suitable for horticultural operations, dedicated, or reclamation sites. While the cadmium and lead limits recommended provide public health protection, application of sludge at agronomic rates provides an additional factor of safety. Several investigators note that application rates which provide good soil conditioning are more practical and economical than the larger volumes that would be permitted on the basis of maximum cadmium concentrations or nitrogen requirements (Logan, 1986, personal communication; USEPA, USFDA, USDA, 1981; Hornick et al., 1984).

Maximum Cumulative Application Rates. Maximum cumulative application rates should also be established for metals other than cadmium. On the basis of the "acid garden" scenario, the maximum cumulative cadmium concentration is sufficiently protective of public health. A maximum level should be set for lead especially because of other environmental contributions to soil lead levels (e.g., leaded gasoline). The USEPA, USFDA, USDA 1981 guidelines recommended a maximum cumulative value of 800 kg/ha DW for lead in soil but the scientific basis for this recommendation was not made clear. This value should be evaluated using the risk assessment methodologies being completed currently by the U.S. EPA (1985).

Soil Monitoring for Background Metal Levels. Monitoring for background levels of metals should be required before sludge is accepted for a site to assure that maximum cumulative metal levels, including background levels, are not exceeded.

Application Restrictions. Sludge should never be directly applied to growing crops destined for direct human consumption. Sludges can adhere strongly to leafy or vegetative parts of the plant and may contribute to human exposure especially for contaminants like lead which are not significantly incorporated into plant tissues. This restriction is also recommended to limit human exposure to sludge pathogens.

A recent USDA bulletin recommends that sludges never be applied to land used for growing tobacco (Hornick et al., 1984). Tobacco prefers acidic soils, incorporates cadmium readily, and already contributes to the body burden of cadmium in smokers.

Grazing restrictions should also be required on lands used for grazing of animals intended for human consumption (meat and dairy products). Reddy et al. (1985) reported elevated fecal cadmium levels in cattle grazed on sludge amended pastures but the levels dropped to pre-sludge levels 3 to 8 months after sludge application. Unfortunately, fecal metal levels could not be correlated with tissue metal levels over time so the public health implications of the fecal cadmium levels are not clear. However, at the termination of the study, Reddy et al. did report elevated cadmium and lead levels in some tissues although not in muscle. Although not conclusive about the public health impact of metal uptake by grazing animals, the study indicates that the one month typically required between application and grazing instituted because of pathogen concerns, may not be sufficient to prevent excess metal exposures.

Recommendations for Pathogens in Composted Sludge.

Assessment of the public health and environmental risks associated with pathogens in composted sludge requires understanding of the several steps lying between the presence of a given pathogen in unstabilized sludge and the infection of a human being or domestic animal. The type of pathogens present, their ability to survive various levels of stabilization, their survival and transport in the environment, and their subsequent infection of human or animal hosts affect the level of risk associated with different uses of or exposure to composted sludge. In this report, each of these steps has been evaluated in order to gain insight into the overall level of hazards from pathogens in composted sludges applied to land.

While the pathogen content of various sludges has been reasonably well characterized, the fate of pathogens in composting processes and in the environment, the routes of exposure by which they pose the greatest hazard to man or animals, and the actual level of infection and disease associated with their presence in composted sludges applied to land, have not. Epidemiologic evidence showing a problem associated with pathogens in composted sludge in human infection and disease is essentially absent.

Despite these limitations, the research conducted for this report supports several general recommendations. They have been divided into two broad sections: recommendations for composted sludges intended for general public use and recommendations for composted sludges for use in controlled land application programs.

General public use of composted sludge. Table 29 lists for regulation of composted sludge intended for general distribution, sale, or give away to the public. The recommendations assume that a minimum of control can be exerted over how and where the sludge is used.

