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Determination of the Metals Balance Within the Missoula
Sewage Treatment Plant

by

Danny W. Corti

B.S., Lyndon State College, 1980

Presented in partial fulfillment of the requirements for the degree of

Master of Science

UNIVERSITY OF MONTANA

1985

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Corti, Danny W., M.S. June 1985

Environmental Studies

Determination of the Metals Balance Within the Missoula Sewage Treatment Plant (65 pp.)

Director: Dr. Wayne VanMeter



This study was designed to determine the concentrations of Cd, Ni, Cr, Mn, Pb and Mg within the Missoula Sewage Treatment Plant during seasonal high and low flow regimes. The analytical method used was atomic absorption spectrophotometry with aspiration into an air-acetylene flame. All samples were digested with a mixture of 90% HNO₃ and 10% HCl.

The results indicate no evident seasonal variation in the chosen metals concentrations. Most metals in the raw influent, final effluent and well water were below the level of detection for this study. Metals concentrations in the secondary digested sludge and belt press cake were low compared to median values nationwide making both the sludge and cake attractive for agricultural application. The cadmium concentration in the digested sludge exceeds the 2.0 ppm EPA limit for unmonitored soil amendments. The Missoula Sewage Treatment Plant should be monitoring recipient soil pH prior to each land application of digested sludge and belt press cake.

ACKNOWLEDGEMENTS

A special thank you to my wife Adrienne for her continual patience and willingness to help throughout this and every project. I also want to thank: Wayne VanMeter for lending his technical expertise and general good humor, Ron Erickson for giving me a nudge when I needed it most, Gail Miller and Pat Carey for making the Missoula Sewage Treatment Plant bearable, and Bill Tomlinson for saving me a great deal of legwork. A salute to you all from a retired Ed Norton.

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CHAPTER I

INTRODUCTION

History of land application of domestic sewage and sludge

The fertilizer value of human and animal excreta has been recognized and utilized for thousands of years in Asian and European countries. The concept of sewage farming (i.e., land application of raw waste) gained wide acceptance throughout England and in Paris and Berlin in the late 1800's and early 1900's. Sewage farming served to dispose of a disagreeable fact of life and to increase crop yield by adding significant amounts of macro and micronutrients to cropland (Fussel 1965). Most of the sewage farming in the United States has been in the arid regions of the West where the water content of the sewage has been deemed more vital than the nitrogen content (Winslow 1952).

The causes of waterborne diseases such as cholera and typhoid fever were not known until the late nineteenth century (Uiga 1980). Once the link was made between excreta contaminated water supplies and disease, sewage and sewage sludges were stigmatized to such a degree that general public distrust of land amendments from those sources still exists today (Sagik 1980).

The first sewage treatment plant that produced sludge in the U.S. was built in 1880. As early as 1914, the City of Baltimore was giving liquid and dried sludge to area farmers. The volume of sludge destined for land application was negligible until the 1970's when federal and state legislation was passed requiring increased levels of sewage treatment resulting in a geometric increase in the volume of

sludge produced (Pahren 1980).

William Sopper (1979) estimated that over 150 million people use public sewers with a resulting discharge of 260,000,000,000 gallons of waste water annually. That translates into approximately 4.5 billion dry kg/y of sludge (Bastian 1977). Sopper expects that amount to double by 1990. While sludge volume is normally less than 1% of the wastewater volume treated, sludge handling and disposal average 25% to 50% of total capital and operating costs for most treatment plants (Monteith 1978).

Sludge can be disposed of in a number of ways. Table I lists the various accepted possibilities and the range of costs associated with each method.

Pahren (1979) emphasizes that,

"No method is without problems. Incineration not only contributes to air pollution but is energy dependent and destroys a natural resource. Ocean dumping disposal is being phased out. Burial results in the loss of nutrients, and, without proper management, could result in groundwater problems. Land application is being considered by many as an alternative which not only solves the sludge disposal problem but also reclaims nutrients."

Table 1

Estimated Operating and Maintenance Costs for Sewage Sludge Disposition Methods in 1979 dollars

<u>Disposition Method</u>	<u>% total sludges treated in U.S. by this method in 1978</u>	<u>dollars/dry ton</u>
Incineration	22	80-240 ^a
Composting	1	70-200 ^b
Surface Impoundments (facultative lagoon)	11	approx. 25 ^c
Landfills	33	73-226 ^d
Ocean Dumping and Ocean Discharge	10	30-50 ^e
Landspreading	24	approx. 20 ^f 40-210 ^g

^a includes fuel costs and dewatering costs but not sludge removal costs

^b includes costs for dewatering, bulking agents, labor, capital amortization and distribution

^c located at POTW and excludes sludge removal costs

^d includes treatment, dewatering and transportation but excludes monitoring

^e cost is based on transportation costs

^f through outfalls at Los Angeles, CA.

^g includes treatment, dewatering, transportation, and application

¹ adapted from, EPA 1980.

The average nutrient content of sewage sludges (% dry wt.) ranges from 3.5 to 6.4 nitrogen, 0.8 to 3.9 phosphorus, and 0.2 to 0.7 potassium (Peterson 1973). Keeney et al (1975) reports N-P-K average values of 2-4-0.5% respectively. Keeney approximated Peterson's findings with the exception of nitrogen. Commercial fertilizer may contain up to a combined N-P-K weight of 43.2% of the total so that sewage sludge with a maximum N-P-K weight comprising 11% of the total dry weight would have to be applied at much higher rates to provide the same nutrients (Keeney 1975). Sommers (1977) estimated that only 1% to 2% of the U.S. cropland could annually utilize all the nitrogen

available in sewage sludge produced through 1985.

From the preceding paragraphs, one could conclude that land application of municipal sewage sludge is a beneficial means of disposing of an otherwise voluminous and disagreeable substance. Sewage sludge has agricultural applications as a fertilizer on forest and cropland and as a soil builder on disturbed land (Elliot 1977). It has limited potential as an animal feed (Edds 1980, Smith 1977, Kienholz 1977). Why, with all these positive aspects of land application of sewage sludge should we hesitate to dedicate all sludges to land application? For a number of reasons.

Health Risks Associated With Land Application of Sewage Sludge

Why Regulate?

What magnitude are the health risks posed by land application of sewage sludge? William Lowrance (1976) puts health risk in this perspective:

"We are disturbed by what sometimes appear to be haphazard and irresponsible regulatory actions, and we can't help being suspicious of all the assaults on our freedoms made in the name of safety. We hardly know which cries of 'Wolf' to respond to; but we dare not forget that even in the fairy tale, the wolf really did come.

In 1900...some rivers were so filthy with raw sewage and industrial waste that, as the saying went, 'bait died on the hook.' Industrial towns were black with coal soot, as were people's lungs. Workers labored at their own peril.

The principal fatal diseases were pneumonia, influenza, and tuberculosis. Infant mortality was high in 1900, more than thirteen percent of all American children died before their first birthday.

No need to belabor the point: in many ways we are better off than we used to be. In a sense we now have the luxury to worry about subtle hazards which at one time, even if detected, would have

at one time, even if detected, would have been given only a low priority beside the greater hazards of the day.

At the same time and partly because of scientific advance, people's values and expectations have changed. Discomforting discoveries were forced by the extraordinary growth in our social and physical scale. We have been startled into profound realizations, no less profound for having become commonplaces...that there is no longer any way in which to throw things; that it is crucial that we stop fouling our earthly nest...

Much of the widespread confusion about the nature of safety decisions would be dispelled if the meaning of the term safety were clarified. For a concept so deeply rooted in both technical and popular usage, safety has remained dismayingly ill defined.

We will define safety as a judgment of the acceptability of risk, and risk, in turn, as a measure of the probability and severity of harm to human health."

Risks posed by sewage sludge can be grouped under three major headings; microbial agents and parasites, toxic organic residues, and metals.

Risks Posed by Microbial Agents

Hyde (1976) reports recovery of Streptococcus faecalis, Clostridium tetani, C. perfringens, C. botulinum, Ascaris lumbricoides, Strongyloides stercoralis, Hymenolepsis nana and several different salmonellae and shigellae from soils receiving anaerobically digested sludge. The tests were conducted 7 months after the last land application. The diseases caused by the above species include endocarditis, tetanus, gas gangrene, botulism, roundworm, strongyloidiasis, tapeworm, food poisoning and typhoid fever respectively (Benenson 1975, Frobisher and Fuerst 1978).

Sagik (1980) notes fecal coliform movement in a variety of soils ranging from 3 to 1500 feet depending on soil type.

Little (1980) cites a study by L.I. Krasonos wherein Krasonos found Ascaris eggs were still infective after 15 years in soil.

Essentially any infective disease or parasite that afflicts man is carried in sewage and is generally concentrated in sewage sludge (Pahren 1980). Many deleterious organisms are destroyed by anaerobic digestion but many are not (Uiga 1980). Obviously some restrictions need to be placed on the land application of sewage sludge to decrease the potential health risk from infectious agents in the sludge (Sagik 1980).

Risks Posed by Toxic Organic Residues

Dacre (1980) has this to say about toxic organic residues in sewage sludge.

"... the organohalogen pesticides and the polynuclear hydrocarbons occur in varying amounts in different municipal sludges. The properties of these organochlorine compounds are such that they resist degradation in the soil environment; they are retained in fat and fatty tissues and hence will bioaccumulate as they pass up the food chain to eventually reach man himself and all of them are highly toxic and proven to be carcinogenic in extensive animal studies."

From Dacre's point of view, the monitoring of toxic organics is a vital link in any sludge analysis program.

Risks Posed by Metals

The toxicity of a particular metal is more dependent on the species of the metal than on the total amount (Sibley and Morgan 1975). Forstner and Wittman (1979) state that "Chromium (VI) compounds are approximately 100 times more toxic than Cr(III) salts. ... Methyl-mercury compounds are by far the most toxic forms of Hg

containing substances."

Metals from sewage sludge can enter the human food chain by direct ingestion, ingestion of plants grown on sludge amended soil or by ingesting livestock fed or grazing on sludge amended soil (Chaney 1980).

Livestock grazing on pasture which has had a recent sludge application are in double jeopardy. Spray applied liquid sludge adheres to the forage and once dried does not wash off in subsequent rainfalls (Batey et al. 1972). Mayland (1977) found that soil adhering to roots can comprise up to 20% by weight of the total forage consumed by cattle grazing on dryland crested wheatgrass.

