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WASTES FROM WATER TREATMENT PLANTS: LITERATURE REVIEW, RESULTS OF AN ILLINOIS SURVEY AND EFFECTS OF ALUM SLUDGE APPLICATION TO CROPLAND

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Illinois Department of
Energy and Natural Resources

James R. Thompson, Governor
Don Etchison, Director

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WASTES FROM WATER TREATMENT PLANTS: LITERATURE REVIEW, RESULTS OF AN ILLINOIS SURVEY AND EFFECTS OF ALUM SLUDGE APPLICATION TO CROPLAND

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NOTE

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WASTES FROM WATER TREATMENT PLANTS:
LITERATURE REVIEW, RESULTS OF AN ILLINOIS SURVEY, AND EFFECTS OF ALUM SLUDGE APPLICATION TO CROPLAND

by Shun Dar Lin and C. David Green

ABSTRACT

The objectives of this study were to update information on the characteristics and management of wastes from water treatment plants and to assess the benefits and risks of alum sludge application to cropland. The report has three major sections: a literature review, a summary of results of a survey of Illinois water plant wastes, and a discussion of findings from a study of alum sludge for agricultural uses.

The literature survey addresses characteristics and management of sludge. It discusses background information on sources and types of wastes, "and waste characteristics of coagulant sludge, lime sludge, iron and manganese sludge, brine wastes, filter wash wastewater, diatomite filter sludge, and sludge from saline water conversion.

Minimizing sludge production can be achieved by chemical conservation, direct filtration, recycling, chemical substitution, and chemical recovery. Methods of waste treatment are co-treatment with sewage treatment, pre-treatment, and solids dewatering. Pre-treatment includes flow equalization, solids separation, and thickening. Dewatering can be achieved non-mechanically (lagooning, drying beds, freezing and thawing, and chemical conditioning) and mechanically (centrifugation; vacuum, pressure, and belt filtration; and pellet flocculation). Land application is usually used as an ultimate sludge disposal method.

The literature review section also discusses laws and regulations (PL 92-500, PL 94-580, PL 93-523) regarding waste disposal from water treatment plants, impacts of environmental regulations on water plant waste disposal, environmental impact studies of direct waste discharge to receiving streams, and water plant sludge land applications.

To obtain information about Illinois water plant sludge characteristics, 456 sludge questionnaires were sent to water plant managers, and 280 (61.4%) responses were received. The questionnaire covered background information on plant operations and sludge. Wastes from Illinois water plants are mainly alum sludge and lime sludge. Flushing is the most common method for removing basin sludge from surface water plants; while blow-down and continuous removal are used most by ground water plants. The majority of plants (70% of surface and 90% of ground water plants) discharge the wastes to lagoons and to sanitary sewers for treatment. Forty percent of surface water plants and 55% of ground water plants ultimately discharge their sludge to landfills, most of which are utility-owned. The annual cost of sludge treatment for the surface water plants averages $ 0.90 per capita.

The results of alum sludge application to agricultural land indicate that soil test (29 parameters) levels did not change significantly from the application of alum sludge to either corn or soybean test plots. There were some differences among the sampling dates for each plot.

The results of a short-term study (April through October 1986) showed that corn yields in the 2.5 and 10 t/a plots were significantly lower than in the 0 and 20 t/a plots. Corn yields were directly related to corn plant populations. The plant population and corn yield at the highest sludge application rate (20 t/a) showed no difference from that of the control plots. The reduction of corn yield at the lower rates could not be pinpointed as being caused by the application of sludge. Soybean yields and soybean plant parameters showed no adverse impact due to alum sludge applications.

Nutrients and heavy metals analyses (11 - 16 parameters) for grains, whole plants, and leaves of both crops showed insignificant effects from the addition of alum sludge. It is concluded that the application of alum sludge to farmland had neither beneficial nor adverse effects on soils and crops.

INTRODUCTION

Background

Most water treatment plants (especially large plants) employ coagulation, sedimentation, and filtration processes for water purification. The major sources of wastes are the sedimentation basins and filter backwashes. Alum coagulation sludges, which are high in gelatinous metal hydroxides, comprise large quantities of small particles. These are among the most difficult sludges to handle because of their low settling rate, low permeability to water, and thixotropic characteristics.

Generally, about 5% of the treated water is used for washing filters. Volume reduction of backwashes and recycling of washwater to the plant influent can reduce waste production and cut costs.

In the case of treatment plants that remove iron and manganese through aeration or potassium permanganate oxidation, disposal of sludge to receiving waters may cause problems such as water discoloration and destruction of aquatic life. Treatment plants that use an ion exchange softening process have brine wastes (high salts) which become critical disposal problems, especially when the sludge has a high manganese content. The salts cannot readily be recovered or removed from the wastes. Brine wastes are almost impossible to treat.

Formerly, wastes from water treatment plants were returned to their original source or discharged to nearby receiving water. Illinois laws and regulations now consider waste discharged directly from water treatment plants to receiving water as a pollutant. All wastes have to be treated to an acceptable level prior to their release into the environment, and water treatment plant wastes are no exception. However, occasionally a site-specific variance for direct discharge may be granted by the pollution control authorities. In these cases, treatment of water plant wastes is not necessary before final disposal.

, Many water treatment plants do not have adequate facilities to investigate the quantity of waste produced, its characteristics and treatability, and appropriate waste disposal practices. Methods for assessing waste production have not been well-defined, and the composition of wastes has" scarcely been reported in the literature. Very little research has been conducted on the effects of coagulant and lime sludges applied to farmlands.

Objectives and Scope of Study

This study had three purposes. A literature review was conducted to obtain information regarding the quantity and quality of water plant wastes, methods of disposal, environmental impacts of waste disposal, and impacts on agricultural lands and crops. Study 1 was designed to obtain and update information on all types of wastes generated by water treatment facilities in Illinois. Study 2 was conducted to assess the benefits and risks of applying alum sludge to farmland to grow corn and soybeans.'

The scope of this study was to:

1. Conduct a review of literature on water treatment plant wastes with respect to:
    a. defining the characteristics of wastes
    b. assessing the environmental impacts of current waste disposal practices
    c. obtaining information regarding the impact of water plant wastes on land and vegetation, if available
2. Conduct a questionnaire survey pertaining to the characteristics, treatment, and disposal of wastes from surface and ground-water treatment plants in Illinois, including:
    a. the quantity and composition of residues produced by water treatment plants
    b. methods of handling and treatment of all types of wastes and residues
    c. the ultimate sludge disposal methods used
    d. the costs of sludge treatment and disposal, if available
3. Conduct a field study on the application of alum water plant sludge to grow corn and soybeans.

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This study was conducted under the general administrative direction of Richard Schicht, Acting Chief of the Illinois State Water Survey, and Dr. Raman Raman, Head of the Water Quality Section. The authors are grateful to other members of the Water Survey who participated. Dana Shackleford, Bill Cook, and David Hullinger performed chemical analyses. Harvey Adkins assisted in alum sludge handling. Gail Taylor edited the report.

The authors acknowledge the water utility personnel and city engineers who responded to the sludge questionnaire.

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LITERATURE REVIEW

Wastes from Water Treatment Plants

This literature review on wastes from water treatment plants discusses previous literature reviews on the subject, sources and types of waste, characteristics of each type of waste, and waste management. The discussion of management of sludge (waste) covers minimizing sludge production, methods of sludge treatment, and ultimate sludge disposal.

Previous Reports

During the period 1969 to 1981 the American Water Works Association (AWWA) Research Foundation and the AWWA Sludge Disposal Committee prepared a series of reports with a comprehensive literature review on the nature and solutions of water treatment plant waste disposal problems. The first report, prepared by the AWWA Research Foundation, was divided into four parts (AWWA Research Foundation, 1969a, 1969b, 1969c, 1970) and was entitled "Disposal of Wastes from Water Treatment Plants." The first part of this report (AWWA, 1969a) covered the status of research and engineering practices for treating various wastes from water treatment plants. The second part (AWWA, 1969b) reviewed plant operations for the disposal of various types of wastes, and the regulatory aspects of disposal. The third part (AWWA, 1969c) described various treatment processes employed and their efficiency and degree of success, and presented cost analyses. The last part (AWWA, 1970) summarized research needs, engineering needs, plant operation needs, and regulatory needs.

Concurrently with the initial preparation of the report by the AWWA Research Foundation, the Water Resources Quality Control Committee of the Illinois Section of the AWWA conducted a survey of the handling of wastes from water treatment plants in Illinois (Evans et al., 1970). This effort was made to determine the type and quantities of waste produced, the characteristics of the wastes, and the existing methods of waste disposal in Illinois.

In 1972, the AWWA Disposal of Water Treatment Plant Waste Committee published an updated report (AWWA, 1972). It dealt with processing and re-processing in sludge production, i.e., selection and modification of treatment processes, reclamation of lime and alum, recovery of filter backwash water, processing of wastes to recover useful by-products, processing of wastes for disposal, ultimate disposal, and future research needs.

In 1978, the AWWA Sludge Disposal Committee prepared a 2-part article (AWWA Sludge Disposal Committee, 1978a, 1978b) entitled "Water Treatment Plant Sludge — An Update of the State of the Art." Part 1 dealt with regulatory requirements, sludge production and characteristics, minimizing of waste production, and European and Japanese practices. Part 2 detailed non-mechanical and mechanical methods of dewatering water plant sludges, ultimate solids disposal, and research and development needs. These reports focused mainly on coagulant sludges.

In 1981, the AWWA Sludge Disposal Committee provided an overview of the production, processing, and disposal of lime-softening sludges; recent technological advances in handling, treatment, and disposal of softening sludges; and research needs (AWWA, 1981).

Sources and Types of Waste

A water treatment plant not only produces drinking water but is also a solids generator. The residues (solids or wastes) come principally from clarifier basins and filter backwashes. These residues contain solids which are derived from suspended and dissolved solids in the raw water, the addition of chemicals, and chemical reactions.

Depending on the treatment process employed, wastes from water treatment plants can be classified as alum, iron, or polymer sludge from coagulation and sedimentation; lime sludge and brine wastes from softening; backwash wastewater and spent granular activated carbon from filtration; and wastes from the iron and manganese removal process, microstrainers, and diatomaceous earth filters.

Waste Characteristics

The amount and composition of waste produced through each treatment process are unpredictable. Because of the wide variation in raw water quality and treatment operations, sludges are different in their characteristics and quantities from time to time within the same treatment plant, and from plant to plant.

Russelmann (1968) discussed general characteristics of water plant wastes. In addition, he addressed special characteristics of coagulation wastes, filter backwashes, ion-exchange brines, and screenings from a few water suppliers. He concluded that it is impossible to make generalizations concerning sludge production in terms of millions of gallons of water treated because sludge production is entirely dependent on raw water quality, the method of treatment, and efficiencies of the treatment processes.

Sludges from water treatment plants may be divided into eight major categories (Westerhoff, 1978): pre-sedimentation sludge, coagulant sludge, lime sludge, iron and manganese removal sludge, ion-exchange sludge (brine waste), activated carbon wastes, spent diatomaceous earth, and sludge from saline water conversion. These categories, as well as filter backwash wastewater, are discussed below.

Pre-Sedimentation Sludge

Some water plants treating high-turbidity ' surface waters employ pre-sedimentation prior to coagulation to reduce the solids loading on the downstream treatment process. The residues generated consist of clays, silts, sands, and other heavy settleable materials present in the raw water.

Treatment and disposal of pre-sedimentation residues in and of itself is not a major problem. They can be treated and disposed of with other sludge. The cleaning cycle of a pre-sedimentation basin is usually very long, 10 years or more (Westerhoff, 1978).

Coagulant Sludge

Coagulant sludge is generated by water treatment plants using metal salts such as aluminum sulfate (alum) or ferric chloride as a coagulant to remove turbidity. The coagulant sludge consists of solids removed from the coagulated water, mainly hydroxide precipitates from the coagulant and material in the raw water. It may also contain water treatment chemical residuals such as polyelectrolytes, powdered activated carbon, activated clay, or unreacted lime.

Alum is the most widely used primary coagulant in the United States. Activated silica, clay, or a variety of polymers are used as coagulant aids. Alum coagulation sludge may contain aluminum hydroxide, clay and sand, colloidal matter, microorganisms including algae and planktons, and other organic and inorganic matter present in the raw water.

Alum sludge contains a high moisture content (97 to 99.5%) and a low solids content. Its color varies from light brown to black depending on the characteristics of the source of water and the chemicals used for treatment. It is feathery, bulky, and gelatinous. Sludge solids are removed from the water stream in a settling basin underflow or as filter backwash wastewater. The residues may be discharged directly to a receiving water (if permitted) or to treatment units and may be allowed to accumulate in settling basins over a long period of time, varying from days to months.

Alum sludge generally settles readily but does not dewater easily. It has been the most difficult sludge to treat because of several peculiar properties. Although alum sludge has high 5-day biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD), it usually does not undergo active decomposition or promote anaerobiasis.

The dewatering characteristic of alum sludge, in terms of specific resistance, was measured by Gates and McDermott (1968) as 1 x 10^9 to 4.4 x 10 secvg, which is about one order of magnitude greater than that of primary sewage sludge. Nevertheless, Hsu and Wu (1976) claimed that the dewatering properties of alum sludge were comparable to those of sewage sludge. Apparently the properties of alum sludge are highly variable from one plant to another, and even within the same treatment plant.

Alum sludge has been reported to have a total solids (TS) content of 1000 to 17,000 mg/L (AWWA, 1969a), of which 75 to 95% is total suspended solids (TSS) and 20 to 35% is volatile solids (VS).- The pH value ranges between 5 and 7 (Reh, 1978). The BOD_5 of alum sludge ranges from 30 to 150 mg/L. The COD values are high, ranging from 500 to 15,000 mg/L (AWWA, 1969a). A high ratio of COD to BOD_5. (13:1) was observed in a Missouri plant (O'Connor and Novak, 1978).

Using spark-source mass-spectrographic analysis, Schmitt and Hall (1975) characterized alum sludge at the water treatment plant in Oak Ridge, Tennessee. The concentrations of 73 elements were determined in settled alum sludge from the sedimentation basin and from filter backwash wastewater.

Fourteen chemical, physical, and biological parameters were measured in the alum sludge from the clarifier blow-downs at Centralia, Illinois (Lin and Green, 1987). The raw water source for this community is a 286-ha (707-acre) lake. The annual values of the blow-downs based on biweekly observations are as follows:

Parameter	Geometric mean	Parameter	Average
TSS, rag/L	2800	VSS, mg/L	750
Turbidity, NTU	2000	Set. solids, mg/L	380
Sulfate, mg/L	76	Dissolved oxygen, mg/L	8.8
T. iron, mg/L	58	Temperature, C	15.7
T. aluminum, mg/L	240	pH (median)	6.6
Fecal coliform/100 mL	5	T. alkalinity, mg/L as $CaCO_3$	95
Dissolved solids, mg/L	215	$B0D_5$, mg/L	29

Settling basin alum sludges contain extremely high concentrations of aluminum and iron. The observed values at three water treatment plants in Illinois, which derive their raw water supplies from streams and rivers, are as follows (Evans et al., 1979, 1982; Lin et al., 1984):

	Aluminum, mg/kg	Iron, mg/kg
Pontiac	1,000 - 134,000	13,000 - 114,000
Alton	39,300 - 55,000	33,000 - 41,000
East St. Louis	13,900 - 61,200	24,600 - 44,900

Lime Sludge

Lime sludge is generated by water treatment plants using lime (CaO) or lime/soda ash (Na_2CO_3) softening. The quantity and composition of the sludge produced from softening may vary widely depending on whether or not alum or another coagulant is used either with or without a coagulant acid. Sludge from the softening of surface water is a highly variable material. It consists mainly of calcium carbonate (85 to 95% total solids); hydroxide of magnesium, aluminum, and other metals; clay and silt particles; minor amounts of unreacted lime; and inorganic and organic matter. The volume of sludge produced from lime or lime-soda softening plants ranges from 0.3 to 6% of the water softened (AWWA, 1969b). The sludge generally contains 85 to 95% solids. Solids content of the sedimentation basins at these plants varies from 2 to 30%. Softening sludge is generally white in color, has no odor, and is low in $B0D_5$ and COD.