The primary recommendation is that the sludge should undergo a process to further reduce pathogens (PFRP) prior to release to the public. As discussions in the body of the report indicated, processes to significantly reduce pathogens (PSRP) are not as effective at reducing numbers of pathogens as PFRP. If sufficient numbers of bacteria remain, regrowth can occur leading to

TABLE 29. RECOMMENDATIONS FOR PATHOGENS IN COMPOSTED SLUDGE: GENERAL PUBLIC USE

Regulation or Guideline	Recommendation
Degree of Stabilization	PFRP (See Appendix II)
Labeling Requirements	1. Recommended sludge application rate based on soil conditioning requirements 10-20 Mt/ha - 50-100 lbs/250 sq ft.
	2. Recommend immediate incorporation into soil.
	3. Recommended washing of all fruits and vegetables grown on sludge-amended soils.

infectious levels of such organisms as salmonella. The ova of several parasites, Ascaris sp. in particular are highly resistant to treatment and it is not clear that the PSRP specifications for composting reach sufficient temperatures for long enough periods of time to achieve ova destruction. One study reported the threshold for the destruction of helminth ova to be 51°C; composting to meet PSRP requires that 55°C be achieved for only 4 hours.

While it is unclear whether or not sufficient numbers of pathogens remain to make human or animal infection likely, end use of composted sludge by the general public cannot be easily controlled. Prudent public policy requires worst case assumptions about human exposure and infection. Children may come into contact with or ingest small quantities of sludge or sludge amended soils which have a sufficient number of organisms to cause disease. Vegetables grown in sludge-amended soils in private gardens could carry sufficient organisms to cause infection. Requiring the use of PFRP for sludges intended for distribution to the public does not eliminate, but substantially reduces, the likelihood that such infections could occur.

The second recommendation is for labeling or notification requirements to promote practices which further reduce the likelihood of infection or disease, such as immediate incorporation into soil in order to avoid accidental contact. The requirements are essentially those recommended for cadmium and lead. Labels or information distributed with the sludge should include recommendations on maximum loading rates, incorporation of sludge into the soil, and on washing of produce grown on sludge amended soils.

Controlled land application of composted sludges. Recommendations for controlling pathogens from land application of composted sludge are in Table 30. When use of composted sludges can be controlled through site selection, permitting, and other requirements, processes to significantly reduce pathogens (PSRP) appear to provide adequate protection of the public, domestic animals and water supplies from sewage pathogens. Application of sludges to agricultural lands, dedicated sites, or to reclamation sites are more readily made subject to land management requirements than smaller scale, private uses. This report found little evidence in recent scientific literature of increased human or animal risk of infection when sound land and sludge management practices have been used.

TABLE 30. RECOMMENDATIONS FOR PATHOGENS IN COMPOSTED SLUDGE: CONTROLLED LAND APPLICATION

Regulations or Guidelines	Recommendation
Degree of Stabilization	PSRP
Application Rates	1. Establish upper limit on the basis of maximum annual loading rate for cadmium or other limiting contaminant.
	2. Incorporate strong recommendations that sludge be used only at agronomic rates, 10-20 Mt/ha, for most agricultural uses.
Application Restrictions	
1. General	Never directly to crops grown for direct human consumption.
2. Between Hay Crops	Apply within 1 week of first harvest to minimize sludge adherence to vegetation. One month minimum required between hay crops.
Grazing Restrictions	Establish a waiting period of 2-3 months after application.

The epidemiologic study recently completed by investigators at Ohio State University provides some of the most convincing evidence. Despite limitations in the study, the investigators found no increase in disease or infection in 40 farm families or their animals on farms receiving 2 to 10 Mt/ha of digested sludge compared to their counterparts on farms receiving no sludge (Brown, 1985). While these application rates are lower than those that can theoretically be permitted for agricultural lands (depending on sludge metal content), other factors could have increased the likelihood of infection. Human access to the pastures or fields receiving sludges was not necessarily restricted and it appears that animals were permitted to graze on the pastures not long after sludge was applied.

Assuming that sludges meet only PSRP requirements, the remaining recommendations address land and sludge management practices. First, application of sludges to agricultural lands should be restricted to agronomic rates, rates which provide basic soil conditioning and some fertilizer value. Rates between 10 and 20 Mt/ha have been recommended by several authors (Hornick et al., 1984, Logan, 1986, personal communication).

There are two recommendations regarding application restrictions. One confirms current federal regulations and the other addresses an issue raised in the scope of work. First, sludge should never be applied directly to crops grown for human consumption. Various pathogens can live for up to two months on plant surfaces and therefore could persist through harvest. Since some organisms, like salmonella, can survive in soil for up to a year or more, root crops in particular should not be grown in sludge amended soil for the 18 months recommended by the federal regulations (USEPA, 1979) at a minimum. Some parasite ova can remain viable and infective for five or more years, although they are typically found in much lower concentrations in sludges and soils than bacteria or viruses.