Plant uptake of metals and the passage of metals up the food chain is dependent upon a number of interrelated variables. Epstein and Chaney (1978) summarized these variables as follows:

Soil Factors

- 1) Soil pH - toxic metals are more available to plants below pH 6.5.
- 2) Soil phosphorus - phosphorus interacts with certain metal cations to decrease their availability to plants.
- 3) Organic matter - organic matter can chelate and complex metals so that they are less available to plants.
- 4) Cation exchange capacity (CEC) - this factor is important in the binding of metal cations. Soils with a high CEC are safer for the disposal of sludges.
- 5) Moisture, temperature, and aeration - these can affect plant growth and uptake of metals.

Plant Factors

- 6) Plant species and varieties - vegetable crops are more sensitive to metals than are grasses.
- 7) Organs of the plants - grain and fruit accumulate lower amounts of metals than leafy tissues.
- 8) Plant age and seasonal effects - the older leaves of plant will contain higher amounts of metals.

Other Factors

- 9) Reversion - with time, metals may change form in soils making them more or less available.
- 10) Metals differ in their relative toxicities to plants and in their reactivity in soils.

Predicting a safe concentration for a particular metal destined for application on a specific soil should take all the preceding factors into consideration. Since this is not always practical, particularly at smaller publicly owned treatment works (POTW's) some general guidelines for permissible metals concentrations in sludge are needed. Chaney (1974) proposed the following upper limits for metals concentrations with the caveat that a sludge exceeding even one of the maxima be rejected for agricultural purposes.

Table 2

Maximum permissible concentrations of toxic metals in sludge destined for land application (Chaney 1974)

Toxic Element	Max. Permissible Conc. <u>(ppm dry wt.)</u>
Cadmium (Cd)	1% of Zinc
Chromium (Cr)	1000
Copper (Cu)	1000
Mercury (Hg)	10
Nickel (Ni)	200
Lead (Pb)	1000
Zinc (Zn)	2000

The above table lists a maximum allowable cadmium (Cd) concentration of 2000 ppm X .01 = 20 ppm. The EPA has gone beyond Chaney's value and listed 2 ppm as a sufficient concentration to require monitoring of recipient soils (Federal Register Sept., 1979). Cd concentration is the primary basis for deciding whether or not a sludge is acceptable for land application under EPA guidelines.

According to Chaney (1974) there exist several mechanisms which limit the migration of metals from soil to plants and on up the food chain. One barrier limiting metals movement is the solubility of a particular element at a neutral pH. Chaney (1973) lists Pb, Hg, Cr³⁺, F, Ag, Au, Ti, Sn, Si, and Zn as relatively insoluble and therefore non-threatening at pH 6.5 or above.

Another barrier to metals entering the food chain centers around the fact that once absorbed by a plant root, a metal can be strongly adsorbed on surfaces in the plant, or strongly chelated in the root cells, limiting that elements translocation to plant shoots. Chaney (1978) discusses this effect in relation to Fe, Pb, Hg, and Al.

Other elements, notably Zn, Cu, Ni, Co, Mn, As and Cd, can cause phytotoxicity if applied at high rates to cropland. The resulting reduction in amount and quality of crops is generally self limiting as related to food chain mobility (Roberts and Johnson 1978).

Chaney (1978) combines the several mechanisms limiting the entry of toxic elements into the food chain and calls the group the Soil-Plant Barrier. he defines the Soil-Plant Barrier as:

"...either due to insolubility of an element in soil, or to its immobility in plant roots, or due to phytotoxicity limiting maximum plant shoot levels of the element to levels safe for animals, the food chain is protected.

Unfortunately, the Soil-Plant Barrier does not protect animals from toxicities of all elements. The exceptions important to assessing risk from utilization of municipal sludge are Cd, Se, and Mo. Fortunately, Se and Mo have rarely been found at excessive levels in sludge; routine sludge monitoring would identify potentially excessive levels of these elements in sludge. Of course soil or sludge ingestion completely circumvents the Soil-Plant Barrier." (emphasis his)

Chaney's data helps illustrate why the EPA has chosen Cd as the primary indicator of sludge heavy metals acceptability and the last sentence of the above quote coupled with Mayland's (1977) findings demonstrate the need for monitoring other potentially toxic metals as well. Pahren et al. (1979) corroborates Chaney's findings concerning the Soil-Plant Barrier and Clevenger et al. (1983) reinforces the concept of monitoring a broad range of sewage sludge constituents.

The adverse health effects of toxic levels of Cd in humans result from selective concentration of Cd in the kidney tissue resulting in renal damage leading to proteinuria (Pahren 1979, Forstner and Wittmann 1979, and Federal Register 1979).

Laws and Regulations Pertaining to the Ultimate Use/Disposal of Sewage Sludge

The numerous laws and regulations governing the utilization and disposal of municipal sludge are in many different sections of the Code of Federal Regulations (CFR). A comprehensive regulation comprised of all preceding regulations pertaining to sludge management was to appear in 40 CFR part 258 in 1981 but as of March of 1985 had not. EPA published, "A Guide to Regulations and Guidance for the Utilization and Disposal of Municipal Sludge, MCD-72 which summarizes the federal regulatory framework for municipal sludge. The section concerning land application of sludge constitutes Appendix A of this text.

The "Guide" referred to above makes the following distinctions between municipal sludge as a hazardous or solid waste:

Subtitle C of RCRA authorized the development of hazardous waste regulations. Under the proposed hazardous waste regulations, issued on December 18, 1978 in the Federal Register, municipal sewage sludges were excluded from coverage under Subtitle C of RCRA. Subsequently, in the final regulations promulgated in the Federal Register on May 19, 1980, municipal sewage sludges were no longer excluded from coverage and thus are potentially subject to control as hazardous waste.

Domestic sewage and any mixture of domestic sewage and other wastes that passes through a sewer system to a POTW for treatment is not considered a solid waste [40 CFR Part 261.4(a)(1)]. Under all circumstances, however, municipal sewage sludge that is separated from the sewage during treatment is considered a solid waste [261.2(a)]. In general, a solid waste is a hazardous waste if it has been listed as such by the Administrator or if it exhibits any of the defined characteristics of a hazardous waste [261.3(a)].

EPA has not listed municipal sewage sludges as hazardous wastes. Therefore, municipal sewage sludges are not considered hazardous unless tested and shown to be hazardous. While not included in the Agency's listing of

hazardous wastes under Subpart D, of Part 261, specific municipal sewage sludges will be considered hazardous if they exhibit any one of the four characteristics of hazardous waste (261.21 through 261.24 i.e., ignitability, corrosivity, reactivity, and EP toxicity). Specific municipal sewage sludges would also be considered hazardous if they were mixed with any hazardous waste other than those entering the publicly owned treatment works (POTWs) through a sanitary sewer system [261.3(a)(2)(ii) and 261.4(a)(1)(ii)].

Municipalities have an obligation to determine if their sludge meets the definition of a hazardous waste. This does not mean that each POTW must test their sludge. Rather, POTW's or other waste handlers must make a determination that the waste is not hazardous, based upon knowledge of the waste, including the contaminants, etc. EPA advises testing, particularly EP toxicity testing, where there are significant contributions of industrial wastewater or stormwater into the POTW or where there is any reason to believe that the sludge may exhibit the EP toxicity characteristic. EPA believes that POTW sludge will rarely, if ever, exhibit the other three characteristics of a hazardous waste and believes that a determination can be made based on knowledge about the sludge, without need of testing.

The regulations place the responsibility of determining whether a POTW sludge is a hazardous waste squarely on the owner or operator of the POTW. He may choose any method he likes to make this determination. If he determines that his sludge is not a hazardous waste or fails to make a determination, and EPA finds that the sludge is a hazardous waste, then he is in violation of the regulations.

EPA believes that the vast majority of the POTW's do not generate a sludge which is a hazardous waste. However, we do not have a large amount of data to indicate which POTW's would be the likely sources of hazardous waste sludges. The characteristic most likely to cause a sludge to be hazardous would be toxicity, determined by the extraction procedure (EP). In very limited tests by EPA, cadmium is the only known element that has caused a sludge to fail the EP, i.e., be considered hazardous.

In addition to a determination of whether or not a municipality's sludge is a hazardous or solid waste, the State of Montana Pollution Discharge Elimination System (MPDES) permit for Missoula requires only that "Solids, sludges, or filter backwash, or other pollutants removed in the course of treatment or control of wastewater shall be disposed

of in a manner such as to prevent any pollutant from such materials from entering state waters."

The Missoula Sewage Treatment Plant (MSTP) currently conducts no tests for metals in their sludge. Past analyses of MSTP sludge metals concentrations vary by as much as four orders of magnitude and as such do not provide reliable baseline data (see Table 3 pg. 16).

The MSTP may be unknowingly violating CFR part 257.3(a)(1)(i) which states, "The pH of the solid waste and soil mixture is 6.5 or greater at the time of each solid waste application, except for solid waste containing cadmium at concentrations of 2 mg/kg (dry wt.) or less."

The Cd concentration is more than 2 ppm in MSTP sludge and the recipient soil pH is never monitored. The above section governs land on which food chain crops are grown. Food chain crops are defined in the 257 regulations as, "tobacco, crops grown for human consumption and animal feed for animals whose products are consumed by humans." Grains grown for either human or dairy cattle consumption fall under this definition.

CFR 257.3(a)(1)(ii) requires that the total annual Cd application rate not exceed 0.5 kg/ha after Jan. 1, 1987. Assuming Ammons' value for a Cd concentration of 10.8 ppm (Table , 3 pg. 16) is representative; the annual Cd loading rate for liquid digested sludge can be calculated as follows.

Assuming that the present tank truck is driven in low gear, low range at idle (as slow as possible) the sludge is spread in a pattern 22ft wide and 420ft long or on 9,240 ft². The sludge weighs

approximately 8.6 lbs/gal. and has a 1.0 to 2.0% solids content (dry weight). The 2.0% solids content was used to give the maximum loading or worst case scenario. In the same vein, the full truck capacity of 3600 gal. was used when in fact, the load is normally 100-300 gal. less, due to foaming inherent in the loading process. Multiplying this out gives:

$$\begin{array}{r}
 \frac{8.6 \text{ lbs.}}{\text{gal. of sludge}} \\
 \frac{10.7643 \text{ ft.}^2}{\text{m}^2} \\
 \frac{10.8 \text{ mg. (Cd conc.)}}{\text{kg.}}
 \end{array}
 \times
 \begin{array}{r}
 \frac{0.4536 \text{ kg.}}{\text{lb.}} \\
 \frac{10,000 \text{ m}^2}{\text{ha}} \\
 \frac{1 \text{ kg.}}{10^6 \text{ mg}}
 \end{array}
 \times
 \begin{array}{r}
 \frac{3600 \text{ gal/truckload}}{9240 \text{ ft}^2/\text{truckload}} \\
 \frac{2 \text{ (percent solids)}}{100} \\
 = 0.03533 \text{ kg/ha/load of sludge}
 \end{array}$$

This means that approximately 14 loads of sludge per year could be spread in the same area and still not exceed EPA's cumulative application rate.