Ground waters tend to be relatively free of turbidity, color, and objectionable levels of organics. Softening of ground water yields a relatively pure residue containing calcium carbonate, magnesium hydroxide, and unreacted lime. The characteristics of ground-water lime sludge are (Reh, 1978): TS, 20,000 - 100,000 mg/L; $CaCO_3$,, 80 - 90%; $Mg(0H)_2$, 5 to 20%; other constituents, 5 to 15%; and pH > 9.0.

As with coagulant sludges, lime sludges are removed from the water stream in the settling basin underdrain and in filter backwash wastewater. Residues from water softening are usually stable, dense, and inert. Lime sludge generally dewaters readily, depending on the ratio of calcium (Ca) to magnesium (Mg) and on the amount of gelatinous solids present in the sludge. The magnesium content plays an important role in the settleability, compactability, and filterability of the softening sludge. The greater the Ca:Mg ratio, the easier the dewatering. Lime sludge with a Ca:Mg ratio of less than 2 is very difficult to dewater, whereas a sludge with a Ca:Mg ratio greater than 5 will dewater easily (AWWA, 1981). A sludge with calcium hydroxide concentrations greater than 1300 mg/L will have poor dewatering characteristics and larger sludge volumes.

The settling properties of sludge resulting from the softening of ground water may be poor due to the colloidal fraction of this sludge. Softening is often supplemented with coagulation, which generates two residue fractions: 1) precipitates at the bottom of the softening reactors, and 2) coagulated precipitates at the bottom of the sedimentation basins. Since this sludge is relatively pure, lime recovery by recalcination is feasible for large plants (see page 14 for a discussion of recalcining).

Iron and Manganese Sludges

These types of sludges are produced by the precipitation process for removal of iron and manganese from water. These sludges are red or black in color. The sludge solids consist of ferric oxide, manganese oxide, and other iron and manganese compounds.

The quantity of iron and manganese sludges is comparable to that of coagulant or softened sludge. These sludges are generally removed as filter backwash wastewater.

Brine Wastes

Spent brine wastes come mainly from the rinse water for the regeneration of ion-exchange softening units using sodium zeolite as the resin. These wastes are in aqueous solution. The volume of brine waste generated is about 2 to 10% of the water treated, depending on the raw water hardness and the operation of the ion-exchange unit (AWWA, 1969a, 1969b; O'Connor and Novak, 1978). These wastes contain extremely high concentrations of chlorides of calcium, magnesium, and sodium (the regenerant) with small amounts of various compounds of iron and manganese. Brine waste is characterized by very high chlorides, total solids, and total dissolved solids (TDS). Very few suspended solids are present in brine wastes.

The high chloride content derived from the salts used for regeneration causes problems in the disposal of brine wastes. Chlorides cannot be removed from wastewater through any inexpensive method. These wastes can generally be discharged to deep underground strata or oceans with a permit.

Filter Backwash Wastewater

Filter backwash wastewater is produced during the filter washing operation. Filters are washed daily, once every two days, or less frequently. There is usually a large volume of washwater with low solids content. The volume of washwater is large because the backwash rate may be 10 to 20 times the filtration rate. For alum coagulation plants, the volume of washwater ranges from 2 to 5% of the water filtered.

The composition of backwash wastewater may be similar to that of coagulant sludge, but with much finer particles. This type of wastewater normally contains hydroxides of aluminum and iron, fine clay particles, added chemicals and reaction products which did not settle in the sedimentation tank, and a small portion of filter media and activated carbon. Since the durations of filter backwash operations and release patterns of solids vary widely, it is necessary to carefully assess the quantity and characteristics of the wastes generated during filter washing operations.

The average solids concentration in wash wastewater is generally low. However, the maximum TSS concentration was found to be about 1800 mg/L in the water treatment plant at East St. Louis, Illinois (Lin et al., 1984). Average TSS values vary widely from plant to plant and from time to time within the same plant. A high average value was cited as 15,000 mg/L of TSS for a plant with iron and manganese removal (AWWA, 1969a). About one-fourth to one-third of the total solids are volatile in most cases (AWWA, 1969a; Lin et al., 1984; Lin and Green, 1987). Detailed solids and chemical analyses for filter backwash wastewaters of alum coagulation plants can be found elsewhere (Lin et al., 1984; Lin and Green, 1987; O'Connor, 1971; O'Connor and Novak, 1978). Granular activated carbon (GAC) wastes are produced in a GAC process as the result of media washing and quenching and exhaust gas scrubbing during GAC regeneration. The most common practice is for GAC to be placed on top of filter sand for taste and odor removal. Large amounts of spent GAC can be found in the filter washes after installation of virgin or regenerated GAC.

Granular Activated Carbon Wastes

Spent GAC wastes consist mainly of activated carbon with small amounts of organic matter and chemical residues. Novak and Montgomery (1975) reported that the COD values for water treatment plants containing activated carbon would be high, perhaps on the order of 10,000 mg/L.

Diatomite Filter Sludge

Diatomaceous earth (DE) is the fossil skeleton of microscopic organisms. The small number of existing water treatment plants where diatomaceous earth is used as a filter medium are mainly water suppliers of small amounts of water, such as for swimming pools. During filtration DE is added as a "body feed" to prolong the filtration cycle. After each filter cycle the filter medium and accumulated solids are discarded and the new medium is re-installed on the filter septum by means of a "precoat."

Because of the nature of diatomite filters, the spent diatomaceous earth has characteristics similar to the DE itself. DE is composed almost entirely of pure silica. It has a dry weight of about 10 lb/cu ft and a specific gravity of approximately 2.0 (AWWA, 1969a). Since the waste consists chiefly of silica it is easily dewatered. The amount of spent DE is small, because the volume of water treated in a diatomite filter is generally small-.

Sludge from Saline Water Conversion

There are few existing saline water conversion plants which treat highly saline waters to produce drinking water. Virtually no chemicals are added in the saline water conversion process. The wastewaters from these plants are characterized by a large volume and a high amount of dissolved salts or minerals which are initially present in the raw saline water. These wastewaters are virtually free of BOD_5, COD, turbidity, color, and odor, which are objectionable in a water supply.

From raw brackish waters in the range of 1000 to 3000 mg/L of TDS, the waste stream from a saline water conversion plant constitutes from 10 to 30% of the water treated and contains 5000 to 10,000 mg/L of TDS. For sea water conversion plants the wastewaters usually consist of TDS ranging from a little above sea water concentration (35,000 mg/L) to as much as 70,000 mg/L TDS (Katz and Eliassen, 1971).

Management of Sludge

Traditionally the waste residues from a water treatment plant have been discharged to a nearby waterway and forgotten. Currently it is required that these wastes (sludges) be well managed. The direct discharge of water plant wastes requires special consideration and approval. The discharge of waste can be continuous, intermittent, or seasonal. The continuous pattern is preferable from a water quality perspective. Nevertheless, direct waste discharge is not likely to be a feasible method of waste management because of regulations concerning the pollution potential of the wastes.

The management of sludge includes minimizing sludge production, sludge treatment, and land applications. Chemical recovery can be used as a way of both minimizing sludge production and treating sludge.

Minimizing Sludge Production

The methods and costs for handling, treatment, and disposal of sludge are influenced by the amount and characteristics of the, sludge. The quantity and characteristics of sludge are affected by the raw water quality and the treatment chemicals used during the water treatment processes. Little can be done to change the raw water quality. However, it is possible in many cases to change the water purification processes to minimize sludge production. The reduction of waste volumes results in operational cost savings at a plant.

Sludge generation can be minimized by the removal of water to reduce the sludge volume, the reduction of the solids content present in the sludge, or some combination of the two. The methods for minimizing sludge production are reduction of chemical dosages (alum or lime), direct filtration of the water, recycling of filter washwater, substitution of coagulant and softening material, and chemical recovery (Westerhoff, 1978; AWWA, 1981).

Chemical Conservation. Stoichiometrically the reduction of each 1 mg/L of alum will result in a savings of about 1400 kg (3000 lb) of alum per year and will reduce the alum sludge by approximately 360 kg (800 lb) per year for a 3785-m /d (1-MGD) plant. At many water treatment plants excessive amounts of coagulants are used since it is difficult to continually determine the optimum coagulant dosage at a plant, especially with rapidly changing raw water characteristics. Small utilities may not have the know-how, manpower, or other resources to monitor and regulate coagulant dosing. Plant operators must be aware that the excessive use of coagulants results in increased costs, both for the coagulants and for handling, treatment, and disposal of the extra residues produced.

Optimization of lime feed systems can reduce solid loads by maximizing the efficiency of chemical dosages and by minimizing the amount of unreacted lime in the waste stream. Improved mixing in feeders, flash mixers, and flocculation zones reduces excess lime dosing. The well-mixed solids contact clarifiers use only 2 to 3% excess lime (AWWA, 1981).

By selective softening to remove only calcium hardness, waste volumes may be reduced and the dewatering characteristics of the softening sludge may be improved. However, this softening method may be a questionable practice for some plants because of incomplete removal of hardness. Another method, reducing the degree of softening, could reduce the chemical costs and also the amount of solids produced.

Direct Filtration. Direct filtration is a water treatment process in which filtration is not preceded by sedimentation. However, it may include rapid mixing with alum or other primary coagulants and the addition of a filter aid immediately ahead of the filter. Contact tanks may also be installed at some direct filtration facilities.

Direct filtration is most applicable to facilities with a relatively stable and high-quality (low-turbidity) raw water source. In the process of direct filtration coagulant dosages are generally low and virtually all residues are produced as filter backwash. This results in a significant cost savings for sludge handling, treatment, and disposal. Westerhoff (1978) reported a case history of direct filtration plants at the Niagara County Water District's plant in Lockport, New York.

The Metropolitan Water Board treatment plant, located in central New York State, has been successful in using direct filtration of Lake Ontario water to serve Syracuse and Onondaga County, New York, with a 94-ML/d (25-MGD) . capacity. Alum dosages were significantly reduced and sludge generation was lessened (Fitch and Elliott, 1986).

Recycling. Direct recycling of residues from the clarifiers and filters is generally not feasible. If sludges are concentrated, the recycling of filtrates from catch basins and clarified supernatant from the dewatering process will reduce solids loads, because these waters have a reduced TSS concentration and are softened. Clarification and filtration waste volumes represent 3 to 5% of the total plant pumpage. The recycling of this water will reduce the waste volume by 3 to 5%.

It should be noted that conditioning alum sludge with lime as a preparatory step prior to filtration may cause the re-solution of humic substances into the process stream. These dissolved organics are suspected of being precursors for the formation of possible cancer-producing trihalomethanes in the disinfection of water supplies with chlorine.

Recycling of concentrate or filtrate from lime-softening sludges is satisfactory. Recycling of lime sludge improves the efficiency of calcium carbonate precipitation and reduces lime usage. The use of a holding basin and limitation of the recycling rate to 10% of the total plant flow are desirable (Reh, 1978).

Chemical Substitution. Through the substitution of other treatment chemicals for all or part of the alum and lime, the quantities of sludge generated may be reduced and the dewatering characteristics may be improved. The substitution should not degrade the finished water quality, lessen the reliability of the sludge treatment, or increase the total cost.

Reh (1980) described the use of magnesium carbonate ($MgCO_3$ $3H_2O$) as an alternate coagulant associated with chemical recovery and recycling. This method was developed by A. P. Black of the University of Florida and was successfully field-tested by the United States Environmental Protection Agency (USEPA). When magnesium carbonate dissolves in water at a high pH it forms magnesium hydroxide, $Mg(0H)_2$, which has the same coagulation power as aluminum hydroxide. In this process, coagulation of raw water is carried out by using $Mg(0H)_2$ at a pH of about 11. Magnesium hydroxide has about the same coagulation power as aluminum hydroxide (Reh, 1980). The sludge is then carbonated to convert $Mg(OH)_2$ to soluble magnesium bicarbonate, $Mg(HCO_3)_2$. A thickener is used to separate $Mg(HCO_3)_2$; it is then recycled back to the flocculation tank. Most heavy metals present in raw water can be removed because the coagulation process is carried out at a high pH. There is no acidification step to release the sludge back to the liquid phase.

Complete replacement for alum is achieved by the use of iron salts such as ferric chloride, ferric sulfate, and chlorinated copperas. Many facilities have used polymers for primary coagulants.

Partial substitution for alum has been obtained by decreasing the alum dosage and adding a polymer or other coagulant aid. This practice is widely used at the present time. New and improved coagulant aids continue to be developed. The advantages of this process are in reducing the alum dosage and the quantity of sludge produced.

Sodium hydroxide (caustic soda) has been used as a partial or complete substitute for soda ash or lime softening. Substituting sodium hydroxide is not widely accepted because it is more expensive. However, the higher cost of sodium hydroxide can be offset by lower solids generation and disposal costs.

When removal of high magnesium hardness is required, split treatment is justified because it eliminates the lime treatment for bypassed water and minimizes re-carbonation requirements and sludge generation.

Chemical Recovery. Chemical recovery is technically feasible for the reclamation of alum, iron, and magnesium carbonate and for the recalcination of lime sludge. In each case finished water quality, side stream discharge, and gaseous emission should be considered. Chemical recovery from water treatment plant sludges can provide the benefits of the reusable chemicals themselves, reduced sludge production, reduced costs for sludge disposal, and/or improvements in the treatability of the sludge.

Alum Recovery. Alum is recovered through acidification. When sulfuric acid is added to the thickened sludge the reaction of aluminum hydroxide with acid takes place almost instantaneously to form aluminum sulfate (alum) solution. Acidulation also hydrolyzes much of the organic matter. Re-dissolved organic matter is a source of concern with regard to public health (Fulton, 1978a), because some carcinogenic volatile organic compounds and toxic chemicals may also be present.

Cornwell and Susan (1979) reported that the optimum acid dose for almost all sludges occurred at a sulfuric acid to total aluminum molar ratio of 1.5:1. The optimal dissolution corresponded very closely to the theoretical acid requirements. The acid demand corresponded to approximately 0.5 kg sulfuric acid per kg of alum added to the raw water.

When sulfuric acid is added to alum sludge, between 70 and 80% recovery of alum can be achieved (Chandler, 1982; Westerhoff, 1978). The recovered alum can be reused for the water treatment process, or it can be employed as a source of alum for phosphate precipitation in wastewater treatment. The transportation of the recovered alum should be carefully considered. The residue has a low pH and the residue cake may require neutralization by lime prior to disposal on land. In case it is reused in the water treatment plant, consideration should be given to whether re-dissolved impurities might cause a possible degradation of the finished water. This is an expensive process and its economic viability depends upon the capital costs of acid-resistant equipment and the relative costs of sulfuric acid and fresh alum.

Recalcining. Lime recovery by recalcination is not a new process and is practiced at many facilities. The recalcination process is the burning of softening sludges at a high temperature of 1010°C (1850°F) as shown in the following reaction (AWWA, 1981):

$$\mathrm{CaCO_3} \xrightarrow[1700\text{–}2000^{\circ}\mathrm{F}]{\text{heat}} \mathrm{CaO} + \mathrm{CO_2} \tag{1}$$

The process generally includes sludge thickening from an initial 3 to 10% solids to 18 to 30%.

Recalcination has the potential to recover even more lime than would be used in the softening process, while reducing the sludge weight by 80% (Westerhoff and Cline, 1980). At the same time, the carbon dioxide produced can be used for re-carbonation.

Recovered lime can be sold for soil pH adjustment or re-used in the water treatment plant. However, the lighter hydroxides of metals such as magnesium, iron, and aluminum are undesirable contaminants in a lime recalcination process. Also the high cost of fresh lime along with the high cost of energy for lime recovery may make recalcination too expensive to adopt. Thompson and Mooney (1978) discussed lime and magnesium recoveries from water plant sludge.

Magnesium Recovery. When magnesium carbonate, $MgCO_3 \cdot 3H_2O$, is added to water as a coagulant at a high pH of about 11.0, magnesium hydroxide, $Mg(OH)_2$, is formed. The sludge then is carbonated to convert $Mg(OH)_2$ to the soluble magnesium bicarbonate $Mg(HCO_3)_2$. A thickener or filter is used to separate $Mg(HCO_3)_2$. The magnesium in the filtrate is recycled back to the flocculation tank for use and the solids portion is disposed of. This coagulant is particularly applicable in conjunction with lime recalcination because of the release of carbon dioxide in the recalcination process. This is used in turn to re-dissolve the magnesium hydrate.

Waste Treatment

Treatment and disposal of waste from a water treatment plant depend on the types of waste and on local conditions. Treatment methods used for domestic wastewater sludge are most likely applicable to water plant wastes. However, further studies should be conducted to evaluate their feasibility.