The second recommendation is that application between hay crops of sludge that has undergone only PSRP, whether by composting or any other means, can be permitted provided that the sludge is applied within a week or less after the harvest. Sludges containing pathogens can adhere strongly to plant surfaces and can make up a substantial percentage of the dry weight of the forages if applied too soon before harvest. If sludges are applied shortly after the first hay crop, one to two months or more (depending on geographical location) will elapse before the second hay crop. The survival times reported for most organisms on grass and clover ranged from a few days to just over a month in the literature reviewed. Dry conditions and sunlight decrease the survival time of organisms and account for the shorter survival time of organisms on plants than in soils.

Grazing restrictions on sludge amended pastures need to be more stringent because animals tend to ingest sludges from both vegetation and soils. Current federal regulations require a waiting period of only a month but three months may be more appropriate. One paper reviewed reported a case in which calves grazing on pastures 9 to 10 weeks after they were treated with sludge containing ova of Taenia saginata (beef tapeworm) became infected (Little, 1985).

In conclusion, the public health and environmental impact of land application of sludges is the subject of ongoing debate. The various toxic metals, organic compounds, and pathogenic organisms that have been identified in sludges can pose a hazard to public health and the environment if sufficient exposure to these contaminants occur. The current debate focusses on the most effective means of reducing the likelihood of exposure and impact. The consensus emerging from this review of recent scientific literature is that a combination of scientifically based limits on toxic and pathogenic constituents of sludge and sound land management practices can effectively protect both public health and the environment.

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APPENDIX I

REGULATIONS AND GUDELINES FOR LAND APPLICATION AND USE OF SLUDGE IN THE UNITED STATES

APPENDIX I

REGULATIONS AND GUIDELINES FOR LAND APPLICATION AND USE OF SLUDGE IN THE UNITED STATES

This appendix is contained on the accompanying computer diskette. This is a high density diskette and must be used in the high density disk drive of an IBM Personal Computer AT or compatible machine. Information on the regulations and guidelines of 40 states plus the District of Columbia and Federal regulations is contained in four Lotus 1-2-3 (release 1) files. These may be read on a computer containing either Release 1 or Release 2 of Lotus 1-2-3. The following table indicates which states' information is contained on each of the four files.

SLUDREG1	SLUDREG2	SLUDREG3	SLUDREG4
Federal	New Jersey	Tennessee	Nebraska
Connecticut	New York	Illinois	Michigan
Florida	Oregon	Pennsylvania	Hawaii
Iowa	Rhode Island	Ohio	Indiana
Maine	Texas	South Carolina	Nevada
Maryland	Vermont	North Carolina	Arizona
Massachusetts	Wisconsin	Georgia	Virginia
New Hampshire		Kansas	Distr. of Columbia
		Colorado	Montana
		California	Mississippi
			Wyoming
			Alabama
			Utah
			Alaska
			Minnesota
			Washington
			Delaware

APPENDIX II

PROCESSES TO SIGNIFICANTLY REDUCE PATHOGENS

PROCESSES TO FUTHER REDUCE PATHOGENS

APPENDIX II

(From 40 CFR Part 257)

A. Processes to Significantly Reduce Pathogens

Aerobic digestion: The process is conducted by agitating sludge with air or oxygen to maintain aerobic conditions at residence times ranging from 60 days at 15° C to 40 days at 20° C, with a volatile solids reduction of at least 38 percent.

Air drying: Liquid sludge is allowed to drain and/or dry on under-drained sand beds, or paved or unpaved basins in which the sludge is at a depth of nine inches. A minimum of three months is needed, two months of which temperatures average on a daily basis above 0° C.

Anaerobic digestion: The process is conducted in the absence of air at residence times ranging from 60 days at 20° C to 15 days at 35° to 55° C, with a volatile solids reduction of at least 38 percent.

Composting: Using the within-vessel, static aerated pile or windrow composting methods, the solid waste is maintained at minimum operating conditions of 40° C for five days. For four hours during this period the temperature exceeds 55° C.