The cake from the MSTP dewatering facility can vary from 10-20% dry solids and is therefore 5-10 times more concentrated than the digested sludge. Prior to this study, no metals analysis has ever been done on the cake, the effluent from the plant or the beltpress filtrate.

Metal Concentrations at the Missoula Sewage Treatment Plant and Nationwide

Table 3 summarizes the results of all the heavy metals analyses performed on MSTP's secondary digested sludge prior to this study. The Mg concentrations show a variation of four orders of magnitude and

the Mn concentrations nearly that much. The most recent analysis was done by J.M. Montgomery, the consulting firm which designed the new dewatering facility at the MSTP.

Table 4 is a compilation of results from 10 separate studies at other plants in the last 12 years and gives the range of values found in all the studies and the average median value from all studies.

In the national perspective, MSTP sludge would be characterized as a light domestic sludge based on present data.

Table 3

Results of Previous Tests on Missoula Sewage Treatment Plant's Digested Sludge (All in ppm)

	Cd	Mn	Ni	Pb	Hg	Cu	Zn	Fe	Al	Mg
State Forest Service Study ^{a*}	--	.032	--	--	--	459.72	721.36	9800.42	8002.38	.542
Stark Samples ^{b*}	--	115	--	--	--	990	242	1300	--	4100
Ammons Study ^{c*}	10.8	--	50.8	296	.0263	925	1311	--	--	--
Msia. T.P. Samples ^d	--	--	20.8	--	4.7	17.7	--	--	--	--
JMM Study ^e	8.0	--	57	246	--	745	901	--	--	--

^a One grab sample from the sludge truck was analyzed in the Fall of 1979. Results were obtained through Jeff Collins, a Soil Scientist for the State Division of Forestry.

^b One grab sample from the secondary digester was analyzed in June of 1979 by Dr. N. Stark, School of Forestry, University of Montana. The results were obtained from Dr. N. Stark.

^c 13 grab samples collected systematically over 4 1/2 weeks from the secondary digester were analyzed. The results recorded are the mean of the means of 3 trials on each sample. The study, entitled, "Trace Element Analysis of Missoula Sewage Sludge," was done in 1978 by Beth Ammons as an independent project through the University of Montana's Chemistry Department.

^d Recorded results are the mean of results obtained from tests on 5 grab samples using a Hach Colorimeter testing procedure performed in 1974 by J. Hamilton, Lab Technician at the Missoula STP.

^e From, City of Missoula, Montana Step 1 Wastewater Facilities Plan Solids Management Study, James M. Montgomery, Consulting Engineers Inc., August, 1980. Analytical method unknown.

*The analyses were run using atomic absorption spectrophotometry.

Table 4

A compilation of results from studies done by Berrow (1972), Peterson (1973), Furr (1976), McCalla (1977), Copar (1978), Laconde (1978), Nesheim (1978), Sommers (1979), Tobatobai (1979), Clevenger (1983). Values recorded for range are lowest-highest values noted in all studies combined and median value is average of reported medians. This table represents data from 377 individual treatment plants with a primarily domestic flow or a combined domestic/industrial flow.

Element	Reported Range	Typical Median
	ppm	ppm
As	1.1 - 230	10
B	4 - 1,000	33
Cd	1 - 3,410	15
Co	1 - 260	10
Cu	84 - 17,000	800
Cr	10 - 99,000	500
F	2 - 739	86
Fe	10,000 - 254,000	1.7%
Hg	0.6 - 130	6
Mn	32 - 9,870	260
Mo	1.2 - 40	10
Ni	2 - 13,000	80
Pb	13 - 26,000	500
Se	1.0 - 25.0	5
Sn	40 - 700	150
V	15 - 400	36
Zn	101 - 49,000	1,700

Statement of Problem and Research Objectives

The EPA requires pH monitoring of soils receiving sludge containing Cd concentrations higher than 2 ppm. At present, the MSTP does not monitor soils amended with MSTP's digested sludge. The results of five independent analyses of MSTP's sludge were contradictory, showing a range of metals concentrations spanning as much as four orders of magnitude. Both Cd values reported were in excess of EPA's limit of 2 ppm which would require recipient soil pH monitoring. The wide range of data rendered values virtually useless

for developing a comprehensive sludge management plan for the MSTP.

In October of 1983, a new sludge dewatering facility was added to the MSTP's process. The MSTP is making tentative plans to market dewatered sludge as a fertilizer alternative for agricultural use. The digested sludge is presently given away with free delivery to area farmers. Digested sludge containing questionable amounts of heavy metals or dewatered and concentrated sludge cake with a completely unknown amount of heavy metals may be spread on regional agricultural property.

The objectives of this study were to determine the range and relative balance of heavy metals concentrations at five distinct stages of the MSTP process. Determination of metals concentrations at the various process stages was intended to serve as a system of checks on the analyses, yield a definitive range of concentrations, provide baseline data for choosing future application sites and acceptable application rates.

CHAPTER II

CONCEPTUAL FRAMEWORK

Missoula Sewage and Sewage Sludge

In 1983, the City of Missoula provided public water carriage sewage disposal to approximately 27,500 individuals within the Missoula City Limits. The collection system includes nearly 116 miles of sewer line and 10 lift stations. Laterals, collectors, and interceptors connect residences and businesses surrounding the lift stations and the raw sewage is lifted from depths of up to 50' to within 6' of the ground surface and flows from the stations to the MSTP by gravity (Robert Haverfield, Superintendent, MSTP, personal communication).

J.M. Montgomery, Inc. (1982) did an extensive survey of the amount of groundwater infiltration in the Missoula collection system. They concluded that during the traditionally high groundwater period of May and June, a substantial portion of the sewer collection system is below the groundwater table. This coupled with the relatively high infiltration rates of most soils in the Missoula area and the mediocre condition of the collection system itself account for the high rate of infiltration and resulting high inflow at the MSTP.

Montgomery apportioned the sewage treatment plant inflow as follows:

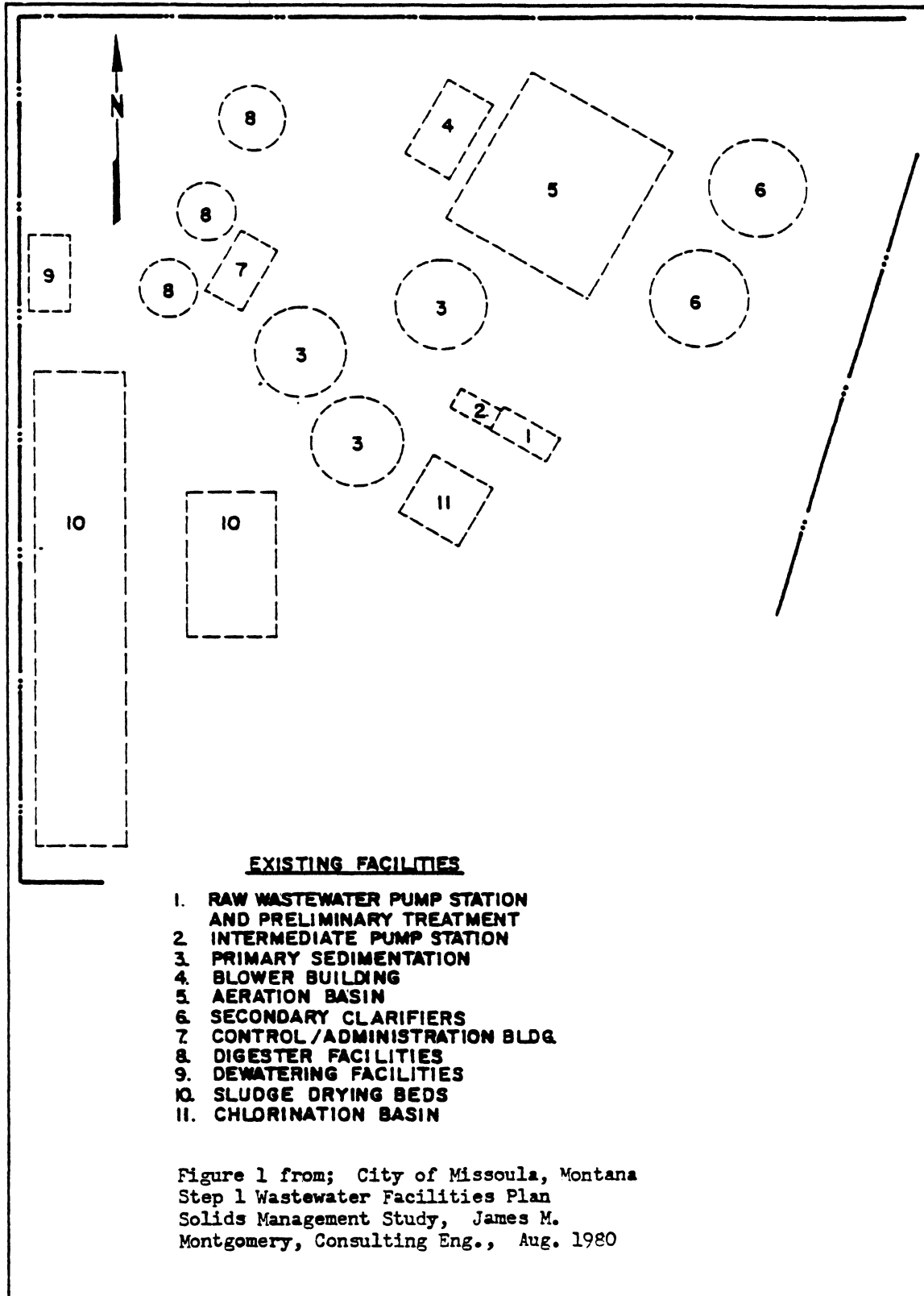
<u>Water Source</u> (For 1980)	<u>Total Flow gpd</u>
Residential	2,118,000
Industrial-Commercial	950,000
Institutional	243,300
*Groundwater Infiltration	1,840,000 - 8,260,000