Generally waste treatment processes for water plants consist of three elements: co-treatment, pre-treatment, and solids dewatering. There are several methods available for each of these elements.

Co-Treatment. Discharge of water plant wastes to a sewage system, either raw or after concentration, has been a common practice for many facilities. It is probably more cost-effective than using separated systems, especially for communities which own both the water and sewer systems. Definite advantages have been reported for" joint dewatering of alum and sewage sludges (Fulton, 1978b).

Hsu (1976) claimed that joint treatment of alum sludge and wastewater plant sludge was the most promising off-site treatment method. Alum sludge can be discharged to the existing wastewater treatment plant, where it can be thickened and mixed with the wastewater sludge, followed by dewatering at a proper pH. Alum sludge can serve as a useful wastewater sludge conditioner, rather than a nuisance.

Lime sludge can be advantageous for increasing pH, as a bulking agent, for neutralizing acid wastes, and for pre-treatment of industrial wastes; and it can be incinerated to -produce high alkaline ash (AWWA, 1981). Water-softening sludge tends to settle well and to deposit in sewers. It needs a good velocity to prevent its settling in sanitary sewers. Spent brines would not have a significant effect on sewage treatment (Reh, 1978). Flow equalization is needed to avoid abrupt changes of TDS and salt concentrations in the sewage.

Pre-Treatment. Some sort of pre-treatment is needed for effective and economical water plant sludge treatment. Pre-treatment includes flow equalization, solids separation, and solids concentration or sludge thickening (Fulton, 1978b). Pre-treatment facilities for a particular water can use one of these methods or a combination of the three.

Flow Equalization. Flow equalization is used to provide storage volume for holding the quantity of waste discharge which exceeds the allowable amount being discharged to a sewer system. Storage requirements depend on the designed waste discharge schedule.

Solids Separation. Solids separation may be accomplished by detention in settling facilities with designed waste withdrawal rates or with adequate overflow. The settling facilities may include a simple settling tank, decant tank, or both decant and settling/thickening tanks. Flow equalization storage preceding settling facilities may be needed for filter wash wastewater because of relatively high discharge rates.

As a decant tank is filled it remains full for a sufficient time (about 2 hours) for the settling of solids without withdrawal. The solids are then removed by a mechanical collector for further treatment and the supernatant is drawn off.

Thickening. Thickening is used to reduce the volume of sludge and to improve sludge dewatering characteristics by concentrating the sludge in the bottom of a thickener or lagoon. It is an inexpensive and effective device. Although coagulant sludge thickens poorly, it can be gravity-thickened to a solids content of 2 to 10% (Westerhoff and Cline, 1980). Lime-softening sludge which primarily contains calcium carbonate can be thickened$_2$ to 30% solids and more at a thickener loading rate of approximately 4.6 m /907 kg (50 sq ft/ton)/d (AWWA, 1981; Westerhoff and Cline, 1980).

Unfortunately, the literature indicates that most water treatment plants make no effort to minimize sludge volume, although thickening can save on the costs for sludge discharge piping and for supernatant recycling.

One of the more efficient methods of sludge thickening is the use of a slow-stir rotating picket fence to enhance solids separation. The theory is that thickening occurs initially by gravity settling and is aided by the compressing action of the stirrer on the sludges. The use of inclined, parallel plates has also reportedly been successful in improving solids separation.

Non-mechanical Dewatering. Following collection and thickening, the sludge can be further concentrated or dewatered either by co-disposal with sewage sludge or by mechanical or non-mechanical dewatering methods. Co-disposal was discussed previously. Non-mechanical sludge dewatering devices include lagooning, drying on sand beds, natural or artificial freezing and thawing (physical method), and chemical conditioning.

Lagooning. Lagoons have been used as an all-purpose treatment device. They may function as a flow equalizer, solids separator, sludge thickener, and sludge storage area all in one unit. Lagoons generally provide sufficient surface area and volume for treatment. They are usually equipped with underdrains and decant facilities for sludge dewatering.

Design criteria for lagoons vary with each particular plant situation depending on the waste received. Generally at least two lagoons are required. Liquid can be discharged by an underdrain or through an overflow. The lagoon can be operated in a fill-and-draw pattern or in a continuous mode. Recovered water can be recycled to the plant. Sludge, cake or wet, may be removed by earth-moving equipment after it has been drained. Sludge can be withdrawn without draining by means of hydraulic equipment. It should be noted that settled alum sludge does not pump well even when it is wet.

Lagooning is the most inexpensive but perhaps the least effective dewatering method for alum sludge, usually resulting in 5% solids. Nevertheless, a successful example was reported by Fulton (1976). One filter plant of the Hackensack Water Company in New Jersey has been discharging alum sludge to settling basins for over 40 years. The sludge in the lagoon compacted to 10% solids with long-term storage. On the other hand, it has been reported that through lagooning, lime-softening sludge can be successfully dewatered to greater than 50% solids (AWWA, 1981).

Drying Beds. The sludge drying bed is an improvement over the sludge lagoon. It incorporates a permeable medium (such as sand and wedge wire) and a system of underdrainage. In England a modified sand drying system using wedge wire was developed. The wedge wire system required a high capital expenditure although maintenance costs were low.

Where rainfall and humidity conditions permit and where large land tracts are available, sand drying beds are an effective and relatively inexpensive method of dewatering water plant waste solids. These beds usually consist of 15 to 30 cm (6 to 12 in.) of sand ranging in size up to 0.5 mm with graded gravel and drainpipes (AWWA, 1969a). Sludge is applied in 30- to 60-cm (1- to 2-ft) layers and allowed to dewater. The beds may be covered or open.

Rainfall is a major factor in the effectiveness of sludge drying beds. Poor dewatering of sludge occurs in cold or rainy climates. The costs of the large land area required and of the sand should be considered. Dewatered sludge can be removed manually if there is a lack of suitable equipment. The difficulty of sludge removal together with the labor-intensive operation make this method uneconomical.

Sludge penetration through sands during the initial sludge application is a problem which requires frequent sand replacement. Polymer conditioning can prevent sludge penetration by increasing the gravity drainage rate by 100% and enhancing' evaporation, thereby preventing cake crust formation (AWWA, 1981).

Sand drying beds have been employed for dewatering coagulant sludge and, to a lesser extent, lime softening sludge. Use of these beds is a feasible method for dewatering mixed coagulation-softening sludge.

Freezing and Thawing. Freezing can be natural or artificial. The freezing and thawing process was developed for sewage sludge in 1950. In 1963 in the United Kingdom the process was first initiated successfully for the treatment of water plant sludge at Stocks, England (Doe et al., 1965).

Pre-treatment by thickening reduced the sludge volume. The sludge was thickened to 4% solids. The process consisted of two 45-min. freezing cycles and one 45-min. thaw cycle. In the freezing process, water of hydration was removed from the gelatinous aluminum hydroxide, changing the sludge characteristics to small granular particles which settled rapidly. The final volume was reduced to one-sixth of the original volume. The capital costs and operational costs of this process are relatively high.

In cold-weather conditions with a large amount of available land, natural freezing on open beds is feasible for dewatering alum sludge. The process of freezing and thawing has no particular benefit for lime-softening wastes. A holding facility with sufficient volume to store waste generated during non-freezing periods is required. Sludge is applied to the bed in successive layers to facilitate freezing.

Freezing and thawing of alum sludge will change sludge concentrations substantially. Recently a successful freeze-thaw process in central New York State was reported by Fitch and Elliott (1986). Alum sludge from a settling basin with 8% solids was concentrated to 25% by freezing, thawing, and decanting. The final sludge was found to be more granular in character. It was also observed that regardless of the pumped sludge concentration it separated quickly into settled sludge and clear decant. The settled sludge was easily handled by standard earth-moving machines for removal from the beds for land application. For the 72-MGD (272-ML/d) plant treating Lake Ontario water, the construction cost for permanent sludge-handling facilities including the freeze-dry beds was about $300,000 in 1981.

Randall (1978) claimed that liquid butane is an ideal refrigerant for direct slurry freezing of waste-activated sludge to promote settling, concentration, and dewatering. Because of the high recovery rate for butane, the process effectively and economically accomplishes wastewater sludge dewatering.

Chemical Conditioning. Conditioning of sludge may be accomplished by judicious use of organic polyelectrolytes, inorganic chemicals, and acidification. Anionic polymers (hydrolyzed polyacrylamides) have been reported to be particularly effective conditioning agents for coagulating sludges prior to gravity or vacuum filtration dewatering (King and Randall, 1968).

Ferric chloride, lime, or fly ash are possibly applicable for particular sludge conditioning. The use of chemicals, separately or in combination, should be evaluated for a particular sludge.

Acidification of sludge is a good conditioning method, particularly with the alum recovery process. The acidified sludge must be neutralized prior to its ultimate disposal.

Mechanical Dewatering. The most frequently used mechanical systems for dewatering water plant sludges are centrifugation, vacuum filtration, and pressure filtration. Belt filtration and dual cell gravity solids concentrators have been installed to a lesser extent. Pellet flocculation is relatively new and is used less often for sludge dewatering. For all mechanical dewatering systems pre-conditioning is generally required.

Centrifugation. Centrifugation is the settling of sludges by a centrifuge that uses the gravitational force created by high-speed rotation to separate the solids. Various types of centrifuges are commercially available. Generally, there are two categories: continuous scroll type and continuous bath bottom feed basket (bowl) type (Hagstrom and Mignone, 1978). Feed solids concentration to the centrifuge usually ranges from 2 to 6%, although alum sludge at a concentration of 0.4 to 1.0% has been successfully dewatered (Westerhoff, 1978). However, several full-scale installations have been found to be unacceptable (AWWA, 1969a). The centrifuges for alum sludge dewatering at Rock Island, Illinois, are an example of a failure. The expected cake dryness is affected by the centrifugal force, feed rate, rate of polymer dosage, raw water quality, floc size and density, and residence time. The water that is removed can be recycled to the plant or properly disposed of.

Lime-softening sludge is reported to be easily dewatered by centrifugation because of its high (80 to 85%) calcium carbonate content. Albertson and Guidi (1969) reported that when a solid bowl centrifuge was used, a thickened lime sludge could be dewatered to a cake solids concentration of 55% with 78 to 93% solids capture. Data from plants using centrifugation showed that the lime cake solids concentrations were in the range of 55 to 70% solids by weight (AWWA, 1969b; Vesilind, 1979), while alum sludge centrifugation can achieve only 12 to 20% solids by weight (Fulton, 1978b).

Vacuum Filtration. Vacuum filtration typically uses a rotary drum with a tilter cloth or medium stretched across its surface. The filter medium can be traveling cloth or a precoated type. The selection of a proper filter medium contributes to the effectiveness of the process. The drum is placed under vacuum or pressure in a reservoir of sludge that is to be dewatered. The precoated filter drum rotates slowly at 5 to 12 revolutions per minute depending on the permeability of the deposited cake and the grade of precoat medium. The average precoat layer of 2 to 3 inches is applied and may be shaved off in very small increments. Approximately 50 to 60 minutes is required for precoating a vacuum filter (Westerhoff, 1978). The process of vacuum filtration includes three basic phases: cake formation, cake drying, and cake discharge. The floc size distribution is the key factor in the performance of the vacuum filter. The sludge cake develops on the outer surface of the medium and is subsequently removed by a scraper and disposed of.

The vacuum filter has long been a popular method of dewatering sludges from sewage treatment plants and chemical industries. However, the vacuum filtration process has had only limited success when used for coagulated sludge. It is difficult to dewater alum sludge generated from raw water with turbidities between 4 and 10 TU (Westerhoff, 1978). Acid is added to the thickened sludge fpr aluminum recovery. Acidified alum sludge is easier to dewater.

Vacuum filters are often successfully used for dewatering lime-softening sludges. A precoat is necessary with hydroxide sludges. It was reported that vacuum filter dewatering of lime sludges produced final cake solids concentrations in the range of 45 to 65% suspended solids, with an acceptable filtrate produced (AWWA, 1969b). Filter loadings were as much as 293 $kg/m^2/h$ (60 lb/sq ft/h) of dry solids per filter surface area.

Dloughly and Hager (1968) reported that a loading rate up to 439 kg/m^2/h (90 lb/sq ft/h) yielded final cake solids concentrations in the range of 65 to 75% suspended solids.

Pressure Filtration. The pressure filter is basically made up of a number of porous filter plates containing depressions, held vertically in a supporting frame. Each plate face is covered with a proper filter cloth. A common feed hole or multiple holes for the sludge inlet extend through the plates. Under pressure, either by mechanical or hydraulic means, sludge is pumped into the filter through the feed holes to the chambers formed by the depressions between the plates. The liquid seeps through the filter medium, leaving the solids behind between the plates. With continual pumping, sludge cakes form and ultimately fill the chamber. After the filtration cycle, the plates are separated and the dewatered solids fall easily to a discharge conveyance. An automatic cake remover can also be used. Details of pressure filters and operational variables are discussed elsewhere (Fulton, 1976; AWWA, 1978b; Vesilind, 1979).

The pressure filtration process was first applied to water treatment plant sludges in the United States in the mid-1960s. Its lack of popularity is due to its cyclical operation. However, the process is popular in Europe. It has been used extensively in the. chemical industry for dewatering sludges. A number of different kinds of pressure filters are on the market. Pressure filtration has the capacity of producing filter cakes with a relatively high solids concentration and high-quality filtrate in terms of low suspended solids. The process is flexible and fits any operational mode.

Dewatering of alum sludge by pressure filtration is likely to need sludge conditioning to lower the resistance to filtration. This can be done by the addition of lime, polymers, or fly ash. The choice of conditioning agents is based on the costs for each application. Lime is added to alum sludge to raise the pH of the slurry to about 11 with a minimum contact time of 30 minutes (Westerhoff, 1978). If fly ash from power plants could be used successfully for conditioning alum sludge this would be beneficial to both industries.

Literature on the application of pressure filtration to lime-softening sludge is limited. No conditioning of the lime sludge is required.

Belt Filtration. The belt press, or the belt filter press, consists of two endless filtration fabric belts held in close contact with each other by guide parallel rollers. The lower belt is made of coarse mesh fabric media consisting of twisted metal, plastic, or mixed fibers. The upper belt is solid. The conditioned sludge is fed onto the belt press at one end (draining zone) and is continuously dewatered by the pressure applied between th two belts (press zone and shear zone). The liquid drains off by gravity. The solids cake is scraped off by a blade at the other end of the belts.

A number of belt filter presses have been introduced. These devices have been used in Europe since the early 1960s for dewatering sewage sludge. In the United States, their use for dewatering water plant sludges in full-scale operations is not documented. Although belt presses are widely used in industries, especially in paper and pulp manufacturing, the process has also been successful for sewage sludge dewatering.

In 1982 a belt filter press was installed at the Belvidere, Illinois, wastewater treatment plant to replace two inefficient vacuum filters. In 1980 the plant dewatered 8000 lb/d of dry solids (23.5 tons/d of wet sludge at 77% cake solids from vacuum filters). A three-year operational record showed an average savings of $60,000 in costs for power, labor, and polymers with the belt press. The 1985 total annual cost for operating the belt press was less than $70,000. The final sludge cake from the belt press contained 23% solids.

Pellet Flocculation. Pellet flocculation is a relatively new process and has been developed in Japan, where a few plants have been using it (Chandler, 1982). The device basically consists of a slowly rotating horizontal drum, the reactor, which is divided into three sections. The conditioned sludge is fed into the first section of the reactor, where the rolling action causes the formation of sludge pellets. The liquid is drained off in the second section, and the sludge is consolidated and further dehydrated by the combined effects of piling up and rotation in the final section.

Dewatering of sludge by the pellet flocculation process is a continuous operation. Its operation and maintenance costs are minimal due to the low rotating speed. A study of a pellet flocculation reactor of 0.5-m diameter at the Hula Filter Station, New Zealand, determined that a final sludge cake of 12 to 15% solids was produced from a conditioned sludge feed of 3 to 4% solids. The unit performance depended on the polyelectrolyte dose, feed rate, and reactor speed (Chandler, 1982).

An AWWA Committee Report (1981) described the sludge pelletization occurring during the suspended-bed cold-softening process used primarily in the southeastern United States. The process seems to work best on high-calcium, warm-temperature ground water. The detention time in a suspended-bed softening reactor is about 8 to 10 minutes. Lime is injected into the reactor while the raw water flow is gradually increased from a low initial rate to design capacity. The lime reacts with calcium bicarbonate and carbon dioxide to form calcium carbonate, which precipitates on the suspended particles. The pelletized sludge contains approximately 60% solids by weight as it leaves the reactor. The volume of pelletized sludge is 10 to 20 times less than that of conventional sludge which is not dewatered. The pelletized sludge has to be transported away for final disposal.