Lime stabilization: Sufficient lime is added to produce a pH of 12 after two hours of contact.

Other methods: Other methods or operating conditions may be acceptable if pathogens and vector attraction of the waste (volatile solids) are reduced to an extent equivalent to the reduction achieved by any of the above methods.

B. Processes to Further Reduce Pathogens

Composting: Using the within-vessel composting method, the solid waste is maintained at operating conditions of 55° C or greater for three days. Using the static aerated pile composting method, the solid waste is maintained at operating conditions of 55° C or greater for three days. Using the windrow composting method, the solid waste attains a temperature of 55° C or greater for at least 15 days during the composting period. Also, during the high temperature period, there will be a minimum of five turnings of the windrow.

Heat drying: Dewatered sludge cake is dried by direct or indirect contact with hot gases, and moisture content is reduced to 10 percent or lower. Sludge particles reach temperatures well in excess of 80° C, or the wet bulb temperature of the gas stream in contact with the sludge at the point where it leaves the dryer is in excess of 80° C.

Heat treatment: Liquid sludge is heated to temperatures of 180° C for 30 minutes.

Thermophilic aerobic digestion: Liquid sludge is agitated with air or oxygen to maintain aerobic conditions at residence times of 10 days at 55-60° C, with a volatile solids reduction of at least 38 percent.

Other methods: Other methods or operating conditions may be acceptable if pathogens and vector attraction of the waste (volatile solids) are reduced to an extent equivalent to the reduction achieved by any of the above methods.

Any of the processes listed below, if added to the process described in Section A above, further reduce pathogens. Because the processes listed below, on their own, do not reduce the attraction of disease vectors, they are only add-on in nature.

Beta ray irradiation: Sludge is irradiated with beta rays from an accelerator at dosages of at least 1.0 megarad at room temperature (ca. 20° C).

Gamma ray irradiation: Sludge is irradiated with gamma rays from certain isotopes, such as ^{60}cobalt and ^{137}cesium, at dosages of at least 1.0 megarad at room temperature (ca. 20° C).

Pasteurization: Sludge is maintained for at least 30 minutes at a minimum temperature of 70° C.

Other methods: Other methods or operating conditions may be acceptable if pathogens are reduced to an extent equivalent to the reduction achieved by any of the above add-on methods.

APPENDIX III

SUMMARY OF STATE CONTACTS
AND BASIS FOR STATE REGULATIONS
AND GUIDELINES IN THE NORTHEAST

APPENDIX III

State	Contact	Basis for Regulations Cited	Background Documents Developed
Connecticut	Brian Curtis 203-566-3654	Penn State (1985)	No
Maine	Karen Townsend Department of Environmental Protection 207-289-3901	Uncertain; Other U.S. State Regs., European Guidelines, U.S EPA (1979) Penn. State, (1985)	No
Maryland	Ernest Spencer Department of Health and Mental Hygiene 310-225-5664	U.S. EPA, (1983) Other state regs.	No
Massachusetts	Fifi Nessen DEQE 617-292-5590	U.S. EPA, (1979) Sludge Task Force recommendations	Yes
New Hampshire	Carl Woodbury NH Office of Waste Management 603-271-4672	Uncertain; U.S. EPA, U.S. FDA, U.S. DA, (1981) U.S. EPA, (1979)	No
New Jersey			
New York	Thomas Easterly Residuals Mgmt. Director Division of Solid waste, NY State DEC 518-457-2051	U.S. EPA, 1979	No
Ohio	S.M. Blyndenburgh Engin. Unit Spvsr. Public WW Section Ohio EPA 614-466-2328	Brown, Robert E. (1985)	No
Pennsylvania	Jay Ort PA Department of Environmental Residuals Bureau of Waste Management 717-787-7381	Penn State (1985) (Dr. Dale Baker)	No

State	Contact	Basis for Regulations Cited	Background Documents Developed
Rhode Island	Chris Campbell 401-277-2234	Uncertain; U.S. EPA, (1979) U.S. EPA, (1983)	No
Vermont	Katie Gehr Hydrologist, State of Vermont 802-828-3395	U.S. EPA, (1979) U.S. EPA, U.S. FDA, U.S. DA, (1981)	No

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