*Highest in May and June

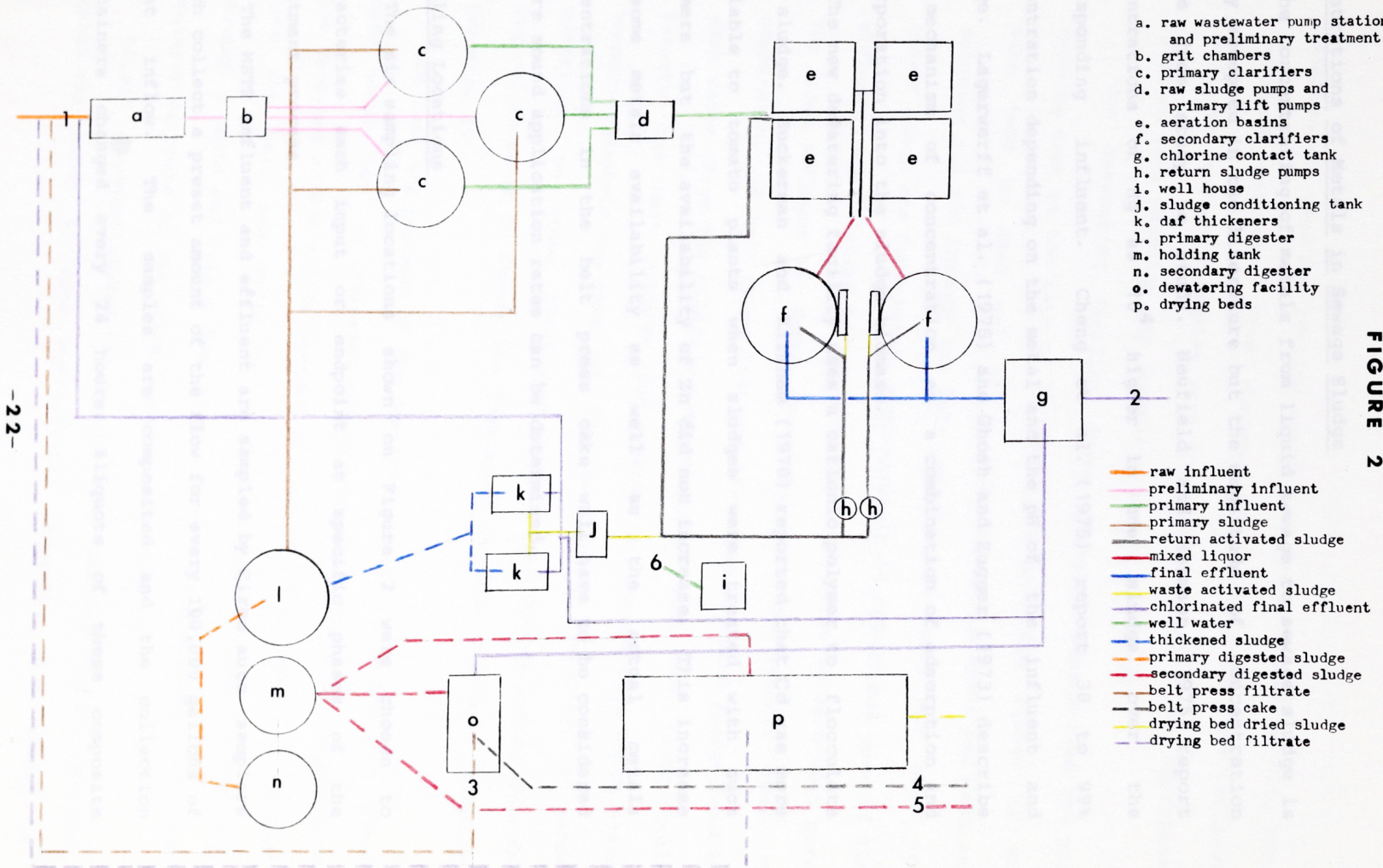
Montgomery data indicate that sewage is at most 61% of the MSTP plant influent and in high groundwater periods may be as little as 27.5% of the total flow treated. All other influent must come from groundwater infiltration or direct inflow (i.e., flooded manholes, etc.).

Figure 1 shows the location and layout of the MSTP physical plant. Figure 2 shows the fluid flow within the system and sampling locations. Figure 2 is not drawn to scale and the layout is not oriented but the individual buildings are located to simplify the piping and minimize the crossover.

FIGURE 1



NUMBERS REFER TO SAMPLING STREAMS



- a. raw wastewater pump station and preliminary treatment
- b. grit chambers
- c. primary clarifiers
- d. raw sludge pumps and primary lift pumps
- e. aeration basins
- f. secondary clarifiers
- g. chlorine contact tank
- h. return sludge pumps
- i. well house
- j. sludge conditioning tank
- k. daf thickeners
- l. primary digester
- m. holding tank
- n. secondary digester
- o. dewatering facility
- p. drying beds

- raw influent
- preliminary influent
- primary influent
- primary sludge
- return activated sludge
- mixed liquor
- final effluent
- waste activated sludge
- chlorinated final effluent
- well water
- thickened sludge
- primary digested sludge
- secondary digested sludge
- belt press filtrate
- belt press cake
- drying bed dried sludge
- drying bed filtrate

FIGURE 2

FLOW SCHEMATIC OF THE MISSOULA SEWAGE TREATMENT PLANT

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Concentrations of Metals in Sewage Sludge

The concentrating of metals from liquid sewage to sewage sludge is widely accepted in the literature but the magnitude of concentration varies from study to study. Neufield and Hermann (1975) report concentrations of Hg as 10^4 higher in one sludge over the corresponding influent. Cheng et al. (1975) report 30 to 99% concentration depending on the metal and the pH of the influent and sludge. Lagerwerff et al. (1976) and Ghosh and Zuger (1973) describe the mechanism of concentration as a combination of adsorption and incorporation into the sludge biomass.

The new dewatering facility uses a cationic polymer to flocculate the sludge. Zuckerman and Kirkham (1978) reported that Cd was more available to tomato plants when sludges were treated with such polymers but the availability of Zn did not increase. This increase in some metals availability as well as the actual metals concentrations in the belt press cake will have to be considered before sound application rates can be determined.

Sampling Locations

The six sampling locations shown on Figure 2 were chosen to characterize each input or endpoint at specific phases of the treatment process.

The MSTP influent and effluent are sampled by Circo auto samplers which collect a preset amount of the flow for every 100,000 gallons of plant inflow. The samples are composited and the collection containers changed every 24 hours. Aliquots of these composite

samples are used for routine testing at the MSTP such as BOD, TSS, and nutrient analysis. Five hundred ml. aliquots of the influent and effluent composite samples were drawn and acidified at approximately 0700 on each sampling day (sampling source #1 and #2).

The dewatering facility draws digested sludge from the sludge holding tank at the rate of 30,000-60,000 gpd. The sludge is mixed with 1600 to 4800 gal. of a 1-2% cationic polymer and well water solution and run through the belt presses. To keep the belt press itself clean and functional, approximately 60,000-80,000 gpd. of final effluent are utilized in two auto belt wash boxes on each belt press. The final effluent is drawn from the chlorine contact tank. The combination of belt press filtrate (from the digested sludge) and the wash water (from the chlorine contact tank) run into floor drains beneath the belt presses and combine in a single line which passes through a manhole due east of the dewatering facility. In normal operation, no other flows pass through said manhole making this the logical location to sample the dewatering facility discharge (sampling location #3).

The real end product of the dewatering facility is the belt press cake which has an increased solids content of 10 to 20% compared to the digested sludge solids content of 1 to 2%. The cake is scraped from the belt and falls on a conveyor which transports the cake through a chute and into a dump truck. Samples were grabbed from the conveyor en route to the truck (sampling location 4).

Liquid digested sludge can be withdrawn from the holding tank and hauled via truck to area agricultural property. When sludge is

withdrawn for hauling, one of the two recirculation pumps are used to pump the sludge from the holding tank to the truck. A sample draw-off line is located on the impeller housing of the recirculation pumps and grab samples are obtained by allowing 30-60 seconds worth of sludge to flow through the sampling line prior to collection.

In cold or otherwise inclement weather only the dewatering facility receives digested sludge and the recirculation pumps are used on the #2 digester, not the holding tank. To sample the feed digested sludge going from the holding tank to the dewatering facility, 4 valves must be changed and a portion of the sludge from the holding tank passed through the recirculation pump. In this manner, a grab sample can be collected as outlined in the preceding paragraph (sample location #5).

The Dissolved Air Flotation (DAF) Thickener utilizes a combination of final effluent and entrained air to float the secondary biomass from the waste activated sludge to the surface of the thickeners. From 100,000 to 400,000 gpd of final effluent are used in the DAF process and after use, piped to the front of the plant. Final effluent from the thickeners comprises from 1.5 to 6.7% of the average daily inflow of 6 MGD.

The well water samples were drawn from the tap in the lab (sample location #6).

CHAPTER III

METHODOLOGY

Duration of Study, Frequency of Sample Collection and Sample Preservation

In determining an appropriate sampling strategy for this project, the first step was to analyze past results of analyses on the MSTP sludge.

In early 1983 Dr. Rudy Gideon of the University of Montana Math Department ran MANOVA and ANOVA statistical analysis of Beth Ammon's 1978 results of heavy metals analysis on the secondary digested sludge from the MSTP. Ammons (1978) grabbed 13 samples over a 4 1/2 week period and split each sample in thirds. Each split was run twice on a IL 250 Atomic Absorption Spectrophotometer. Gideon's recommendations included more sampling days, only 2 splits per sample, and one observation per split. The variation between the two observations on the same split was minimal for all metals tested. The variation was not reduced by using three splits instead of two and Gideon concluded that the time would be better spent analyzing more samples rather than more splits.

Gideon's conclusions were based on the desire to characterize MSTP sludge with a single "average" value for each individual metal concentration. Nesheim (1978) concluded that in 1 of the 3 sludges he studied, seasonal variation in metals concentrations can occur and suggested that studies should consider the possibility of a change in metals content with the seasons.

Klein et al. (1974) attempted to apportion sources of metals in

New York City's then 13 major sewage treatment plants. Flow-proportioned, daily samples for 12 metals were composited for monthly analysis over a 21 month period. Analyses were run on influents, effluents, and sludges. Klein concluded that no reproducible seasonal variation was detectable and the source of metals was predominantly domestic, even in the more industrial areas.

Elliott and Stevenson (1977) ran a 13 month heavy metals analysis program at the West-Southwest Sewage Treatment Plant in Cicero, Ill. from Aug. 1973 to Sept. 1974. In their study, three grab samples of digested sludge were composited every fourth day and analyzed for heavy metals. No seasonal trend could be detected. The variation of metal levels from one sample day to the next was high and unpredictable.

Oliver and Cosgrove (1974) studied the sources and efficiency of metal removal in activated sludge treatment plants. They observed that metals input into a treatment plant was not a continuous process but generally consisted of slugs of metals lasting for a discrete time. The slugs of metals did not occur periodically and could not be predicted. Oliver and Cosgrove also concluded that even a large single slug of metals would have a minimal impact on the metals content of a digested sludge due to the large dilution factor. (The MSTP has a total digester capacity of 1,409,000 gallons).