Ultimate Sludge Disposal

Although a limited amount of alum or lime can be recovered and reclaimed, this quantity still represents a small percentage of the total solids volume. The conditioned and dewatered sludges still need ultimate disposal. This is a difficult task for large urban plants. Ultimate disposal for water plant sludges is basically confined to land or water bodies and can involve incineration, disposal into sewer systems, barging to the ocean, lagooning (in rural areas), underground disposal, compositing, spreading on land, or landfill.

The dewatered sludge can be composited with municipal refuse. It also can be used for cropland (as a soil conditioner or fertilizer), land reclamation, forests, raw material recovery, mixing with soil, landscaping, and fill material. The most popular form of ultimate sludge disposal is to a landfill.

The advantages and disadvantages of each alternative for ultimate disposal should be evaluated. Each plant has its own situation and the final disposal method needs to be approved by regulatory agencies.

Land Application. Conditioned and dewatered sludges may be disposed of on public or private lands, or on land owned by the utility. The operation should be controlled with adequate provisions to guard against water or soil pollution resulting from high loading rates and surface runoff. The landfill area is eventually reclaimed and grassed.

The amount of land required for disposal of sludge from water plants varies with the degree of solids content in the sludge. On the basis of an annual alum sludge production of 1980 tons (4.16 x 10° pounds) per day and at a filling depth of 2.4 m (8 ft), the annual land requirements are as follows (Reh, 1978):

Sludge concentration, % solids	Land requirements	
	Acres	Hectares
10	600	243
30	230	93
50	135	55

These are net requirements and exclude any allowances for roads, service areas, and the like.

Lime sludge can be spread on agricultural land for soil pH adjustment with fertilizer application. The lime-softening sludge should be thickened as a liquid from 1-5% to 8-10% solids or as a solid after being dewatered to approximately 40% solids. Application rates of 2 to 3 tons per acre have been used on a 4- to 7-year schedule. At this rate about 11,300 ha (28,000 acres) of land is needed for the disposal of the estimated lime sludge produced at a 10-MGD water treatment plant (Reh, 1978).

In the Champaign-Urbana, Illinois, area 1.4 to 1.8 kg (3-4 lbs) of limestone must be applied for each 0.45 kg (10 lbs) of ammonia fertilizer, because it takes approximately 4 pounds of agricultural limestone to neutralize the acidity of one pound of nitrogen fertilizer which is applied on corn as an ammonium form, urea, ammonium nitrate, or manure. The calcium carbonate equivalent (CCE) values and the neutralization power of lime-softening sludge are found to be higher than those of limestone. Softening sludge with 50% solids was successfully applied to farmland in Illinois (Russell, 1975, 1980). Currently a minimum of 30,000 tons per year of "liquid lime" can be marketed in the Champaign-Urbana area (Kieser, 1986). Land application of lime-softening sludge not only serves as a waste disposal practice but also aids the agricultural community.

Bugbee and Frink (1985) studied the use of alum sludge as a potting soil amendment and also for application to forest land. A study of silvicultural applications of two types of alum sludge was conducted by Grabarek and Krug (1987). They found that the application of alum sludge on forested land would not affect tree growth and was a low-cost disposal alternative.

Conclusion

Regardless of which method of sludge treatment is used, the end product still must be disposed of on land or water. Reclamation, of course, can reduce the amount of end products. Greater emphasis should be placed on minimizing the amount of sludge production and maximizing the solids content. The effect of various types of waste disposal on the environment should also be evaluated.

The disposal problem regarding wastes from water treatment plants is not new. Each plant has a unique situation. In designing a water treatment plant, it is not adequate to consider only the optimization of various treatment unit operations and processes without giving due consideration to waste disposal. Plans for the handling and disposal of wastes should be included in the total design for a water treatment plant. This may be an important limiting or controlling factor.

Laws and Regulations

In the late 1960s, several state pollution regulatory authorities classified water works wastes as potential pollutants. Notably, the states of Illinois and New York established treatment standards for water plant discharges in this early period of environmental awareness.

Responding to public demand for clean water, after two years of intense debate, negotiations, and compromises the Congress overrode a Presidential veto on October 18, 1972 and enacted Public Law 92-500, entitled "The Federal Water Pollution Control Act of 1972." This was the most assertive step in the history of national water pollution control programs. Thereafter, several laws and regulations were amended.

In Illinois, the legal requirements applicable to waste discharges from public water supplies are generally found in the following federal and Illinois legislation (Reh, 1978; Hunt, 1978; Haschemeyer, 1978; Randtke, 1980):

1. PL 92-500, the Federal Water Pollution Control Act (FWPCA) of 1972 as amended by the Clean Water Act of 1977

2. PL 94-580, the Resource Conservation and Recovery Act (RCRA) of 1976

3. PL 93-523, the Safe Drinking Water Act (SDWA) of 1974, amended in 1977

4. PL 91-512, the Solid Waste Disposal Act of 1976

5. Chapter I: Pollution Control Board, Subtitle C: Water Pollution, Title 35: Environmental Protection, IEPA, revised in 1986

6. Part 391, Design Criteria for Sludge Application on Land, Chapter II, Subtitle C, Title 35, IEPA, 1984

7. The Illinois Environmental Protection Act III, Chapter 111 1/2, Public Health & Safety Section 1001-1051, amended Jan. 5, 1984

PL 92-500

In Public Law 92-500, enacted in 1972, the federal government increased funding for construction of publicly owned wastewater treatment plants maintaining uniform technology-based effluent standards. The objective was to control all point source pollution discharges in navigable waters by 1985 (Hunt, 1978). This law pertains to water pollution control.

There were two phases of implementation in the PL 92-500 act. By 1977, all plants were required to install "best practicable control technology currently available (BPCTCA)" to meet state or federal water quality standards. For phase 2, in order to meet more stringent standards, all treatment plants were to install "best available technology economically achievable" by July 1, 1983 toward the national goal of eliminating the discharge of all pollutants, including reclaiming and recycling of water, and confined disposal of pollutants (from wastewater discharge). Ultimately, all point source pollution controls were directed toward achieving the national goal of the elimination of the discharge of pollutants by 1985.

Section 402 of PL 92-500 stipulates that the discharge of any pollutant by any person is unlawful without a National Pollutant Discharge Elimination System (NPDES) permit.

The NPDES permitting process in Illinois is generally governed by Part IX, Permits, Subpart A: NPDES Permit Sections 901-916 of Chapter 3 of the Illinois Pollution Control Board Rules and Regulations (Haschemeyer, 1978).

Section 901 of Chapter 3 states:

"Except as in compliance with the provisions of the Act, Board Regulations, and the FWPCA, and the provisions and conditions of the NPDES Permit issued to the discharger, the discharge of any contaminant or pollutant by any person into the waters of the State from a point source or into a well should be unlawful."

See also Section 12(f) of the Illinois Environmental Protection Act (January 1987).

Discharging waste without an NPDES permit is a violation of both state and federal laws, exposing the discharger to potentially serious consequences (fines and imprisonment). Waste dischargers presently discharging to a publicly owned treatment works (POTW) need not obtain an NPDES permit but will be subject to limited regulations. Waste streams presently discharging to waters of the state, but which were planned to be connected to a POTW, are required to have an NPDES permit (Haschemeyer, 1978).

On December 27, 1977, President Carter signed the Clean Water Act of 1977, known as PL 95-217, which significantly changed certain provisions of PL 95-500 (Hunt, 1978). The original act was amended to permit an extension of the best available technology for sources utilizing innovative technology until no later than July 1, 1987. The USEPA is required to evaluate the best conventional pollutant control technology.

PL 94-580

The Resource Conservation and Recovery Act of 1976 defined water treatment plant sludge as one of the "solid wastes." The RCRA concerns the conservation of valuable resources. Federal agencies offer assistance to state and regional solids wastes management planners to develop methods of solid waste disposal, such as resource conservation and recycling, which are environmentally sound and which maximize the use of valuable resources (Reh, 1978).

PL 93-523

No matter what methods of waste disposal are to be used to meet the requirements of regulations PL 92-500 and PL 94-580, the 1974 Safe Drinking Water Act (SDWA), PL 93-523, is preemptive (Reh, 1978). The SDWA deals with water quality at the tap and in the surface and ground waters which may be employed as the source of water supplies. PL 93-523 considers the effects of recycling upon the final waste stream. This includes the purity of recycled chemicals, toxic substances, heavy metals, and trace organics. The Office of Drinking Water of the USEPA is responsible for developing a program strategy that will help implement the SDWA (Robeck, 1980).

With the exception of deep-well injection, the SDWA (PL 93-523) as amended in 1977 does not regulate the disposal of waste products or waste streams. The SDWA along with certain requirements of the Illinois Environmental Protection Act and Chapter 6 of the IPCB Rules and Regulations generally imposes certain legal requirements and standards on public water-supplies, such as limits on arsenic, barium, chromium, other heavy metals, and various other organic and inorganic chemical constituents (Haschemeyer, 1978).

Impacts of Environmental Regulations on Water Works Waste Disposal

The Federal Water Pollution Control Act (PL 92-500) as amended has required the promulgation of numerous new regulations. The legal responsibility of each state for waste disposal is one of the areas changed by PL 92-500 (Haschemeyer, 1978; Graeser, 1978).

A major consideration in environmental protection is the proper handling of wastes generated by water treatment facilities. Historically, the production and disposal of solids have been considered to be of primary importance. More recently concern has been expressed about the toxicity of some of the metals in the wastes, such as aluminum and manganese. PL 92-500 as amended permitted the USEPA to formally declare public water supplies an industry. However, unlike the case of many other "industries," for which guidance documents were developed for various categories of industrial waste, such national effluent guidelines were not adopted for the water supply industry.

The current USEPA policy governing wastes from water treatment plants is set forth in 49 Federal Register 38026 (September 26, 1984). According to this policy, discharge requirements for clarifier residues and filter backwashes are best determined at the local permitting level, with due consideration given to appropriate technology-based effluent limits and water quality standards. This in effect requires professional judgment at the state level rather than the application of uniform national effluent requirements.

In order to meet established in-stream water quality standards at the edge of the mixing zone, discharge decisions are made either by the regional USEPA or by the state office. In the development of technology-based effluent limitations, a controlled release of wastes from water treatment plants in a manner that meets water quality standards may, in appropriate circumstances, be considered to be technology-based controls (AWWA, 1987). This issue remains to be resolved in Illinois.

The necessity for treating wastes from water works will stimulate the development of new methods for reduced sludge production, solids dewatering, and ultimate disposal. For example, the use of polymers in coagulation has proven effective in reducing sludge volume. Recovering spent chemicals and recycling may become more attractive. The resolubilization of aluminum hydroxide as a function of some treatment techniques will have to be explored, and the reaction of the solids to disposal in an anaerobic environment, such as a landfill, will require monitoring. All parties must be mindful of the possibilities of creating hazardous conditions where such conditions do not now exist in the handling and ultimate disposal of wastes from water treatment plants.

Recycling and chemical reclamation are encouraged by the regulations of the RCRA, PL 94-580. The recovery of treatment chemicals and re-use of process wastewater flow may reduce the cost of waste treatment and water production. To minimize the impact of water plant waste treatment on the production cost of water, it is essential that these additional costs be kept to a minimum (Fulton, 1978a). The waste treatment process should not introduce complexities in operation, control, and maintenance, and should not require additional staff time if possible. Some new water treatment technologies that have focused on these issues are discussed by Randtke (1980).

In Section 1004 of the RCRA (PL 94-580), sludge is defined specifically to include the wastes generated by a water treatment plant. In many cases, water plant sludges contain elevated levels of metals and radioactive materials from the raw water. These sludges must be disposed of in compliance with hazardous waste regulations promulgated under the RCRA. The disposal of concentrated hazardous wastes will continue to pose a serious problem. According to Robertson (1980), sludge disposal will require increasingly greater consideration in future water works designs, regardless of the treatment process selected.

The RCRA also emphasizes municipal water conservation. According to Gloriod (1980), municipal water conservation may impact the water industry not only in the area of plant operations but also in regard to customer relations, rate structure, design and timing of production, and transmission facilities. Increased costs of sludge treatment and disposal due to the imposition of industrial cost recovery charges will accelerate the need for more effective means of sludge reduction and disposal.

PL 93-523 provides that the states do not have to report to the USEPA except yearly, and some of those reports required by regulations are years away from delivery. The regulations were designed for a team approach to solving environmental protection problems. The state is recognized to be the primary enforcement power. There is a state/federal partnership, and it requires the full cooperation of local populations.

Shaw (1980) reported adverse impacts of federal regulations in South Carolina. Prior to the federal program, when a water quality violation occurred the state agency would send a qualified engineer to the system to provide technical assistance in correcting the problem. Under the SDWA, PL 93-523, when a violation occurs the state sends the violator a letter saying it must notify its customers of the violation. In reality, the state agency still sends an engineer out to investigate the water quality violation, but nowhere in the federal reporting system does the USEPA ask the states how much time and effort was spent in correcting that water quality problem. Various forms of guidance from the USEPA leave virtually no room for states to use their judgement in applying the regulations to specific cases.

Illinois Situation

In Illinois water systems serving 25 or more people or more than 15 pipe connections are defined as community water supplies. All community water supplies are regulated by IEPA. The Illinois Department of Public Health is responsible for regulating the smaller non-community water supplies. At least 25,000 community water suppliers are estimated to be operating in Illinois. Supervision is a difficult task in terms of available manpower. Presumably such difficulties exist throughout the nation.

Water treatment plant wastes in Illinois cannot be discharged into streams or sewers without a permit. The Illinois policy requires adequate treatment of all wastes from such plants, with some consideration given to local conditions. The necessity for treatment has led some water purveyors to begin legal proceedings to obtain relief.

The disposal of" water treatment plant residues on land has to follow the requirements listed in "Design Criteria for Sludge Application on Land, January 1984" which is Part 391, Chapter II, Subtitle C, Title 35 of the State of Illinois Rules and Regulations.

For disposal of water plant sludge on land, the sludge generator (water purveyor) has to apply to the IEPA for a permit for the land application of sludge. Sludge distributors who sell or give away sludge at a rate exceeding the equivalent of 1500 dry tons per year are required to obtain a permit or be included as part of a sludge management plan in a sludge generator's permit. Sludge users who apply sludge to sites greater than 300 acres under common ownership or control in any year or apply more than 1500 dry tons of sludge per year are also required to obtain a permit unless the site is specifically identified in the permitted sludge generator's management plan.

Sludge permit applications should include Schedule WPC-PS-1, Schedule G, laboratory analyses data, agronomic calculations, and a sludge management plan narrative.

The IEPA requires that data on the following parameters be submitted as part of an application for a land application permit:

Metals (dry weight basis, mg/kg)	Others
Arsenic	% total solids (TS)
Barium	pH
Cadmium	% calcium carbonate equivalent (CCE)
Chromium (total and hexavalent)	
Copper.	
Mercury	
Nickel	
Selenium	
Zinc	

If a specific utilization site has been chosen, the following must be provided:

1) The location and acreage of the sludge utilization site shown on a U.S. Geological Survey map or plat map

2) A soil survey map with a description of the soil as provided by a published soil survey

3) The slope of the utilization site

4) Previous and expected crop yields for crops to be grown

5) Depth to mean annual water table

6) Soil pH and cation exchange capacity

If a permit is granted, usually some special conditions are stated. For example, there is a limit on the maximum application rate. The permittee shall provide the following alum sludge analyses on at least one sludge sample per test plot composited from the trucks applying sludge to that test plot: pH, % TS, total aluminum, boron, specific gravity, and % CCE. The permittee also shall provide the following soil analyses on soil samples collected after alum sludge application, but just prior to spring fertilization and crop planting: aluminum (total and trivalent), Bray available phosphorus, CCE, % organic matter, and pH. All analyses shall be performed in accordance with the method indicated in Section 391.503 of the Sludge Regulations.

Environmental Impact Assessments

Environmental Impact Studies of Direct Waste Discharge to Receiving Streams

Direct discharge of wastes from water treatment plants has been a concern for regulatory agencies and water works operators for a long time. In the early 1950s Dean (1953) discussed the effect of water plant waste discharges on streams.