Monteith and Stephenson (1978) downplay the role of dilution as a factor reducing the effect of a slug of influent metals. In their study on mixing efficiencies in full-scale anaerobic digesters, they found that as much as 75% of digester capacity can be useless as a

result of short-circuiting and/or dead zones within the digester.

In an earlier publication Monteith and Stephenson (1977) offered the following recommendations and observations: When multiple batch loads are hauled from a digester within the same sampling day, each load must be sampled and composited because there is a decrease in solid phase constituent concentration in a sequence of batches. Rapid sludge withdrawal to tank trucks leads to potential channeling in the sludge blanket and a resulting reduction in solids concentration. Depending on the mixing efficiency within the digester, the solids concentrations can vary within the same day by 7 to 55% for batch withdrawal and 5 to 16% for semi-continuous withdrawals with a belt press. The reduced variability stems from slower draw off to a belt press and reduced channeling resulting in the digester. Total solids and metals concentrations are correlated when the plant influent is all domestic. With a combined domestic/industrial inflow, a correlation may not exist. Digested sludge quality should be assessed using a frequency of one sampling day every two weeks. The sampling day should be varied to eliminate daily bias. The sludge samples should be composed of at least three grab samples collected during the sampling day from belt press facilities. A minimum of 3 to 4 sampling days would normally provide a representative range of heavy metals concentrations in digested sludges.

Three sampling days were chosen at the request of Bob Haverfield, MSTP plant Superintendent, during both the annual high and low flow regimes at the MSTP. Expediency played as great a role in deciding sample dates as did randomness.

Sampling Procedures

The raw and final sample 500 ml aliquots were drawn from the MSTP composite samples immediately after the sample jugs were changed in the morning. The samples were acidified with concentrated HNO_3 to pH 2 and stored in linear polyethelene (L.P.) containers until digested.

Three 175 ml grab-samples of digested sludge and belt press filtrate were composited on each sampling day and acidified and stored as above.

Three approximately golf-ball size lumps of belt press cake were collected in a 500 ml L.P. container and 100 ml of distilled deionized water added with sufficient conc. HNO_3 to acidify to pH 2. The water was added to ensure wetting and acidification of the entire sample.

EPA (1979) allows metals samples to be held for 6 months without refrigeration if the sample is acidified to pH 2. Four to six weeks was the maximum holding time in this study.

Analytical Methods

A number of options exist for quantifying the concentrations of metals in aqueous solutions.

Colorimetric methods such as those marketed under the Hach Chemical Co. name provide a rapid and simple technique of obtaining ballpark values. The accuracy of colorimetric analyses for heavy metals is typically in the plus or minus 50 to 100% range and can be useful as an indicator of the approximate concentrations (EPA 1979).

Anodic stripping voltammetry (ASV) is a highly sensitive electroanalytical technique for detecting trace metals (Wang 1982).

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About 20 metals can be tested using this technique compared with 60 testable on an atomic absorption spectrophotometer (AAS) (EPA 1979). ASV is better suited for dilute solutions in the ppb range than for the higher concentrations found in wastewater and sludges (Wang 1982).

Atomic Emission (AE) spectroscopy is faster than AAS for qualitative work but saves little if any time in quantitative analyses and in most cases AAS is more sensitive quantitatively (EPA Jul. 1979, Ewing 1975).

AAS is the analytical method of choice and the most widely used method for trace analysis (Standard Methods 1980). Sample preparation for analysis is relatively simple and the measurement is rapid (Ballinger 1972)

not Al, (6) 7
The elements Cr, Cd, Ni, Pb, Mn and Mg were chosen for analysis because of potential toxicity, discrepancies in existing data and/or potential input from industrial sources. More or less coincidentally, all the above elements could analyzed using direct aspiration into an air-acetylene flame (Standard Methods 1980).

The major decision was what digestion procedure to use in preparing the samples for analysis.

Ritter et al. (1978) compared dry ash digestion, wet ash digestion, nitric acid digestion and complete digestion with HF as alternatives for analysis of soils and sludges. He concluded that where volatilization of a particular element was not a concern, dry ash digestion was the most accurate and precise method available.

Standard Methods (1980) recommends a combination of HNO_3 , HClO_4 and HF acids for digestion of sludge with a high or refractory organic

content.

Due to the lack of a regulatable muffle furnace for dry digestion or a hood capable of withstanding repeated fuming of HClO_4 at the MSTP, another method for digestion was used.

Sinex et al. (1980) reported on the effectiveness of a mixture of 90 HNO_3 - 10 HCl in extracting Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd, and Pb from sediments. Even sediments with high organic fractions rendered reproducible results. The following digestion procedure is a modification of Sinex's procedure.

The belt press cake and digested sludge were oven dried at 100 to 110 degrees Celsius for 48 hours and cooled in a desiccator, then ground and weighed. One hundred ml of raw, final, filtrate or well water or 0.5g of dried cake or sludge were placed in a reflux flask with 20 ml of a 9:1 solution of conc. HNO_3 and conc. HCl . The samples were refluxed for approximately 4 hours and evaporated to near dryness. More HNO_3 : HCl was added as necessary and reflux continued until an ashy white digestate was apparent.

The filter and all glassware were washed with 1:1 HCl , the samples filtered and brought to a final volume of 50 ml for analysis.

CHAPTER IV

RESULTS

Introduction To Tables

The concentrations of cadmium, nickel, chromium, manganese, lead and magnesium were determined for six phases of the Missoula Sewage Treatment Plant operation. The concentrations for cadmium, nickel, chromium and in some cases manganese were too low for meaningful results in the well water, final effluent and raw influent samples. Any value below 0.10 ppm was reported as <0.1 ppm (less than 0.1 ppm). The sensitivity of air-acetylene flame aspiration atomic absorption analysis is generally lower than 0.1 ppm (Ewing 1975). The raw data from the following analyses did not appear sound enough to support conclusions based on concentrations of less than 0.1 ppm. While one of the original purposes of this study was to determine the balance of metals within the system, the 0.1 ppm detection level was chosen to ensure no erroneous conclusions were drawn based on number juggling.

Each sample was split into triplicates and the numbers in parentheses in Table 5 through 9 represent the range of values obtained from triplicate analysis of the same sample. The average value of the triplicate results is given immediately below the range. Where a single value appears with no range, either spillage, spattering, or some other mishap rendered two of the triplicates unacceptable for analysis.

Results for the raw and final samples collected on June 6, 1984 are not included as the samples and containers were lost prior to

analysis.

Northern Engineering and Testing Inc. of Billings, Montana ran comparative analysis for each sample collected during the high flow sampling period. The results of Northern's analyses of the same samples appear directly beneath this study's results in the following tables.

TABLE 5

WELL WATER AND FINAL EFFLUENT METALS CONCENTRATIONS (all in ppm)

Source	Date	Analyst	Flow Regime	Cd	Ni	Cr	Mn	Pb	Mg
Well Water	21Apr84	DC*	Low	<0.1	<0.1	<0.1	<0.1	0.3	28.0
	5Jun84	DC	High	<0.1	<0.1	<0.1	<0.1	0.8	20.0

Final	29Feb84	DC	Low	<0.1	<0.1	<0.1	<0.1	<0.1	47.8
	11Mar84	DC	Low	<0.1	<0.1	<0.1	<0.1	<0.1	55.3
	25Mar84	DC	Low	<0.1	<0.1	<0.1	<0.1	(0.12-0.25)*** 0.18	53.5
	5Jun84	DC	High	<0.1	<0.1	<0.1	<0.1	(0.54-0.94) 0.74	62.2
	5Jun84	NET**	High	<0.02	<0.02	<0.02	----	0.4	----
	6Jun84	DC	High	----	----	----	----	----	----
	6Jun84	NET	High	<0.005	<0.02	<0.02	----	0.03	----
	10Jun84	DC	High	<0.1	<0.1	<0.1	<0.1	0.60	50.8
10Jun84	NET	High	<0.005	<0.02	<0.002	----	0.02	----	

* D. Corti

** NE & T values are results from comparative analyses on split samples run by Northern Engineering and Testing Inc. of Billings, Montana.

*** Numbers in parentheses are range values. The number below the parentheses is the average value from triplicate analyses on the same samples.

TABLE 6

RAW EFFLUENT METALS CONCENTRATIONS (all in ppm)

Date	Analyst	Flow Regime	Cd	Ni	Cr	Mn	Pb	Mg
29Feb84	DC	Low	<0.1	<0.1	<0.1	(0.12-0.20) 0.16	(0.12-0.49) 0.37	59.6
11Mar84	DC	Low	<0.1	<0.1	<0.1	(0.15-0.15) 0.15	(0.49-0.92) 0.80	51.8
25Mar84	DC	Low	<0.1	<0.1	<0.1	(0.12-0.15) 0.14	(0.12-0.25) 0.19	55.2
5Jun84	DC	High	<0.1	<0.1	<0.1	(0.13-0.14) 0.13	(0.54-0.70) 0.62	53.9
5Jun84	NET	High	<0.005	<0.02	<0.02	----	<0.02	----
6Jun84	DC	High	-----	-----	-----	----	----	----
6Jun84	NET	High	<0.005	<0.02	<0.02	----	0.2	----
10Jun84	DC	High	<0.1	<0.1	<0.1	(0.12-0.14) 0.13	(0.74-0.80) 0.77	56.3
10Jun84	NET	High	<0.005	<0.02	<0.02	----	<0.02	----

TABLE 7

BELT PRESS FILTRATE METALS CONCENTRATIONS (all in ppm)

Date	Analyst	Flow Regime	Cd	Ni	Cr	Mn	Pb	Mg (Conc. are 1×10^{-2})
29Feb84	DC	Low	(0.10-0.18) 0.14	(0.46-0.50) 0.48	(0.50-0.68) 0.59	(0.68-0.70) 0.69	(3.0-3.2) 3.10	15.9
11Mar84	DC	Low	(0.10-0.15) 0.13	(0.32-0.46) 0.34	(0.48-0.50) 0.49	(0.58-0.64) 0.61	(2.31-2.41) 2.36	14.9
25Mar84	DC	Low	(0.12-0.14) 0.13	(0.10-0.21) 0.16	(0.26-0.32) 0.29	(0.32-0.32) 0.32	(0.87-1.12) 1.00	12.8
5Jun84	DC	High	<0.1	(0.20-0.54) 0.37	(0.40-0.40) 0.40	(0.40-0.45) 0.43	(1.50-1.54) 1.52	64.5
6Jun84	DC	High	<0.1	0.56	0.55	0.67	2.06	72.5
10Jun84	DC	High	<0.1	(0.54-0.55) 0.55	(0.50-0.60) 0.55	(0.58-0.59) 0.59	(1.94-2.06) 2.00	57.5

TABLE 8

SECONDARY DIGESTED SLUDGE METALS CONCENTRATIONS (in mg/kg dry wt.)