In some plants, coagulation sludge is allowed to accumulate in settling basins for several months and is then discharged over short periods of time to a receiving water body. A substantial increase in TSS and turbidity in the receiving waters will then occur. If continuous withdrawal is used it may minimize the problems. Filter backwashings alone may not create serious problems because of the large quantities of finished water used. Unfortunately, field evaluations of impacts of direct waste discharges are scarce.

Evans et al. (1979) assessed the impact on the Vermilion River (a mid-size river) of waste discharges from a water works (1.83 MGD) using alum coagulation/filtration at Pontiac, Illinois. They observed increases in aluminum and turbidity in river water near the waste outfall, which were limited to a relatively short section of the stream. High levels of aluminum were found in the bottom sediments in the vicinity of the outfall. However, they concluded that the influence of the waste discharges on macroinvertebrates was imperceptible.

In 1981, W. E. Gates and Associates, Inc., used the mass balance and the added concentration approaches to determine the pollutant concentration downstream of waste discharges and the percent increase in pollutant level. They concluded that neither method for describing the impact of water plant residues showed much numerical consequence of discharging such residues to large streams. They also discussed the phenomena of desorption, colloidalization, solubilization, and de-suspension of the water plant residues in high- and low-velocity streams.

A study undertaken in 1981 (W. E. Gates and Associates, 1981; Vicory and Weaver, 1984) concluded that discharges from water treatment plants employing coagulation, sedimentation, and filtration contributed little or no additional loading to the Ohio River. Vicory and Weaver concluded that across-the-board, technology-based requirements for removing solid wastes from discharges were inappropriate because of the cost of such systems and the lack of significant benefits to the receiving streams. The policy adopted by the Ohio River Valley Water Sanitation Commission allows controlled release of plant process waste discharges on a case-by-case basis, provided there are no adverse effects on designated stream uses.

In a study (Evans et al., 1982) of the effect of waste discharges from an alum coagulation/rapid sand filter plant (12.5 MGD or 19.3 cfs) at Alton, Illinois, on the Mississippi River (64,430 MGD or 99,680 cfs), aluminum and iron were the major chemical constituents of the solid wastes found. Aluminum was derived from the use of alum as a supplemental coagulant. Iron was probably inherent in the suspended sediments in transport in the river. There was no marked environmental degradation, as determined by sediment size distribution and the abundance and diversity of benthic macroinvertebrates.

A similar impact study of waste discharges from a large water treatment plant (43.5 MGD or 67.3 cfs) at East St. Louis, Illinois, on the Mississippi River (114,000 MGD or 176,000 cfs) was conducted by Lin et al. (1984). The water works uses alum coagulation and granular activated carbon (GAC)/sand filtration. The effect of the water plant wastes was detectable in the bottom sediments of the river by increases in aluminum, iron, sediment moisture content, and volatile (organic) content. Nevertheless, that effect was limited to an impact area about 100 feet offshore that extended 4000 feet downstream of the waste outfalls. Within the impacted area aluminum and iron concentrations increased about 8-fold and 3-fold above measured background concentrations of 760 and 2590 mg/kg, respectively. There was also a detectable modification in the composition of gravel-sand-silt relationships within the impacted area. Despite the change in bottom sediment composition, there was no measurable blanket of sludge deposits. The natural bottom sediment of the Mississippi River is sandy. It was found that high silt in the plant wastes, with some organic enrichment, provided an aquatic substrate which permitted "burrowing" and "clinging" organisms to colonize. Although these types of changes in chemical, physical, and biological parameters in the limited impacted area were evident, there was no significant environmental degradation.

Lin and Green (1987) reported the results of a comprehensive and intensive study to evaluate the influence of waste discharge from the Centralia (Illinois) water plant on Crooked Creek. Samples for water quality and sediment characteristics were collected at eight creek sampling stations. The plant employs alum coagulation and GAC/sand filtration. Concentrations of water quality characteristics at the first sampling station immediately downstream of the outfall (900 feet from the outfall) were statistically the same or lower than those measured at the control station upstream of the outfall. There were also no significant differences in water quality parameters measured at the other six downstream locations. It was concluded that the water plant discharge had no adverse impact on Crooked Creek water quality.

In the same study (Lin and Green, 1987), the evaluation of stream sediments indicated that the effect of the water plant discharge was detectable in the bottom sediments at the first station downstream of the discharge, but not at the other downstream locations. The location immediately downstream showed an increase in chemical concentrations, a change in particle size distribution, and a shift in the diversity and abundance of macroinvertebrates. However, the macroinvertebrate biotic index (MBI), which is used by the IEPA as a measure of the long-term effect of the ambient water quality, showed that there was no difference in the MBI at the sample stations immediately upstream and downstream of the water plant discharge.

It should be noted that one should not generalize about the production and characteristics of wastes from a water treatment plant, nor about the environmental impacts of wastes. Rather, an intelligent examination at each site in question is necessary to permit rational decisions concerning the impact of water plant wastes on the water and sediment qualities of receiving streams.

Application of Water Plant Sludge to Land

Excellent guidelines for sludge land application are listed in Design Criteria for Sludge Application on Land (IEPA, 1984). They cover general limiting factors, site selection, nutrient and heavy metal loading rates, site monitoring, etc.

The cation exchange capacity (CEC) of soil influences the soil to retain the heavy metals contained in the sludge. In Illinois, soils having a CEC in the range of 5 to 15 meq/100 gm are acceptable for sludge utilization providing the application rates do not exceed the following limits over the life of a project site:

	Rate , pounds/acre	
Metal	Total	Annual
Pb	1000	
Mn	900	
Zn	500	
Cu	250	
Ni	100	
Cd	10	2
Ag	178	

	Rate, pounds/acre	
Metal	Total	Annual
Sb	700	
As	100	
Cr^{+3}	3500	89
Cr^{+6}	440	44
Hg		7
Se	8	

In Germany (Moller, 1983), the application of sewage sludges to soils used for agricultural or horticultural purposes is not permitted unless the concentration (mg/kg air-dried soil) of each of the following heavy metals in amended soil falls within the limits as follows:

Metals	Concentration, mg/kg
Lead	100
Cadmium	3
Chromium	100
Copper	100
Nickel	50
Mercury	2
Zinc	300

Lime sludge has been used on agricultural land for pH adjustment in Illinois and elsewhere. However, assessments of the impact of lime sludge on land are not found in the literature. Soil pH should be maintained at a level of 6.5 or above to minimize the uptake of metals by crops (USEPA, 1983). Land application of lime-softening sludge is reported to be beneficial not only to farmers but to the water industry for waste disposal (Russell, 1975, 1980; Kieser, 1986).

In a study by Bugbee and Frink (1985), alum sludge from the Lake Saltonstall and West River plants in Connecticut produced similar declines in lettuce growth, indicating that little difference existed between the two sources of alum sludge. Alum sludge may improve physical characteristics of the media, aeration, and moisture-holding capacity, but it inhibits plant growth by adsorbing phosphorus and thereby making phosphorus unavailable for growing plants. Phosphorus deficiencies caused by the addition of dried alum sludge are not likely to be overcome by doubling the initial phosphorus application. Bugbee and Frink did not observe direct effects on lettuce growth due to manganese, although uptake of manganese may be affected by alum sludge.

Little effect on tree growth, nutrient levels, or the appearance of the forest floor were noticeable after 1170 m^3/ha (124,800 gal/acre) of liquid alum sludge containing 1.5% solids was applied in the fall of 1983 and the spring of 1984. However, at that application rate soil pH increased by 0.5 to 1.0 units. Plant nutrient uptake, as measured by tissue analyses, showed there was no effect due to liquid alum sludge application.

A follow-up study of the silvicultural application of alum sludge was made by Grabarek and Krug (1987). They concluded that alum sludge has no significant impact with respect to organic or metal leachate production, or to aluminum toxicity in trees (principally sugar maple). The only adverse impact noted was that the applied alum sludge was capable of binding up soil phosphorus and making it unavailable to plants. A thick (11.7-cm) application of alum sludge containing 1.5% solids on forest plots in Connecticut was found to substantially dewater within two weeks and was barely noticeable in two months.

STUDY 1. A SURVEY OF WATER PLANT WASTES

The work of Evans et al. (1970) was probably the first and the only previous study on the disposal of water treatment plant wastes in Illinois. The purpose of the current study was to obtain and update information on all types of wastes produced by water treatment processes in Illinois.

Materials and Methods

A questionnaire (Appendix A) was developed to focus on raw water quality, water treatment processes, characteristics and management of water plant wastes, and costs. It was reviewed by plant managers, scientists, regulatory personnel, private consultants, and AWWA personnel. Modifications were made on the basis of their comments and suggestions to insure a well-worded, unbiased, and technically sound questionnaire.

On April 10, 1986, 442 questionnaires, each with a cover letter and a stamped self-addressed return envelope, were sent to the managers of water plants. Fourteen additional questionnaires were mailed later on, bringing the total to 456. The plants included 188 surface water plants and 268 ground water plants serving more than 600 people each. The response rate was very good. In order to gain more responses, two reminder letters were sent out, one on June 9, 1986 and one on July 9, 1986. Other efforts, such as letters sent to city engineers and telephone calls to water plants, were made to encourage them to respond.

Results and Discussion

Questionnaire Returns

Of the 456 sludge questionnaires mailed, 280 were returned. The replies received represent a 61.4% response rate. These plants included 149 with surface water and 131 with ground water sources. The response rate for surface water plants was 85.6%. All the plants represented produce 1413+ MGD of potable water. Unfortunately, the replies of four large plants of an investor-owned company were held at the regional headquarters. It was not possible to get them released although many attempts were made.

Of the 149 municipalities using surface water sources, 61 purchase water from large water purveyors (such as Chicago) and generally do not treat the water except for additional chlorination.

Water Plants

The general facility information for the 88 surface water plants that do not purchase water from other purveyors, and for the 131 ground water plants, is given in Appendix B. In the plant numbers, S and G stand for surface and ground water sources, respectively. However, five of the facilities (S205, S301, S303, S310, and S320) use both types of sources. The first digit of the number following S or G indicates the region in which the plant is located. The last two digits of the number were assigned to each plant in a region by order from west to east and from north to south. Figure 1 shows the six public water supply regions in Illinois.

Appendix B also includes the names and titles of those who responded to the questionnaires, and the names, addresses, regions, counties, and telephone numbers of the water treatment plants. Information for the 61 communities that purchase water from other facilities is given in Appendix C.

Raw Water Sources

Appendix D lists the source and quality of raw water, mean and maximum flows, and population served for each plant. Some water treatment plants use both surface and ground waters as their sources of supply. Most of the communities in the northern half of Illinois use ground water except for the Lake Michigan and Quad-City areas.

In Illinois, three major surface water sources are used for public supply: Lake Michigan; interstate rivers such as the Mississippi, Ohio, and Wabash; and intrastate streams, rivers, and impoundments. Water supply allocations from Lake Michigan for 15 towns and entities in northeastern Illinois (Chicago, Evanston, Wilmette, Kenilworth, and Winnetka in Cook County; Glencoe, Northbrook, Highland Park, Highwood, U.S. Army Fort Sheridan, Lake Forest, North Chicago, Great Lakes Naval Training Center, and Waukegan in Lake County; and the Lake County Public Water District) are managed by the Division of Water Resources, Illinois Department of Transportation.

Water from the Mississippi River is used by East Moline, Moline, Rock Island (RI), the RI Arsenal, Dallas City, Nauvoo, Hamilton, Warsaw, Quincy, the Illinois-American Water Company (Alton, Granite City, and East St. Louis), Menard Correctional Center, and Chester. The Ohio River is the source for Golconda, Rosiclare, and Cairo (Illinois-American Water Co.). The Wabash River is the source for Mount Carmel.

The water supply systems serving Elgin and Peoria meet part of their demands from the Fox and Illinois Rivers, respectively, and the rest from ground water supplies. There are 146 impoundments for public water supplies in the southern half of the state. A list of public and food processing water supplies using surface water has been published elsewhere (IEPA, 1983).

The water utilities using ground water as sources are distributed throughout Illinois, especially in the northern half, except as mentioned above. Some surface water plants have auxiliary or stand-by ground water wells.

According to the definition of a public water supply in PL 93-523, it is estimated that there may be 25,000 public water suppliers in the state of Illinois (Reh, 1978). In Illinois, the total water withdrawal in 1984, estimated from over 1900 public water supply systems, was 1797 MGD (Kirk et al., 1985). This includes 1322 MGD for surface water and 475 MGD for ground water supplies. Public water supplies furnish potable water to 88.7% of the state population of 11.554 million. Thus about 10.251 million people are

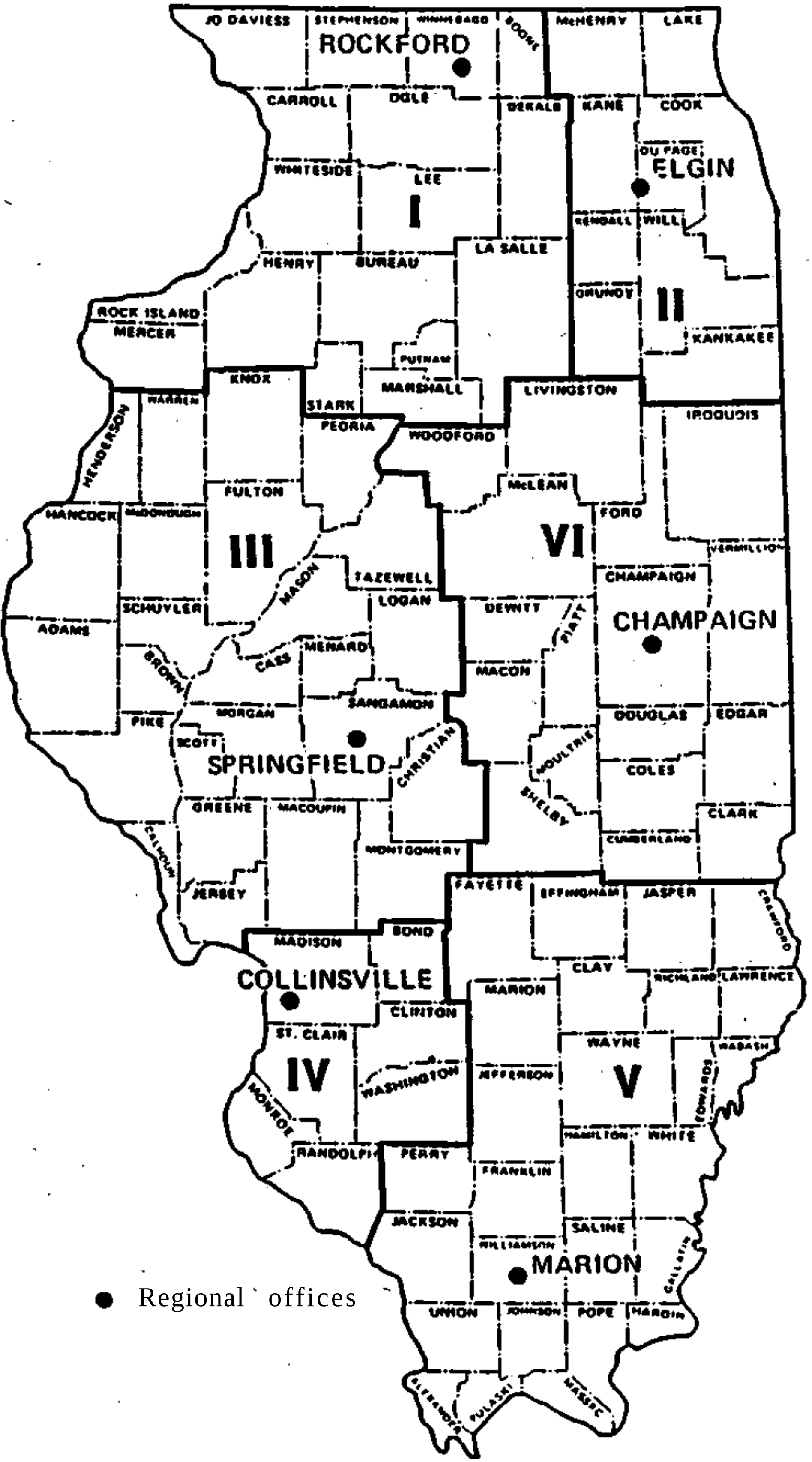

Figure 1. Map of Illinois public water supply regions

furnished with potable water, of which surface water supplies about 6.122 million people, ground water supplies about 3.702 million people, and combined sources supply about 0.427 million people. This leaves about 1.303 million people (11.3%) to furnish their own supply of potable water.