Date	Analyst	Flow Regime	Cd	Ni	Cr	Mn	Pb	Mg (Conc. are 1 X 10 ⁻²)
29Feb84	DC	Low	5.0	51.0	42.0	61.3	397.5	56.7
11Mar84	DC	Low	(5.1-10.0) 7.53	(46.5-57.0) 51.5	(46.0-70.0) 57.6	(66.1-70.9) 68.8	(368.9-385.1) 379.7	58.4
25Mar84	DC	Low	(6.0-7.8) 7.1	(38.5-65.0) 53.7	(43.0-64.0) 53.00	66.1-80.6 73.6	(326.0-413.7) 360.4	51.6
5Jun84	DC	High	5.5-6.0 5.8	(39.5-45.0) 42.3	(50.0-50.0) 50.0	(64.4-66.7) 65.6	(200.0-213.3) 206.7	76.1
5Jun84	NET	High	8.0	46.0	58.0	-----	230	-----
6Jun84	DC	High	(6.0-6.0) 6.0	(47.0-49.5) 48.1	(50.0-50.0) 50.0	(63.4-74.7) 69.1	(207.0-223.3) 215.2	68.8
6Jun84	NET	High	4.0	60.0	46.0	----	232	----
10Jun84	DC	High	(5.0-5.0) 5.0	(39.0-45.0) 42.0	(51.0-51.0) 51.0	(57.5-61.4) 59.5	(197.0-203.3) 200.2	51.8
10Jun84	NET	High	2.5	52.0	35.0	----	234.0	----

TABLE 9

BELT PRESS CAKE METALS CONCENTRATIONS (in mg/kg dry wt.)

Date	Analyst	Flow Regime	Cd	Ni	Cr	Mn	Pb	Mg (Conc. are 1 X 10 ⁻²)
29Feb84	DC	Low	(6.0-6.2) 6.1	(52.0-57.5) 54.8	(50.0-56.0) 53.0	(83.9-90.3) 87.1	(372.7-403.7) 388.2	66.9
11Mar84	DC	Low	(5.0-10.0) 7.8	(57.5-62.0) 59.8	(65.0-68.0) 66.5	(87.1-88.7) 87.9	(403.7-416.1) 409.9	70.7
25Mar84	DC	Low	(7.4-10.5) 8.5	(48.0-48.2) 48.1	(56.0-61.0) 58.5	(75.8-85.5) 80.7	(360.2-381.4) 367.3	63.6
5Jun84	DC	High	8.4	88.6	53.0	87.4	276.7	46.6
5Jun84	NET	High	4.0	63.0	47.0	----	241.0	----
6Jun84	DC	High	6.0	88.0	60.0	85.9	273.3	43.0
6Jun84	NET	High	6.5	68.0	44.0	----	254.0	----
10Jun84	DC	High	(6.8-9.5) 8.2	(87.0-87.0) 87.0	(50.0-53.0) 51.5	(91.3-94.3) 92.8	(280.0-287.0) 283.5	48.8
10Jun84	NET	High	8.0	32.0	42.0	----	258.0	----
Apr84	JMM*	Low	15.5	37.0	36.0	----	168.0	----

* Analysis done by J.M. Montgomery Engineering in April, 1984.

DISCUSSION

Solids Balance

The intent of this study was to determine the fate of specific metals entering the Missoula Sewage Treatment Plant (MSTP) by ascertaining their concentrations at various stages of the treatment process. Thirty to ninety percent of the metals present in raw sewage are taken up and concentrated by sewage sludge (Cheng et al. 1975).

If metals concentrations follow approximately the same course as solids through the treatment process, it should be possible to predict the metals concentrations at a given stage of the treatment process given a thorough knowledge of the solids fate and the metals concentrations at one or more stages of the treatment process.

*An average daily flow of 6,000,000 gallons per day (gpd) of raw sewage enters the MSTP at an average suspended solids concentration of roughly 200 ppm (For this discussion, suspended solids will be defined as those solids retained on a #41 Whatman Filter). A concentration of 200 ppm can be thought of as 200 gallons of solids per 1,000,000 gallons of raw sewage so 6,000,000 gallons of raw sewage should bring 1200 gallons of suspended solids into the system each day (6,000,000 gpd X 200 gallons of solids/1,000,000 gallons of raw sewage). The average concentration of suspended solids leaving the MSTP in the final effluent during periods of normal operation is approximately 25 ppm.

* All flow and concentration values are taken from MSTP operational charts.

This means that 150 gpd of suspended solids are lost in the final effluent and 1050 gpd of suspended solids are retained for treatment resulting in an 87.5% solids capture ratio. If metals do travel primarily with the solids, then depending on solubility, one could expect to see roughly an 87.5% reduction in metals concentrations from the raw influent to the final effluent.

An average of 36,000 gpd of sludges are pumped to the primary digester. This total is made up of approximately 18,000 gpd of raw sludge from the primary clarifiers and 18,000 gpd of thickened sludge from the DAF thickeners. The thickened sludge has a total solids content of about 3.0% and the raw sludge averages 2.5% total solids. Total solids are defined as combined filterable and dissolved solids. Nine hundred and ninety gpd of total solids are being added to the primary digester from the combined sources of raw and thickened sludge with a loss of $(1 - 990 \text{ gpd}/1,050 \text{ gpd}) = 5.7\%$ solids from either inaccurate meter readings or volatilization during aerobic digestion.

Since the sludge entering the primary digester has an average solids content of 2.75% or 27,500 ppm, one could predict that the digested sludge should have 137.5 times higher metals concentrations than the raw influent which has a suspended solids concentration of 200 ppm.

Using the same line of reasoning, the belt press filtrate containing 1,200 ppm suspended solids should have six times higher metals concentrations than the raw influent.

The dewatered sludge cake at 17% total solids concentration or 170,000 ppm should have 850 times higher metals concentrations per

unit volume than the raw influent. Since the sludge cake is basically filtered digested sludge, the cake metals concentrations would be the same as the digested sludge values with the subtraction of the soluble portion which should be reflected in elevated belt press filtrate metals concentrations.

Inaccuracies Inherent In This Solids Balance

While the preceding predictive model appears logical, there are deficiencies in the system. All existing data for the solids concentrations in the raw influent, final effluent and belt press filtrate are for suspended (filterable) solids. All existing data for the raw and thickened sludges, digested sludge, and dewatered sludge cake are for total solids from moisture balance analyses. Comparing unlike types of analyses makes the predictive capability of the model tenuous at best.

Cadmium

The well water, raw influent and final effluent had cadmium concentrations below the level of detection for this study. The belt press filtrate showed slightly elevated levels of cadmium during the low flow regime and was below the level of detection in the high flow regime.

The secondary digested sludge cadmium concentrations ranged from 5.0 ppm to 10.0 ppm with an average for all results of 6.07 ppm. The comparative testing from Northern Engineering and Testing (NET) showed discrepancies of up to 2.5 ppm in the analyses of split samples. The average cadmium concentration over the study period was about 4.0 ppm

lower than those noted in Ammon's 1978 study.

The belt press cake cadmium concentrations were generally within 1.5 ppm of the secondary digested sludge values but were consistently higher while adherence to the solids balance model would have made the cake metals concentrations the same or lower. Decisions concerning the sludge and cakes acceptability for land application should use the range of 5.0-10.0 ppm cadmium concentration as the "normal" concentration. This range is well above the 2.0 ppm concentration allowed by EPA for unlimited soil amendment. The MSTP must monitor recipient soil pH to be in compliance with CFR part 257.3(a)(1)(i). As of this writing, it does no soil pH monitoring.

Nickel

The well water, raw influent and final effluent had nickel concentrations below the level of detection of this study. The belt press filtrate had an average nickel concentration of 0.41 ppm. The high and low flow regime averages were 0.49 and 0.34 ppm respectively, well within the plus and minus 50% within day variation noted by Monteith and Stephenson (1978).

The secondary digested sludge results show discrepancies between this studies analyses and the comparative analyses done by NET. The average low flow nickel concentration was 52.1 ppm. The high flow average concentration was 52.7 ppm according to NET and 44.3 according to this analyst with as much as 11.9 ppm difference on the same sample. This difference is not unexpected in light of the highly variable nature of sludge.

The belt press cake proved to have consistently higher nickel concentrations than the digested sludge with an average value of 65.7 ppm or roughly a 21% increase in nickel concentration from the digested sludge to the belt press cake.

Chromium

The well water, raw influent and final effluent had chromium concentrations below the level of detection for this study. The belt press filtrate had an average 0.48 ppm chromium concentration with a 0.29-0.59 ppm range.

The secondary digested sludge had an average chromium concentration of 49.2 ppm with a 35.0-57.6 ppm range. The results of comparative analyses from two different days show a 14.0 ppm difference on split samples.

The belt press cake had an average concentration of 52.8 ppm with a range of 42.0-66.5 ppm. The cake chromium concentration was higher than the secondary digested sludge by 6.8%.

Manganese

Well water and final effluent samples had manganese concentrations below the level of detection of this study. The raw influent contained consistent concentrations of manganese ranging from 0.13 to 0.16 ppm with an average concentration of 0.14 ppm.

The secondary digested sludge average manganese concentration was 66.3 ppm or 473 times that detected in the raw influent or roughly 2.5 times more than would be expected from the solids balance model. The belt press cake average manganese concentration was 86.9 ppm, an

increase of 23% dry weight concentration over the secondary digested sludge.

Belt press filtrate results yielded an average value of 0.55 ppm manganese or 3.9 times higher than the raw influent.

Lead

The MSTP well water contained more lead than the final effluent (see Table 5). The lead concentration was variable in the final effluent ranging from <0.1 ppm to as high as 0.74 ppm.

The raw influent lead concentration averaged 0.55 ppm using only this analyst's results. Comparative analyses from NET found <0.02 ppm lead in the raw influent (see Table 6).

Belt press filtrate lead concentrations averaged 2.00 ppm or 3.7 times higher than the raw influent lead concentrations.

Lead is the only element that displayed high vs. low flow regime differences in concentrations in both the secondary digested sludge and belt press cake. The average concentration in the sludge was 379.2 ppm lead during low flows and 207.4 ppm in the high flow regime. This difference is not reflected in the raw influent results as they are relatively consistent over the sampling period.

Belt press cake results averaged 388.5 ppm lead in the low flow period and 277.8 ppm in the high flow period.

This apparent seasonal difference must be attributed to something other than change in raw influent concentrations as the trend in average lead concentrations in the raw influent is opposite the one in the sludge and cake. For a comparison of actual results see Table 6,

8, 9:Pb.

Magnesium

the results for magnesium are both confusing and contradictory. The average concentration in the raw influent is 55.4 ppm while the final effluent is almost the same at 53.9 ppm. On two of the six days tested for magnesium, the concentration in the final effluent proved to be higher than in the raw influent. In some instances, the magnesium concentration was higher in the belt press filtrate than the digested sludge or belt press cake.

I believe that the results of the magnesium analyses are suspect and no attempt to draw conclusions from them will be made.

Conclusions and Recommendations

The results of these analyses indicate no evident seasonal (high-low flow regime) changes in the concentration of the metals tested. The concentrations determined in this study are a reflection of the normal metals content at the Missoula Sewage Treatment Plant. Beth Ammon's 1978 values were approximated by my results as were Dr. Starks's 1979 results for manganese.

The secondary digested sludge would be characterized as a light domestic sludge compared to other sludges (see Table 4). The introduction of a very large slug of metal(s) would have to occur for the MSTP sludge to be agriculturally unattractive as a soil amendment.

Cadmium concentration in the digested sludge exceeds the 2.0 ppm EPA limit for unmonitored soil amendments. The MSTP should immediately start monitoring recipient soil pH to insure that it is at

or above 6.5 prior to each application of digested sludge.

The concentrations of all metals tested in the belt press cake are relatively low on a ppm dry weight basis. The volume reduction that occurs in the dewatering process leads to an approximately nine-fold increase in the metals concentrations per unit volume above the levels found in the digested sludge. Even considering these elevated concentrations per unit volume, the belt press cake makes an attractive fertilizer substitute but the MSTP should be wary of repeatedly inundating the same patch of soil with belt press cake as it has with digested sludge in the past.

The validity of the solids balance model outlined in the beginning of the discussion section is still largely undetermined. Valid raw influent results were obtained only for manganese and lead. Suspended solids concentrations are six times higher in the belt press filtrate than in the raw influent but the concentration ratio for manganese was only 3.7:1 and for lead 3.9:1. The 3.7:1 and 3.9:1 appear fairly consistent for manganese and lead but without actual data for support, these ratios should not be used for other metals.

Based on present methods of determining solids at the MSTP; suspended solids for raw influent and total solids for digested sludge and belt press cake, the solids model is not viable as a predictive tool for comparing other metals:solids ratios.

The most surprising outcome of this study is the fact that the belt press cake in 37 of 42 analyses had a higher metals concentration for all metals tested than did the digested sludge. On a mg/kg or ppm dry weight basis I would have expected the concentrations to be equal

or slightly less in the belt press cake than in the digested sludge since the only difference is dewatering. Apparently, enough metals are being added to the belt press cake from the final effluent wash water to account for as much as a 23% increase in manganese concentration and lesser amounts for the other metals under consideration.

The correlation between the solids balance model and the metals balance would be improved by experimental determination of how much of the sludge solids content at various stages of the process is comprised of biomass generated in the process itself. As biomass is generated, a greater proportion of total solids within the system will be filterable solids.

In addition to recipient soil pH monitoring, the MSTP should immediately have further analysis of its well water lead concentrations. The 0.3 ppm and 0.8 ppm lead concentrations observed in this study are well above the 0.05 ppm maximum lead concentration for drinking water as cited in ARM 16.20.203.

The wells are both driven through approximately 20 feet of abandoned dump overburden with the 8 inch well driven to a depth of 80 feet and the 6" well driven to a depth of 120 feet. Percolation and leaching from the dump overburden may account for the elevated lead levels.

The original objectives of this study were only partially met. Determining the metals balance within the Missoula Sewage Treatment Plant proved infeasible for most metals due to their low concentrations in the raw influent, final effluent and well water.

✓
✓
The most useful products of this study were determination of baseline data for belt press cake where none previously existed and verification of concentration values from previous analyses on the digested sludge.

✓
Determination of the metals balance within the system could be accomplished using the same analytical technique but concentrating samples of raw influent, final effluent and well water before analysis.

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APPENDIX A

Reprinted from, A Guide to Regulations and Guidance for the Utilization and Disposal of Municipal Sludge, U.S. EPA 430/9-80-015, MCD-72.

LANDSPREADING

I. Background

- (A) in 1978, approximately 24% of the sludge produced was applied to land
- (B) municipal sewage sludge is a useful material for conditioning soils and providing plant nutrients, but its usefulness becomes limited when concentrations of pollutants are high
- (C) the utilization of municipal sludge for plant production or land reclamation helps fulfill the goal of Congress and EPA for waste recycling

II. Applicable Laws, Regulations, and Guidelines

(A) laws

- (1) CWA (Clean Water Act of 1977, PL 95-217 and the Federal Water Pollution Control Act of 1972, PL 92-500) authorizes Federal funding of 75% (85% for innovative and alternative technology projects) of the eligible costs involved in the construction of municipal wastewater treatment plants and sludge treatment and disposition facilities; authorizes EPA to issue comprehensive sewage sludge management guidelines and regulations; authorizes the NPDES (National Pollution Discharge Elimination System) for point source discharges and development of areawide waste treatment or water quality management plans for non-point source pollution; requires the implementation of pretreatment standards for industrial discharges that enter POTW's; and establishes a major research and demonstration program to develop improved wastewater treatment and sludge management practices.
- (2) RCRA (Resource Conservation and Recovery Act of 1976, PL 94-580) provides financial assistance to state and local governments for development of solid waste management plans which provide for the safe disposal of solid waste; provides that technical assistance be provided to help establish acceptable solid waste management methods; requires regulations for the safe disposal of hazardous and nonhazardous wastes; and encourages the research and demonstration of more effective solid waste disposal and resource conservation technologies.
- (3) SDWA (Safe Drinking Water Act of 1975, PL 93-523) requires coordination with the CWA and RCRA to protect drinking water from contamination.
- (4) NEPA (National Environmental Policy Act of 1969, PL

91-190) authorizes Regional Administrators, at their discretion, to require Environmental Impact Statements (EIS) (40 CFR, Part 6) if potential adverse social, economic or environmental impacts are suspected for a new or modified sludge disposition facility or practice. An EIS or negative declaration (40 CFR, Part 35, Sect. 35.925-8) is also required when applying for Federal Construction Grants.

- (5) TSCA (Toxic Substances Control Act of 1976, PL 94-469), Section 9, requires coordination with the Clean Air Act and the Clean Water Act to restrict disposal of hazardous wastes. Presently only PCB (polychlorinated biphenyl) is specifically regulated in regards to sludge disposition.

(B) regulations

- (1) Criteria for the Classification and Solid Waste Disposal Facilities and Practices (40 CFR, Part 257; FR, September 13, 1979)
- (2) Federal Construction Grants Regulation (40 CFR, Part 35, Subpart E)
- (3) state regulations
- (4) PCB Regulations (40 CFR, Part 761)
- (5) NPDES Regulations (40 CFR, Part 125)
- (6) Hazardous Waste Regulations (40 CFR, Parts 260-265; FR, May 19, 1980)

(C) guidelines

- (1) Classifying Solid Waste Disposal Facilities, A Guidance Manual (SW-828)
- (2) Sludge Technical Bulletin (EPA 430/9-77-004; MCD-28)
- (3) Application of Sludges and Wastewaters on Agricultural Land: A Planning and Educational Guide (MCD-35)
- (4) Sludge Treatment and Disposal (EPA-625/4-78-012)
- (5) Sludge Process Design Manual (EPA-625/1-79-011)

III. Procedure for Implementing Sludge Landspreading Practices

- (A) meet local, state, and Federal requirements for landspreading. The state requirements are to be based upon the minimum

standards contained in the Criteria for the Classification of Solid Waste Disposal Facilities and Practices. State regulations can, however, be more restrictive than the Criteria

(B) an existing or planned facility for landspreading sewage sludge must comply with the Criteria

(1) facilities must immediately be in compliance with the Criteria. If the facility is not in compliance, the facility must either cease operations or apply to the state solid waste management authority for a compliance schedule. The state may grant any facility built prior to January 1986, up to five years (not to extend beyond January, 1986) to meet the Criteria. The compliance schedule will involve steps to either upgrade or close the facility. EPA recommends that the factors used by the state to determine if a compliance schedule should be granted or how the compliance schedule should be formulated should be based on the following: availability of disposal at other facilities, cost constraints, existing contractual agreement, likelihood of incremental environmental damage and other pertinent factors.

(2) the Criteria are enforceable through the solid waste management programs of each state and/or through Federal courts under RCRA provisions. If a state does not enforce the Criteria directly through its solid waste management program, the state or a private citizen could seek enforcement of the Criteria in Federal court through the "citizen suit" provision of RCRA. The Criteria is enforceable by EPA under Section 405(e) of the CWA.

(3) a landspreading facility must meet the provisions in the Criteria for surface water, ground water, disease, endangered species, safety, floodplains, air and food-chain crops. Provisions in the Criteria relating especially to sludge landspreading (i.e., sections 257.3, 257.3-6(b) and Appendix II of the Criteria) are interim final. Interim final status is the same as the final status for regulations with respect to enforceability (i.e., the interim final provisions in the Criteria apply now as written). The difference, however is that comments are received and considered for possible change. Finalization with possible change is expected by early 1981.

(a) A landspreading facility, where the waste has been incorporated into the soil for the enhancement of vegetative growth, is not normally considered as having a point source discharge (EPA Criteria Guidance, SW-828). This is true even through there

may be a discharge to waters of the United States from an outfall or clearly delineated channel that drains the landspreading area. "Incorporate into the soil" means the injection or mixing of the sludge into the soil.

a landspreading facility must also comply with the state or local areawide plan for non-point source pollution of surface waters (authorized by Section 208 of the CWA). Non-point source pollution from landspreading can be minimized by good soil conservation management practices, including use of a grassed border (e.g., 15 feet in width) downslope from an application site. Research in Minnesota has shown that polluted surface water runoff can be minimized when liquid sludge (about 1/2 inch) has been applied at about one half to one day before the next rainfall.

- (b) all waste disposal facilities, including landspreading operations, must generally avoid the contamination of underground drinking water sources beyond the waste boundary (257.3-4). A sludge landspreading practice will not normally contaminate underground drinking water where the sludge has been applied to the soil for the enhancement of vegetative growth, especially where the sludge application rate provides nitrogen in amounts equivalent to the needs of the vegetation. The potential for groundwater contamination from landspreading increases as sludge application rate and level of contaminants increase, where the soil is more porous, and where there is appreciable rainfall. The Sludge Technical Bulletin (STB) guidance for determining the nitrogen needs of the crop and subsequent rates of sludge application to avoid nitrogen contamination of groundwater should be followed.
- (c) interim final provisions in the Criteria in the disease section, regarding pathogen reduction, must be met by all practices that apply sewage sludge to the soil surface or incorporate it into the soil. Sludge must be treated by a Process to Significantly Reduce Pathogens (PSRP) before the application or incorporation. Public access to the facility must be controlled for at least 12 months, and grazing by animals whose products are consumed by humans must be prevented for at least 1 month. PSRP are defined in Appendix II of the Criteria.