The largest system is the Chicago Water Commission, serving more than 4.5 million people. The Chicago system, on average, pumped approximately 1000 MGD from Lake Michigan in 1985. The public water system that serves the largest area is the Rend Lake Conservation District, which serves an area of more than 1800 square miles and pumped 13.8 MGD (average) from Rend Lake in 1985.

Water Quality

Inspection of Appendix D shows that the average raw water turbidity varied widely from 0.2 NTU at plant S514 to 130 NTU at S412 for the surface water suppliers, and from less than 0.05 NTU at G402 to 16 NTU at G212. The pH values for all supplies are between 6.6 and 8.5, with only four sources having a pH level of less than 7.0. For all facilities reporting, the average total alkalinity ranged from 21 mg/L as $CaCO_3$ at S519 to 440 mg/L at G308; and the average total hardness varied from a low of 42 mg/L as $CaCO_3$ at S517 to a high of 796 mg/L at G246. Both alkalinity and hardness are generally higher in ground waters than in surface waters (Appendix D).

Generally water utilities do not monitor solids concentrations in waters. The sparse solids data are shown in Appendix D. For the surface water plants, a high total suspended solids concentration of 425 mg/L was recorded on the Illinois River (S301). Total solids are usually high in ground waters. For. the ground water plants, the highest total solids concentration (1221 mg/L) was recorded at wells 3 and 4 at G232.

Treatment Processes

Appendix El lists the treatment processes used by the 88 surface water plants. The various arrangements of clarifier basins and filters are summarized as follows:

Arrangement	Surface water plants reporting Number	Surface water plants reporting Percent
Coagulation, sedimentation, and filtration	54	61.4
Lime softening and filtration	1	1.1
Coagulation, sedimentation, lime softening, and filtration	32	36.4
Filtration only	1	1.1
Total	88	100.0

The questionnaire responses indicate that the majority (61.4%) of surface water supplies in Illinois use clarification and filtration processes. More than one-third of the reporting plants employ coagulation, sedimentation, lime softening, and filtration for water purification. Only one facility (S314) uses lime softening and filtration. Also only one plant (S203) is being operated with filtration only, without conditioning basins.

Thirty-eight facilities (43.2%) use either powdered or granular activated carbon for taste and odor removal (Appendix El). One plant (S214) uses pressure filtration. Aeration as a part of water treatment is used by three plants. Fluoridation and phosphate addition are used by 18 (20.5%) and 5 (5.7%) of the facilities, respectively. All 88 plants use chlorine for disinfection.

Appendix E2 shows the treatment processes used for the 131 Illinois ground water supplies. Information is also included for the 5 plants that use both surface water and ground water sources. Some facilities employ a combination of treatment processes. The processes used by the 131 plants are summarized as follows:

Process	Ground water plants reporting Number	 Percent
Iron (manganese) removal	52	39.7
Iron removal and zeolite softening	8	6.1
Softening	28	21.4
Coagulation, sedimentation, and filtration	18	13.7
Filtration	36	27.5
Chlorination only	67	51.1
Fluoridation	46	35.1
Phosphate addition	13	9.9

More than one-half (51.1%) of the ground water plants reporting use only chlorine for disinfection purposes. Some of these plants also add fluoride for dental hygiene and phosphate for sequestering iron. Thus, about 49% of the plants reporting use chlorination combined with other treatment processes.

Approximately 40% of the ground water supplies provide iron and manganese removal. The methods of removal are either aeration, retention, pressure sand filtration, or combinations of these methods. Aeration is the most popular (37 plants) means for iron removal. Eight plants use iron removal and zeolite softening.

As shown in Appendix E2, 28 plants use softening processes. Lime softening and zeolite softening are equally popular. Of the 131 ground water supplies, only 18 facilities use the coagulation, sedimentation, and filtration method which is the most popular treatment technique for surface waters. Thirty-six plants provide filtration in combination with other chemical and physical treatments.

Chemical Dosage

Chemical dosages for all surface and ground water plants are tabulated in Appendices F1 and F2. Annual average values and ranges for each chemical used are given. Of the 88 reporting surface supplies, 80 plants (90.9%) use alum for coagulation; four use ferric chloride; and one (S324) uses a polymer as a coagulant (Appendix F1). Lime is used for either coagulation or softening at 82 (93.2%) of the surface water plants (Appendix F2). Of the 131 ground water plants, only 11 plants (8.4%) use alum coagulation and 17 plants (13%) use lime.

Basin Information

Basins include those for pre-sedimentation, flocculation, primary and secondary sedimentation, and softening. Number, size, and detention time for each basin at both surface and ground water treatment plants are given in Appendix G. The amount of sludge generated at each basin is also listed.

Filter Information

Data on number, size, media, filter aid, and operational records for filters at each of the responding plants are shown in Appendix H. Operational records include maximum loading rate, maximum wash rate, filter run, and the quantity and solids levels of filter washwaters. The quantity of washwater is expressed in terms of the percentage of the total plant flow.

Sludge Production and Characteristics

Appendix I shows type and quantity of sludge production, and sludge characteristics of the clarification basins. The majority of sludges are alum and lime sludges. Only two plants (S309 and G601) with brine sludge responded. The quantity of sludge generated is expressed in terms of either pounds per million gallons (lb/MG) or gallons per million gallons (gal/MG) of water treated.

As shown in Appendix I, the weight of sludge generated from surface water plants exhibited a wide range: from 66 lb/MG at S213 to 3361 lb/MG at S604. For ground water treatment plants the average weight varied between 567 wet lb/MG at G402 and 10,400 dry lb/MG at G227 (11,144 wet lb/MG at G614).

The volume of waste from basins in a water plant is generally less than that produced from filter washwater. Appendix I shows that the volume of basin sludge generated at 11 surface water plants ranged from 145 gal/MG at S204 to 87,300 gal/MG at S311. Similarly, Evans et al. (1970) reported basin sludge volumes in the range of 200 to 49,000 gal/MG for 14 surface water plants. For ground water supplies, as shown in Appendix I, the sludge volumes produced were between 500 gal/MG at G320 and 85,000 gal/MG at G312.

The sludge characteristics in Appendix I that were generally reported include percent solids, pH, total suspended and dissolved solids, aluminum, iron, and barium. Some facilities provided extensive chemical analyses of their sludges, which are also included in Appendix I. The units used are for either dry weight or liquid concentrations. Again, the characteristics of sludges vary with differing source waters and treatment methods used. It should be emphasized that each water treatment plant should be considered a unique process in the design of its wastewater treatment facilities.

Sludge Removal

Appendix J lists methods of removing sludges from sedimentation basins and flocculators for both surface and ground water plants. Flushing of the basin sludge is done with a fire hose unless stated otherwise. A summary of the information regarding the removal of sludge from basins is given in Table 1. The plants listed in Appendices J through L are those having at least one filter unit.

Three methods — flushing with a fire hose, continuous mechanical removal, and manual removal — are the most popular means of sludge removal from basins. Facilities may use one, two, or all three of these methods. As shown in Table 1, 6 surface water plants and 1 ground water plant use a combination of all three removal methods for removing sludge from sedimentation basins. The responses for these plants are included for each of the three methods. Both types of treatment plants also frequently use heavy equipment to remove sludge from sedimentation basins.

Table 1. Methods of Removing Sludge from Basins

	Sedimentation basin		Flocculator	
	Number of plants	%	Number of plants	%
SURFACE WATER PLANTS				
Flushing	47	66.2	34	52.3
Continuous mechanical removal	18	25.4	9	13.9
Manual	22	31.0	7	10.8
Combination of the above	6	8.5		
Blow-down			15	23.1
Pumping			3	4.6
Other	14	19.7		
No. of replies	71		65	
GROUND WATER PLANTS				
Flushing	8	38.1	1	7.2
Continuous mechanical removal	6	28.6	5	35.7
Manual	9	42.9	3	21.4
Combination of the above	1	4.8		
Blow-down			6	42.9
Pumping				
Other	7	33.3	1	7.2
No. of replies	21		14	

For removing sludge from flocculation tanks, flushing (52.3%) and blow-down (42.9%) are the most popular methods for surface water facilities and ground water facilities, respectively (Table 1). Blow-down at surface water plants and continuous removal at ground water plants are also used frequently.

Sludge Discharge

Appendix K lists the number of water plants disposing of basin sludges, filter washwater, spent granular activated carbon (GAC), and brine waste. A summary of the reported methods of sludge discharge for these wastes is given in Table 2. Approximately 37.6% of the surface water plants discharge basin sludge to a lagoon or impounding basin, and 27.1% discharge to a sanitary sewer; i.e., almost two-thirds of the reported plants treat their wastes and one-third of the plants discharge their waste directly into watercourses. In 1970, Evans et al. (1970) reported that only approximately 22% of 91 Illinois surface water plants treated their wastes. A 1953 nationwide survey showed that only 4% of 1530 surface water plants had sludge treatment, and 96% discharged basin sludge directly to streams, lakes, and other water bodies without treatment (Dean, 1953). Quite an improvement has been made.

It can be seen in Table 2 that flocculator sludge and filter washwater from 71.6% and 63.6% of the surface water plants, respectively, are treated by lagooning and sewage treatment processes. Spent GAC from 3 plants is discharged into lagoons, and GAC from one plant is discharged into a stream. In most plants filter washwaters and spent GAC are discharged in the same manner as the basin sludge.

Evans et al. (1970) reported that in Illinois, approximately 8.7% of 91 surface water plants discharged filter washings to lagoons or sanitary sewers, and/or recycled them through the plant. In other words, 91.3% of Illinois plants discharged filter washwaters directly into waterways, etc., without treatment. From a nationwide survey, Dean (1953) found that 82.5% of 1699 plants discharged filter washwaters directly into streams or lakes, and 10.5% discharged them into storm sewers or surface drains. Thus the filter washwaters from 93% of the plants eventually were discharged into watercourses without treatment.

Sludge problems are generally less for ground water plants, except for the plants using clarification, filtration, and softening. Appendix K shows that 42 ground water suppliers reported sludge discharges. For ground water plants, as indicated in Table 2, the majority (83 - 93%) of wastes are discharged to lagoons and sanitary sewers for treatment.

Table 2. Locations Where Wastes are Discharged

	Basin sludge		Flocculator sludge		Filter washwater		Spent GAC
	No. of plants	%	No. of plants	%	No. of plants	%	No. of plants
SURFACE WATER SUPPLIES							
Stream or river	15	17.6	11	14.9	14	16.9	1
Dry creek	6	7.1	4	5.4	6	7.2	
Lake or reservoir	3	3.5	1	1.4	3	3.6	
Low ground	4	4.7	2	2.7	4	4.8	
Storm sewer	2	2.4	2	2.7	2	2.4	
Impounding basin or lagoon	32	37.6	35	47.3	31	37.3	3
Sanitary sewer	23	27.1	18	24.3	22	26.3	
Other			1	1.4	1	1.2	
Total	85	100.0	74	100.0	83	100.0	
GROUND WATER SUPPLIES							
Stream or river					2	5.7	
Dry creek							
Lake or reservoir	1	3.4	1	8.3	1	2.9	
Low ground							
Storm sewer	1	3.4			1	2.9	
Impounding basin or lagoon	11	37.9	8	66.7	11	31.4	
Sanitary sewer	16	55.3	2	16.7	19	54.2	
Other			1	8.3	1	2.9	
Total	29	100.0	12	100.0	35	100.0	

Sludge Treatment

Appendix L lists sludge treatment methods of plants which have possible sludge generation from any of their water treatment processes. The information in Appendix L is summarized in Table 3.

In Table 3, the sum of the percentages is more than 100, because some plants use both lagoons and co-treatment of sludge with sewage treatment plants. The plants that do this are S611, G227, G402, G406, and G615. It can be seen from Table 3 that the use of lagoons or impounding basins and co-treatment (sewage) are widely practiced in sludge treatment. Lagooning is the most popular method for surface water plants (43.8%), while treatment at sewage treatment plants is the most popular method for ground water plants (61%). Approximately 30 and 10%, respectively, of surface water and ground water plants do not treat the wastes they produce.

Gravity thickening is the most commonly used method for sludge thickening in both surface and ground water plants. One surface water and one ground water plant use centrifuges. At plant S101, a centrifuge is designed for thickening and dewatering sludge from the recovery basin for filter wash wastewaters but is not effective.

Only 10 (12.5%) and 5 (12.2%) surface water and ground water plants, respectively, recycle filter wash wastewaters to the plants (Table 3). Fourteen (17.5%) and 8 (19.5%) surface water and ground water suppliers, respectively, have sludge dewatering facilities.

Table 3. Methods of Sludge Treatment

Method	Surface water plants Number	%	Ground water plants Number	%
Lagooning	35	43.8	15	36.6
Sewage treatment	24	30.0	25	61.0
No treatment	24	30.0	4	9.8
No data	4		8	
Number of plants listed in Appendix L	84		49	
Sludge thickening				
Gravity	9	11.3	12	29.3
Flotation	3	3.8	1	2.4
Centrifuge	1	1.3	1	2.4
Stabilization or chlorination				
Lime	3	3.8	1	2.4
Chlorine	2	2.5	3	7.3
Wash water recycle	10	12.5	5	12.2
Recycling with settling	5	6.3	3	7.3
Sludge dewatering	14	17.5	8	19.5

[*] Percentage is determined on the basis of the number of plants listed in Appendix L minus the number with no data, or 80 and 41 surface and ground water plants, respectively

Sludge Dewatering

Methods of sludge dewatering, number and size of dewatering units, and solids content are given in Appendix M. Approximately 89% (25/28) and 67% (8/12) of surface water and ground water plants, respectively, use drying lagoons for sludge dewatering. Some of these plants use lagoons or impounding basins for both sludge treatment and sludge dewatering. Three of each type of the plants reporting use drying beds for sludge dewatering. A centrifuge is used by S101 and G317 for sludge dewatering. None of the plants reporting uses a vacuum filter, belt filter, filter press, strainer, or freezing process for sludge dewatering.

As indicated in Appendix M, wide ranges of sludge production and solid contents are reported. These data seem unreliable because most are rough estimations. Evans et al. (1970) reported a similar conclusion.

Sludge Final Disposal

Appendix N shows a breakdown of the sludge final disposal methods currently used by Illinois water treatment plants. A summary of this information is shown in Table 4. Two (5%) of the surface water plants and three (15%) of the ground water plants compost their sludges.

As indicated in Table 4, both surface water (40%) and ground water plants (55%) most commonly use sludge as fill material or for landfill. The use of sludge for cropland application is the second most popular usage for both types of plants. Approximately 38% of surface water plants and 25% of ground water plants apply their sludge to croplands.

Table 4. Summary of Sludge Final Disposal

Sludge disposal	Surface water plants: No. of plants	Surface water plants: %*	Ground water plants: No. of plants	Ground water plants: %*
Composting	2	5.0	3	15.0
Utilized for				
Cropland	15	37.5	5	25.0
Land reclamation	3	7.5	2	10.0
Fill or landfill	16	40.0	11	55.0
Mixed with soil	7	17.5	1	5.0
Landscaping	1	2.5	0	
Others	3	7.5	1	5.0
Never dredged sludge	3	7.5	0	
No data	3		1	
Number of plants which should have sludge disposal	43		21	
Final disposal - Land				
Landfill - Own	16	40.0	8	40.0
Public	4	10.0	4	20.0
Private	11	27.5	7	35.0
Dedicated land	4	10.0	1	5.0

* Percentage is determined on the basis of the number of plants that should have sludge disposal minus the number with no data, or 40 and 20 surface water and ground water plants, respectively

Forty percent of both surface water and ground water facilities dispose of their sludge to utility-owned lands (Table 4). Approximately 28% of surface water plants and 35% of ground water plants make their final disposal of sludge to private lands. A small portion of plants dispose of their sludge to public or dedicated lands.

Sludge Disposal Limitations

Appendix 0 presents the replies on sludge direct discharge limitations and cost estimations, and this information is tabulated in Table 5.