Sludge must be treated by a Process to Further Reduce Pathogens (PFRP) prior to application to land (i) where crops for direct human consumption are planted

within 18 months after application and (ii) if the sludge will be in contact with the edible portion of the crop. PFRP are defined in Appendix II of the Criteria. Contact between the edible portion of the crop and the sludge is considered to be by either direct application of the sludge to the growing crop or by rainfall splash after the sludge application. The point of concern in determining the potential for contact are the timing and method of application and the type of crop grown. Taller growing crops such as many grains and citrus fruits can be considered as not having contact with the sludge as long as it is applied in a manner or at a time that direct contact with the crop does not occur.

- (d) if a landspreading facility is properly designed and operated, then access by the public to the landspreading site should not result in potential health and safety hazards. If there is some aspect of the operation that could expose the public to potential health and safety hazards (e.g., spray application of liquid sludge and surface application in playgrounds), then the practice may need fences or other methods (e.g., hedges, ditches, remoteness, and/or controls within the facility) to control public access to the site. If the sludge has undergone PFRP prior to landspreading, then the facility would not need access controls.
- (e) sewage sludges can be applied to soils in floodplains provided the facility does not (i) cause the restriction of base flood waters (base flood has a 1% or greater chance of recurring in any year or a flood of a magnitude equalled or exceeded once in 100 years on the average), (ii) reduce the temporary water storage capacity of the floodplain or (iii) result in the washout of the sludge. EPA expects that if sludge is applied to the surface and incorporated into the soil and if vegetation is grown, the Criteria should be satisfied.
- (f) the interim-final provisions for food chain landspreading provide limits on the amount of cadmium and PCB that can be added to the soil. Food chain crops are defined as crops grown for human consumption, tobacco and feed for animals whose products are consumed by humans. When the project involves high application rates of sludges with a relatively high concentration of contaminants, it may be necessary for the Regional Administrator to consult with USDA and FDA as part of the review process.

(i) Cadmium Two options are provided for controlling cadmium additions to food chain land. Option I specifies phased in controls on annual application rates and maximum cumulative cadmium loadings, with the soil pH being controlled. Annual limits for cadmium additions to soils on which vegetables, rootcrops, and tobacco are grown are initially more restrictive than for other food chain crops. Option II allows unlimited application providing (1) crops grown are used only for animal feed, (2) soil pH is controlled, (3) facility operating plan prevents human ingestion of crops, and (4) future owners of the land are provided notice in the land deed that the soil has received high cadmium additions and that food chain crops should not be grown.

(ii) Polychlorinated biphenyls (PCB): PCB limits in sludge have been based upon causing levels in soils and crops to be low enough to meet FDA's tolerance levels for animal feeds and milk fat. Currently, therefore, the Criteria allow for the surface application of sludges containign up to 10 mg/kg PCB, dry weight basis. Where PCB levels in the sludge are above 10 mg/kg, direct contact with crops could cause the FDA tolerances to be violated. In this case the Criteria requires that the waste be incorporated into the soil rather than spread on the soil/crop surface. If analysis of the sludge shows PCB to be greater than 50 ppm, see 40 CFR Part 761 for the appropriate disposal procedures.

(C) funding

(1) Federal construction grant funding (85 percent of eligible costs, 40 CFR Part 35, subpart E) is available for the design, and construction of landspreading facilities for sludge uitlization if it is the most cost-effective and environmentally acceptable and if the various necessary state and Federal requirements are met. The purchase or lease of land for landspreading is also potentially grant eligible (PRM 75-39).

(2) funding to support the development and implementation of the State Solid Waste Management Plan is available under RCRA (FR, July 31, 1979, p. 45066). These funds go the the state and are not available to the municipality for funding the construction of landspreading facilities.

(D) monitoring and recordkeeping

Federal regulations are currently being drafted by the Office of Water and Waste Management. In these draft regulations, EPA is considering requiring that records be kept for landspreading practices. Until the regulations are finalized (expected sometime in 1981), the following voluntary monitoring and recordkeeping recommendations are provided to assure that the landspreading practice does not result in an adverse environmental effect.

- (1) as mentioned in the STB, the monitoring plan should be specifically designed for local conditions, including site and sludge characteristics, proposed rate of application, crops to be grown, size of the project, etc. In addition to the contaminants of concern that are presently addressed in the Criteria, the monitoring plan should also address other heavy metals, persistent organics, and pathogens, as well as nitrates in groundwater, surface water, sludge and soils. If the facility is aware of a high contaminant input into the treatment plant by a local industrial source, or if the treatment process adds contaminants to the sludge (e.g., chlorination of sludge for stabilization), then these contaminants should also be addressed in the monitoring plan.
- (2) the STB guidance that heavy metal additions be most restricted and the least amount of sludge be applied to privately owned agricultural land should still be followed. Since the levels of sludge and metals added to privately owned agricultural land would be low, the level of monitoring suggested is minimized. On the other hand, sludge contaminant limits are higher on dedicated disposal sites. Likewise, the degree of necessary control, via monitoring, permits, etc., increases. In other words, where the potential for pollution is greater, the level of control and monitoring should also be greater.
- (3) municipalities are generally responsible for the analysis of their sludges. They should maintain records on the sludge pH; lime level; N, P, K, Mg, and organic matter contents; concentrations of Zn, Pb, Cu, Ni, Cd, and PCB; and method and extent of stabilization.
- (4) soils that receive sludges should also be analyzed. Important parameters include pH, cation exchange capacity, and cadmium concentration. There also should be a knowledge of the crops that will be grown. A number of state (e.g., MD, OH, WI, and OR) have arranged for testing of the soils by the State or County Agricultural Extension Service. These groups also recommend rates of sludge application and years of effective site life based upon

the soil, crop, and sludge characteristics. Records should also be maintained by each municipality on site locations, the annual and total amounts of sludge each site has received, the crops grown, and the soil pH.

- (E) in the Criteria, the Agency has indicated its preference for the application of sewage sludge to non-food chain land rather than to agricultural lands. However, the Agency believes that food chain land application practices which comply with the Criteria will pose no reasonable probability of adverse effects on public health or the environment.

IV. Problems Associated with Sludge Landspreading Practices and Solutions to Problems

- (A) many sludge land application systems have been publicly opposed in the past, even though facilities that have undergone proper environmental assessments are operating with no apparent demonstrated odor, health or safety problems.

the public should be made aware that the landspreading of sewage sludge can be a cost effective and beneficial method for waste recycling (e.g., plant production, land reclamation). The public should also be made aware that all methods of sludge disposal have risks and that few adverse environmental effects result from landspreading when regulations and good management practices are followed. A general discussion on gaining public acceptance is contained in the introduction section of this document.

- (B) Federal regulations for non-food chain landspreading have not been developed for the control of cadmium and PCB additions to the soil. However, after receiving sludge applications, non-food chain land may be converted to food chain land. Hence, it is argued that the regulations should be the same for both types of landspreading. The issue of conversion of non-food chain land to food chain land will be considered more fully in the rulemaking process at a later time. Meanwhile where it is rather certain that non-food chain land will not be converted to food chain uses, more liberal amounts of contaminants such as cadmium and PCB's might be permitted.

- (C) operators of landspreading facilities and food processors who utilize crops grown on sludge ammended soils have expressed concern that they may be held liable for possible adverse environmental and health effects that may result from landspreading sewage sludge.

the issue of liability for any possible adverse consequences of landspreading municipal sewage sludge has been raised in the various states where sewage sludge is spread on privately owned land. Ultimately such questions of liability are matters for the courts to resolve and are primarily matters of

State law. Under most circumstances, compliance with Federal or state regulations guidelines concerning landspreading may provide a strong defense for POTW's against charges that they are responsible for the adverse consequences associated with the landspreading of their sludge. Likewise, written disclaimers of responsibility for the effects of the sludge may also protect a POTW from liability. Nevertheless, it should be made clear that neither compliance with Federal or state regulations, nor written disclaimers, can guarantee that those participating in a sludge landspreading program would not be held liable for adverse consequences. While EPA does not necessarily endorse their approach, the following are examples of state programs that could be relevant to questions of liability:

- (1) Maryland (1): Guidelines are provided for the application of sewage sludge to land by the University of Maryland. These guidelines give guidance for submitting soil samples to the University's Agronomy Department for determining the sludge application rate. The State Department of Health issues permits for sludge landspreading projects. While the University indicates that sewage sludge can provide valuable plant nutrients in its sludge application recommendation, the University disavows responsibility for possible unforeseen long-term effects of sewage sludge on the environment.
- (2) Ohio (4): Ohio provides guidelines for land application of sewage sludge. These include the need for information on the composition of sludge to be applied, the properties of the soil, and the nature of the crop to be grown. The Ohio Extension Service provides a soil testing service, makes recommendations for amounts of sludge to be added and provides for reporting to the Ohio Environmental Protection Agency (OEPA). The guidance states that an approved plan for sludge application does not remove a landowner responsibility for water pollution or health hazards that may result from the application of sludge on their land. Plan approval means that in the judgement of OEPA, the proposed system should function satisfactorily. If unforeseen problems arise, OEPA gives the landowner a reasonable period of time to rectify the problem. The guidance suggests that a written contract be negotiated between the landowner and the sewage sludge applicator and suggests items for inclusion in the contract. The treatment plant is responsible for keeping accurate records of the sludge quality.
- (3) Oregon (2): The Oregon guidelines provide guidance for safe beneficial use of sludge. Oregon regulates land application practices by issuing permits to municipal authorities in charge of operating POTW's. These

authorities must keep records of the sludge quality and application sites and rates. The authorities are responsible for conducting their landspreading in accord with the Oregon guidance and the facility permit.

(4) Michigan (3): The Michigan guidelines were prepared by the Michigan Department of Natural Resources. The guidelines emphasize beneficial use in a safe manner. They utilize state-issued NPDES permits to regulate sludge disposal. The wastewater treatment plant has the responsibility for effective sludge management.

(D) availability of sites may be limited by the weather, cropping patterns and the allowable annual or cumulative application rates.

since landspreading is seasonal and an adequate number of landspreading sites may not always be available, the facility should have adequate storage and/or a back-up disposal method.

(E) some landspreading practices can lead to odor production

odor from landspreading sludge can be minimized by proper sludge stabilization before application and prompt incorporation of sludge into the soil.