Table 5. Summary of Sludge Disposal Limitations and Costs

	Surface water plants		Ground water plants	
	No. of plants	%	No. of plants	%
A. Within the past 15 years, received orders by IEPA to stop discharging sludge				
Yes	45	58.4	9	28.1
No	32	41.6	23	71.9
Total	77	100.0	32	100.0
B. If YES to A, has stopping sludge discharge improved water quality?				
Yes	12	26.7	1	11.1
No	29	64.4	8	88.9
No opinion	4	8.9	0	
Total	45	100.0	9	100.0
C. If NO to B, would your utility resume discharge if permitted to do so?				
Yes	16	55.2	7	87.5
No	8	27.6	1	12.5
No opinion	5	17.2	0	
Total	29	100.0	8	100.0

	Surface water plants	Ground water plants
D. Sludge cost reporting		
Sum of annual cost savings if sludge disposal was resumed	$4,640,000	$185,000
Range of annual cost savings	$500 - 1,600,000	$300 - 150,000
No. of plants	20	4
Total population served	5,175,000	65,200
Cost savings per capita	$0.90	$2.84
E. Range of cost ratios, % (sludge treatment/ plant operation)	0.3 - 33.8	0.3 - 29.4

As shown in Table 5 (question A), approximately 58% of surface water plants have been ordered by a regulatory agency to stop the discharge of water treatment plant sludge into the watercourses. In the case of eleven of the 88 plants (12.5%), no answer was given to this question. As expected, fewer ground water plants (28.1%) have received this order.

For question B (if the answer to question A was YES), approximately 64% of those responding from surface water plants and 89% of those at ground water plants believe that stopping sludge disposal to the water source did not significantly improve the water quality of the water source. Four respondents replied "no opinion" to question B.

For question C (if the answer to question B was NO), 16 out of 29 (55%) surface water plants and 7 of 8 (88%) ground water utilities would resume sludge disposal to the water source if the regulatory barriers were removed. Five surface water plant respondents made no comment on question C.

Costs

It can be seen in Table 5 that 20 surface water plant respondents replied to question D (if the answer to question C was YES), and estimated the annual cost savings if the utility was allowed to resume sludge disposal to the water source. The estimated annual cost savings for the surface water supplies ranged from a low of $500 at S304 to a high of $1,600,000 at S212 (Chicago-Jardine), with a total of $4,640,300 (Table 5 and Appendix 0). With conversion based on the populations served, the average annual cost savings is $0.90 per capita.

Respondents from only four ground water facilities replied to Question D. Their possible annual cost savings would be between $300 and $150,000 with a total of $185,000 (Table 5). The average annual per capita cost savings would be $2.84. As seen in Appendix 0, the annual cost savings would be $150,000 for G610 which serves only 11,000 people. At this plant the sludge treatment annual cost saving per capita would be $13.64. If G610 is excluded, the average annual cost saving for the other three ground water plants would be only $0.65 per capita.

In the case of both surface water and ground water plants, more respondents answered the questions on the annual treatment costs of sludge and entire plant operation. The cost ratio of sludge treatment to whole plant operation varied from 0.35 at S103 to 33.8% at S102 for the surface water plants and from 0.3% at G130 to 29.4% at G302 for ground water plants (Appendix 0).

Summary

To update information on waste disposal practices of water treatment plants in Illinois, 456 sludge questionnaires were sent to water utility managers, and 280 (61.4%) responded.

The obtained data are tabulated in appendices and summarized in tables. The data include basic information regarding water plants, raw water quality, unit treatment processes, chemical dosages, physical characteristics of basins and filters, sludge, and costs.

Fifty-four out of 88 (61.4%) of the reporting surface water facilities use clarification and filtration, and 32 (36.4%) plants use coagulation, sedimentation, lime softening, and filtration.

More than half (51.1%) of the ground water plants reporting use only chlorination. Approximately 40% and 21% of the ground water plants use iron removal and softening, respectively.

The majority of surface water plants use alum (91%) for coagulation and lime (93%) for softening or pH adjustment. The quantity of sludge generated and the sludge characteristics vary widely from plant to plant.

Flushing with fire hoses is the most common method used by surface water plants for removing sludge from basins (66%) and flocculators (52%). Manual and continuous (mechanical) removal are also popular for basin sludge removal. Blow-down is the second most popular means for removal of sludge from flocculators.

The most common methods used by ground water plants to remove basin sludge (flushing, continuous removal, and manual removal) are the same three methods most often used by surface water plants. Blow-down and continuous removal are commonly used for removal of sludge from flocculators at the ground water plants.

A majority of both surface water (70%) and ground water (90%) plants discharge wastes from basins, flocculators, and filter washings to lagoons or impounding basins and sanitary sewers for treatment. Approximately 30 and 10% of surface water and ground water plants, respectively, directly discharge the wastes into watercourses without treatment.

Gravity thickening is the most popular sludge pre-treatment method for both types of plants. Fewer than 20% of plants reported installing sludge dewatering units.

For both types of plants, the sludges are most commonly disposed of to landfills or used as a filling material (40 - 55%). The application of sludge to cropland rated as the second most popular method, used by approximately 38 and 25%, respectively, of the surface water and ground water plants. Forty percent of both types of plants use landfills on utility-owned lands. Approximately one-third of sludge landfills are put on private lands.

Approximately 58% of surface water plants and 28% of ground water plants have been ordered to stop direct discharge of sludge to a watercourse. The annual cost of sludge treatment for the surface water plants is estimated at $0.90 per capita, and that for ground water plants is $2.84 per capita (not reliable).

STUDY 2. ALUM SLUDGE FOR AGRICULTURAL USES

Background

Solid residues from water treatment plants have to be properly disposed of. They can be discharged to waterways, incinerated, or applied to land. Land application is the most widely used and the least costly method. The options of sludge land application are agricultural utilization, application to forest lands, application for reclamation of disturbed and marginal lands, disposal to dedicated land, and other applications such as at turf farms, park and recreation areas, highways, and airports, and for construction landscaping (USEPA, 1983).

Land application of sewage sludge and other solid wastes has been practiced in many countries for centuries. Not until recently has the land application of water plant solids waste gained much attention. However, complete and pertinent data on the land application of water plant sludge is lacking. For example, alum sludge use on agricultural land may have nutritional benefits. On the other hand, possible disadvantages are as follows: the sludge might be toxic to soil microorganisms which degrade organic compounds in the sludge; phytotoxicity of metals in sludge might reduce crop yields; heavy metals uptake and accumulation in plant tissue and in crops might make them unsafe for animal or human consumption; and the constituents in the sludge might pollute ground water, thereby posing a public health threat.

The purpose of this study was to assess the benefits and risks of alum sludge application on farmland soil used for growing corn and soybeans. It was intended to address some of the concerns listed above.

Material and Methods

Alum Sludge

Alum sludge was hand-shoveled from, a sludge lagoon at the Peoria water treatment facility (Illinois-American Water Co.) and dried on the driveway of the lagoons on March 27, 1986. The sludge was turned over several times for drying. On April 7, 1986, a truck load (about 20 tons) of dry alum sludge was transported to the test site. It was impossible to break apart the lumps of sludge by hand during application. Many of these small lumps were still visible at harvest.

Test Plots

The field study was conducted at the Northwestern Agricultural Research and Demonstration Center of the University of Illinois, Monmouth, Illinois. The types of soil at the Center are Tama silt loam, Muscatine silt loam, and Sable silty clay loam, which are typical of much of the agricultural lands in Illinois.

Each test plot was 4.6 m x 9.2 m (15 ft x 30 ft) with a 4.6-m border area around all the plots. Three replicate plots for a control and for each sludge application rate were used for each type of crop grown. Treatments were applied in a randomized block design for corn and in a completely randomized design for soybeans. The four application rates were zero (control), 0.56, 2.24, and 4.48 kg of dry sludge/m^2 of land, which is equivalent to 0, 2.5, 10.0, and 20.0 tons/acre (t/a) of sludge, respectively.

Field Operation

The schedule of field work is summarized in Table 6. The table gives information on tillage, fertilizer, and herbicide applications; weed control; sludge application; planting; and collection of soil samples. The major field work was carried out from April 1986 through October 1986.

Prior to sludge application 150 lb/a of P_2O_5 was applied to the soybean plots, including the border areas. Anhydrous ammonia was applied at a rate of 180 lb/a of nitrogen to the corn plots and border areas. Sludge was spread by hand (Figure 2) on April 22, 1986 and then incorporated with a disk to a depth of 4 inches. Each area was disked and harrowed again prior to planting.

Sieben-brand 35XS corn was planted at 26,600 kernels per acre on April 24, 1986. Counter 15G insecticide was applied with the planter to control rootworms. Sieben-brand 235 soybeans were planted in 30-inch rows on May 23, 1986 at a rate of approximately 165,000 seeds/acre. Ridomil (6.67 lb/a) and Amiben 10G (10 lb/a) were added with the planter.

A preemergence application of Bicep (3 qt/a) and Bladex 80W (0.6 lb/a) gave excellent weed control in the corn.' Amiben DS (2.6 lb/a) and Dual (3 pt/a) controlled most of the weeds in the soybean area. Field bindweed was controlled in the soybean plots with a spot application of Roundup. The corn was cultivated once in June 1986.

Sample Collections

Soil Samples

Soil samples were pulled out with a Hoffer soil sampling tube to a depth of 6 inches (15 cm). The sampler is 3/4 inch (19 cm) in diameter and 36 inches (91 cm) in length. Eight soil samples were pulled and composited for each test plot. The soil samples were refrigerated until they were analyzed. During the study, soil sample collections were made at each test plot on four different dates after applying the sludge and then every other month during the growing season (Table 6).

Leaf Tissues

On July 21, 1986 when pollination started, one corn leaf opposite and below the ear at tasseling was cut off for tissue analyses. Ten corn leaves were cut per test plot.

Table 6. Field Record

Corn Test Plots

4/3/86	Applied 180 lb/a of anhydrous ammonia
4/22/86	Applied sludge, disked (8' disk) to incorporate sludge to 4 inches in depth
4/24/86	Pulled soil samples, planted Sieben 35XS, Counter 15G, 8.7 lb/a (26,600 k/a), disked with harrow
4/29/86	Preemergent Bicep applied at 3 qt/a (Dual 1.875 lb/a, Atrazine 1.5 lb/a), and Bladex 80W at 0.6 lb/a (0.5 lb/a active ingredient) was applied
5/3-4/86	Plant emergence
6/3/86	Cultivation
6/13/86	Pulled soil samples
7/21/86	Leaf samples taken
8/13/86	Pulled soil samples
10/21/86	Pulled soil samples, harvested

Soybean Test Plots

11/7/85	Soil sampled (Research Center)
11/8/85	Applied 150 lb/a of P_9O_5
11/21/85	Chisel plowed
4/2/86	Disked
4/22/86	Applied sludge, disked with 8 ft disk to incorporate sludge to 4 inches in depth
5/6/86	Disked with harrow
5/21/86	Disked with harrow twice, pulled soil samples
5/23/86	Planted with Sieben 235 (165,000 kernals/a), applied Ridomil 6.67 lb/a and Amiben (granual) 10 lb/a in a 10 inch band
5/29/86	Applied Amiben DS 2.6 lb/a and Dual 3 pt/a
7/18/86	Pulled soil samples
7/21/86	Leaf samples taken
8/29/86	Pulled soil samples
10/21/86	Pulled soil samples, harvested

Figure 2. Hand spreading of alum sludge

For soybeans the uppermost fully expanded trifoliate was cut from the stem. Fifteen soybean leaves were collected per test plot. The leaf samples, as well as the whole plant tissues and grains, were ground at the Orr Research Center of the University of Illinois.

Harvest (Grains)

The corn ears in the two center corn rows were harvested by hand. The total weight of the harvested corn ears was determined with a tripod scale and then averaged for each treatment. Several ears from each row were shelled (Figure 3) to determine the shelling percentage (weight of grain/weight of corn ear), grain moisture, and test weight.

The two center soybean rows were harvested with a Hagie plot combine (Figure 4). The grain was then air-dried in a grain bin and ground with a Bur mill.

Whole Plant Tissues

Five corn plants were cut randomly at harvest for plant tissue analyses. This did not include roots and corn ears, in conformance with general practice. Soybean plant tissues were collected with a paper grocery shopping bag from the residue left at the rear-end of the plot combine during harvesting. Plant tissues were ground by a Willey mill.

Field Measurements

Field measurements were made on grain weight, plant populations for corn and soybeans, and soybean height.

Yields

The total weight of 6 to 8 corn ears before shelling and the total weight of the cobs were measured. The difference between these two measurements represents the weight of the kernels. The percentage of kernel weight compared to the total weight was then determined.

The total weight of corn ears harvested from the 2 center rows was also measured. Multiplying the percentage of kernels and total harvested weight gave the grain weight for the 2 rows harvested in each test plot. By knowing the dimensions of the area and assuming 60 pounds per bushel, the corn yield can be calculated from the kernel weight and the size of the area. The corn yield is expressed in bushels per acre (bu/a) at 15.5% moisture.

Similarly, soybean yields were determined after measuring the total weight of soybeans harvested and the growing area. Soybean yield is expressed in bushels per acre at 13% moisture content.

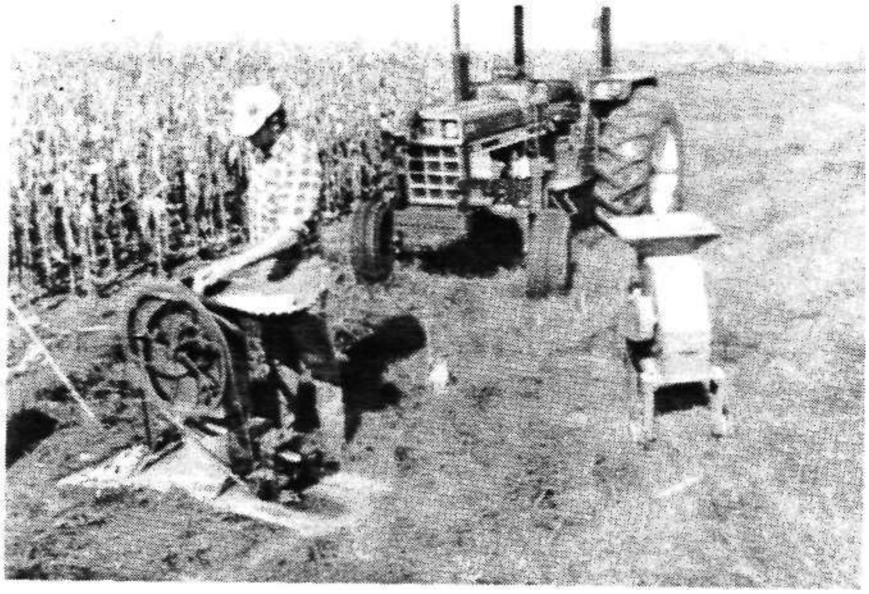

Figure 3. Shelling corn

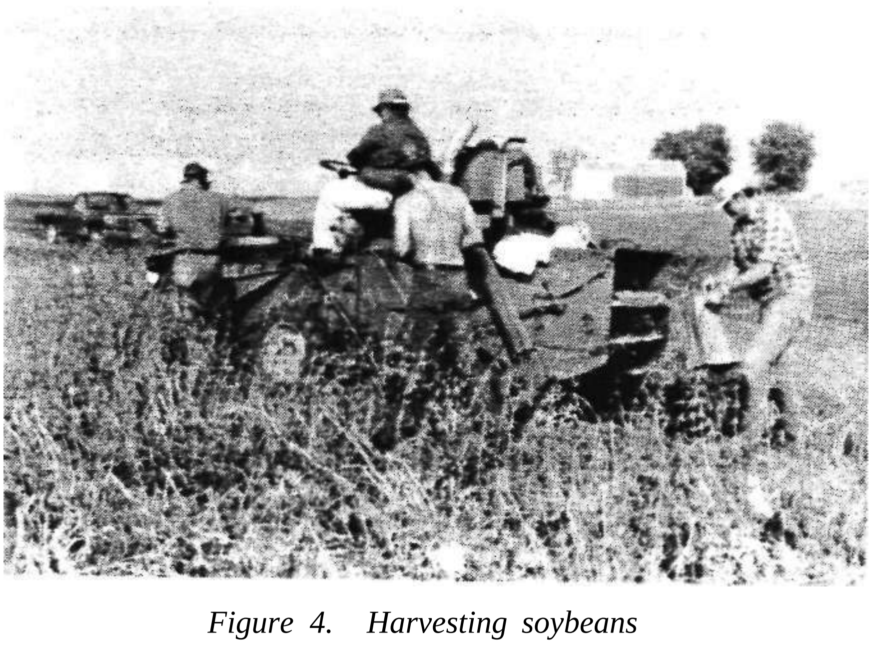

Figure 4. Harvesting soybeans

Plant Population

For both corn and soybeans the number of plants in two 5-foot-long sections were counted. On the basis of the area covered by these two 5-foot-long sections, the plant population was converted to the number of plants per acre.

Soybean Height

The soybean height was measured in inches from the surface of the ground to the top of the main stem after the leaves fell. The heights of ten soybean plants per test plot were determined, and the average value is reported.

Laboratory Analyses

The following physical and chemical determinations were made on the soil samples in the laboratory: total solids, organic matter, moisture content, specific gravity, pH, soil acidity, cation exchange capacity (CEC), ammonia-nitrogen (NH_3-N), nitrate-nitrogen.(NO_3-N), Kjeldahl-nitrogen, Bray P-1, total phosphorus, aluminum, boron, calcium, magnesium, manganese, iron, potassium, cadmium, chromium, copper, lead, zinc, and particle size distribution. For dry alum sludge, calcium carbonate equivalent (CCE) and citric acid soluble phosphorus were determined in addition to the above parameters, and soil acidity was not determined. The methods and procedures involved in these determinations are shown in Table 7.

Eleven metals analyses were carried out on both corn and soybean grains, leaves, and whole plants. Metal analyses included aluminum, cadmium, calcium, chromium, copper, iron, lead, magnesium, nickel, potassium, and zinc. The metal concentrations in soil samples as well as leaves, grains, and plants were analyzed by atomic absorption (AA) spectrophotometry. However, the extraction procedures were different.

For the metal analyses of soil samples, 0.5 g of dried soil was placed in 75 mL of deionized water. One mL of metals grade HC1 and 1 mL of metals grade $HN0_3$ were added. The soil sample was heated to about 70°C until the volume was reduced to 25 mL. The volume was brought up to 50 mL by rinsing the sides of the beaker. Then 1 mL of HNO_3 was added and heated to 70 C until the volume was reduced to 25 mL. The solution was filtered through a 0.45 µm membrane, diluted to 50.0 mL, and analyzed by AA spectrophotometry.

For the metal analysis of the leaves, grains, and plant samples, 5.0 g of tissue sample were placed in 50 mL of 50% HNO_3 solution. The sample was allowed to sit for 2 hours and then was heated to. 70 C until the NO_2 fumes were gone. Five mL of concentrated HNO_3 was added and heated again at 70°C until the NO_2 fumes were gone. The beaker was cooled and 5.0 mL of concentrated HC1 was added. The beaker was heated again to 70°C until the volume was reduced to 30 mL. The solution was then filtered with a 0.45 µm membrane and made up to a volume of 50 mL. The extractant solution was analyzed by AA spectrophotometry.

Table 7. Analytical Procedures

Parameter	Method
Total solids	% residue after evaporation @ 110° C for 24 hrs.
Moisture content	100% minus % of total solids
Organic matter	% loss after 550° ± 50°C for 1 hr
Bulk density	Methods of Soil Analysis (Black et al., 1973), Part 1, core method, p 375
pH	Measured on a slurry (10 g soil saturated with double distilled water) after stirring 4 times during a 30-min period
Soil acidity	Methods of Soil Analysis (1982), Part 2, Potassium Chloride Method, p 163
Calcium carbonate equivalent, CCE	Methods of Soil Analysis (1982), Part 2, Pressure-calcimeter method, p 188
Cation exchange capacity, CEC	Modified by using a centrifuge instead of filtration (Wang, 1975)
Ammonia-nitrogen, NH_3-N	Methods of Soil Analysis (1982), Part 2, distilled with HBO_3, p 653-654; and analyzed by the indophenol blue method, p 674
Nitrate nitrogen, NO_2-N	Dried soil is extracted with 0.02 N $CuSO_4$ solution containing Ag_2SO_4, (Jackson, 1958). The extract is analyzed by the chromotropic acid method of Standard Methods, 16th ed. 1985, 418 D
Total Kjeldahl nitrogen	Methods of Soil Analysis (1982), Part 2, digested by the regular Kjeldahl method, p 610; and analyzed by the indophenol blue method, p 674
Total nitrogen	Sum of NH_3-N, NO_3-N, and T.Kjeldahl-N; assuming NO_2-N is minimal
Citric acid soluble	Methods of Analysis of the Association of Official Analytical Chemists, W. Horwitz, Ed. 13th ed. 1980, p 13
Bray P-l	Methods of Soil Analysis (1982), Part 2, phosphorus soluble in dilute acid-fluoride, p 416
Total phosphorus	Weighed dried soil is digested with sulfuric/nitric acid mixture and then analyzed according to Standard Methods, 16th ed., digested by H_2SO_4 + HNO3 Sec 424 C - II, and analyzed by ascorbic acid method, Sec. 424 F
Boron, B	Methods of Soil Analysis (1982), Part 2, extracted by hot water, p 443, and analyzed by the azomethine-H method, p 435
Heavy metals Ca, K, & Mg	Extracted with HCL and HNO_3 and then analyzed by atomic absorption
Particle size	Sieve-pipet method, by H.P. Guy (1969), Particles greater than 0.062 mm in size are sand, 0.062 - 0.004 mm are silt, less than 0.004 mm are clay

Statistical Analyses

There are three general approaches to mean separation (determination of which treatment means are significantly different): the use of least significant differences (LSD), the use of Duncan's multiple-range tests, and the use of planned F tests (Little and Hills, 1978).

The LSD method is simplest and is the method most widely used by agronomists. For this study, the LSD was used for mean separation. The LSD is used only to compare adjacent means in an array unless the F test shows a significant difference. LSD is calculated as follows:

$$LSD = t\sqrt{\frac{S_1^2}{r_1} + \frac{S_2^2}{r_2}} \qquad (2)$$

where t = a tabulated value determined by the degrees of freedom of the variance and the level of significance desired

S_1^2, , S_2^2 = the estimated variance of plots receiving treatments 1 and 2

r_1, r_2 = the number of experimental units receiving treatments 1 and 2, respectively

Assuming $S_1^2 = S_2^2$ and $r_1 = r_2$,

$$LSD = t\sqrt{\frac{2\ S^2}{r}} \qquad (3)$$

All of the data (soils, grains, and tissues) obtained except for pH and cadmium were subjected to statistical analyses. Since treatments were applied in a randomized block design and completely randomized design for corn and soybeans, respectively, two-way analyses of variance and one-way analyses of variance were used for the corn and soybean data analyses, respectively. Only when the F test is significant is LSD calculated by Equation 2 with a confidence level of 90%.

Results and Discussion

Background Information

The characteristics of alum sludge and composited soil samples collected in both corn and soybean plots prior to sludge application are shown in Table 8. Sewage sludge characteristics for the Greater Peoria Sanitary District are also included for reference. Generally, most of the soil properties for both test plots are comparable except for higher nitrogen and total phosphorus concentrations in corn plots and higher manganese in soybean plots.

In comparing alum sludge and soil samples, as indicated in Table 8, there were higher concentrations of organic matter, percent moisture, pH, CEC, all forms of nitrogen, total phosphorus, potassium, boron, aluminum, iron, calcium, magnesium, manganese, and other heavy metals in the sludge.

Table 8. Characteristics of Alum Sludge and Test Plot Soils Prior to Sludge Application, April 22, 1986

Parameters	Alum sludge	Corn plot	Soybean plot	GPSD* sewage sludge
Total solids, %	70.3	79.5	80.1	63.6
Organic matter, %	14.4	5.3	7.0	10.5 (VS)$^+$
Moisture content, %	29.7	20.5	19.9	
Bulk density, g/cc ‡	1.97	2.01	2.06	
PH	8.08	5.37	5.39	7.8
Soil acidity, meq/100 g		0.22	0.11	
CCE, %	12.5	0	0	
CEC, meq/100 g	17.8	13.9	14.0	
NH_4-N, mg/kg	297	229	157	500
NO_3-N, mg/kg	15.1	8.9	4.5	200
T. Kjeldahl-N, mg/kg	4423	2262	1642	6800
Total N, mg/kg	4735	2500	1804	7000
Citric acid soluble-P, mg/kg	3543.8			
Bray P-l, mg/kg	3.6	21	20	
Total P, mg/kg	3544	698	584	27,900 (P_2O_5)
Potassium (K), %	0.104	0.058	0.070	0.37 (K_2O)
Aluminum (Al), total, %	2.78	0.99	1.12	2.35
Boron, mg/kg	0.7	0.5	0.3	
Cadmium (Cd), mg/kg	1.9	<1.0	<1.0	11
Calcium (Ca), %	4.936	0.313	0.283	
Chromium (Cr), mg/kg	53	15	17	220
Copper (Cu), mg/kg	35	10	13	469
Iron (Fe), total, %	2.08	1.55	1.18	0.24
Lead (Pb), mg/kg	62	16	11	129
Magnesium (Mg), %	0.759	0.170	0.245	
Manganese (Mn), mg/kg	830	520	680	518
Nickel (Ni), mg/kg	60	26	35	62
Zinc (Zn), mg/kg	160	38	43	310
Particle size distribution, %				
Sand	60.4	2.3	1.3	
Silt	23.0	76.9	68.1	
Clay	16.6	20.8	30.6	

* GPSD = Greater Peoria Sanitary District (Data from Garcia et al. 1981)

$^+$ VS = volatile solids, %

‡ = Samples were inadvertently compacted

Only Bray P-l available phosphorus and percent total solids in soils were found to be greater than those in alum sludge. In other words, the fertility values of alum sludge, based on the major and micronutrients, are better than those of the soils at Monmouth except for the values for Bray P-l plant-available soil phosphorus.

The calcium carbonate equivalent (CCE) test is often used to evaluate the effect of the impurities of agricultural lime. The CCE test involves titrating a sample with an acid until a neutral pH is obtained. An equivalent amount of pure calcium carbonate is then titrated with the acid. Any reduction in acid required for neutralization of the sample is assumed to be a result of the impurities.

The alum sludge from Peoria, which was applied to the test plots, had a CCE value of 12.5% (Table 8). CCE levels for lime-softening sludge from the Champaign-Urbana water treatment plant were reported to be between 92 and 95% (Russell, 1980). Typically CCE values for agricultural limestone in east-central Illinois range from 87 to 91%. These values are well above 80%, which is generally considered a minimum acceptable value.

The 1986 daily precipitation data listed in Appendix P were provided by the Northwest Agricultural Research Center of the University of Illinois. No soil moisture shortage occurred during the crop growing period.

Monthly 1986 weather data are shown in Appendix Q for the ranges in air temperature, relative humidity, soil temperature, and precipitation. These data were also obtained from the Research Center.

Effects on Soil Properties

Results of physical and chemical analyses of soils in the test plots are listed in Appendices Rl through R29. The effects of alum sludge application on 29 parameters measured in soils, based on the averages of three replicates, are shown in Tables 9a through 9f.

The percentage of total solids (TS) in soils (Table 9a), tested four times each for corn and soybean plots, showed no significant differences among the four treatments with alum sludge. The average TS ranged from 76.0 to 81.0% and from 79.4 to 82.2% for corn and soybean plots, respectively.

As shown in Table 9a, alum sludge application did not affect the percent organic matter in corn plots. For soybean plots, on May 21, 1986, the percent organic matter in the control plots was significantly higher than that of the 10 and 20 t/a application plots. Also on July 18, 1986, organic matter was significantly different between the 2.5 and 10 t/a plots and between the 2.5 and 20 t/a plots, but no significant difference was observed between the control and any sludge application rate. There was no significant effect observed in August 29 and October 21, 1986 samples as a result of sludge applications. One can conclude that sludge application has no effect on the organic content of soybean plots.

As indicated in Table 9a, alum sludge application has no effect on the percent moisture in soils growing either corn or soybeans. For a potting

Table 9a. Effect of Sludge Applications on Total Solids, Organic Matter, Moisture, Bulk Density, and pH in Soils

Rate,	Corn plots				Soybean plots			
t/a	4/24	6/13	8/13	10/21	5/21	7/18	8/29	10/21
TOTAL SOLIDS, %								
0	81.0	79.9	77.9	77.0	79.4	81.5	80.0	79.5
2.5	80.5	79.9	77.9	76.9	79.9	81.0	79.9	79.1
10	80.6	80.4	77.9	77.0	80.1	81.8	81.7	80.7
20	79.7	79.3	77.0	76.0	80.1	82.2	81.2	80.8
LSD 10%	NS	NS	NS	NS	NS	NS	NS	NS
ORGANIC MATTER, %								
0	6.4	6.2	6.3	6.7	5.8	5.2	5.2	5.4
2.5	6.8	6.6	6.9	6.8	5.3	6.3	5.8	5.8
10	6.6	6.5	6.8	6.6	3.7	4.2	4.2	4.3
20	6.9	8.0	7.1	7.1	4.0	3.7	4.2	4.4
LSD 10%	NS	NS	NS	NS	1.0	1.6	NS	NS
MOISTURE CONTENT, %								
0	19.0	20.1	22.1	23.0	20.6	18.5	20.0	20.5
2.5	19.5	20.1	22.1	23.1	20.1	19.0	20.1	20.9
10	19.4	19.6	22.1	23.0	19.9	18.2	18.3	19.3
20	20.3	20.7	23.0	24.0	19.9	17.8	18.8	19.2
LSD 10%	NS	NS	NS	NS	NS	NS	NS	NS
BULK DENSITY,* g/cc								
0	2.06	1.52	1.34	1.22	1.81	1.50	1.43	1.37
2.5	2.03	1.64	1.23	1.25	1.89	1.38	1.42	1.41
10	2.06	1.67	1.30	1.32	1.92	1.75	1.49	1.48
20	2.05	1.69	1.26	1.16	1.95	1.69	1.44	1.44
LSD 10%	NS	NS	NS	0.08	NS	0.24	NS	NS
pH (median)								
0	5.07	5.21	5.17	5.20	5.30	5.35	5.26	5.52
2.5	5.31	5.26	5.11	5.22	5.64	5.67	5.75	5.85
10	5.37	5.03	5.63	5.37	5.82	5.81	6.25	6.15
20	5.52	5.23	5.54	5.73	6.10	5.99	6.63	6.36

*Samples collected in April and May were inadvertently compacted

Note: NS = no significant difference
LSD = least significant difference

Table 9b. Effect of Sludge Applications on Acidity and Ammonia-, Nitrate-, Kjeldahl-, and Total Nitrogen in Soils

Rate,	Corn plots				Soybean plots			
t/a	4/24	6/13	8/13	10/21	5/21	7/18	8/29	10/21
ACIDITY, meq/100 g								
0	0.26	0.33	0.35	0.39	0.33	0.29	0.36	0.36
2.5	0.27	0.28	0.27	0.33	0.13	0.17	0.15	0.10
10	0.25	0.26	0.28	0.21	0.17	0.14	0.14	0.11
20	0.19	0.30	0.18	0.16	0.17	0.13	0.14	0.10
LSD 10%	NS	NS	NS	NS	NS	NS	NS	NS
AMMONIA NITROGEN, mg/kg								
0	188	164	172	152	107	113	105	115
2.5	261	160	190	162	122	168	122	141
10	274	171	190	160	65	91	72	81
20	201	183	197	184	72	68	72	72
LSD 10%	NS	NS	NS	NS	NS	NS	37	NS
NITRATE NITROGEN, mg/kg								
0	23.6	19.5	16.8	4.9	3.0	3.0	2.3	3.2
2.5	38.0	16.9	10.7	5.1	2.4	3.5	3.0	3.7
10	43.2	20.8	8.3	6.5	2.0	2.0	2.7	3.7
20	30.7	20.2	8.6	4.7	1.9	2.6	2.7	3.5
LSD 10%	NS	NS	8.2	1.2	NS	NS	NS	NS
TOTAL KJELDAHL NITROGEN, mg/kg								
0	2243	2233	2262	2136	1239	1533	1222	1455
2.5	2441	2153	2339	2174	1488	1931	1548	1639
10	2366	2226	2208	2200	1027	963	900	973
20	2338	2398	2373	2325	1048	1089	1004	1056
LSD 10%	NS	NS	NS	NS	NS	NS	NS	NS
TOTAL NITROGEN, mg/kg								
0	2455	2416	2451	2293	1348	1649	1329	1573
2.5	2641	2330	2539	2342	1612	2102	1957	1784
10	2683	2418	2406	2366	1093	1056	975	1048
20	2567	2601	2578	2514	1122	1160	1079	1132
LSD 10%	NS	NS	NS	NS	NS	NS	639	NS

Note: NS = no significant difference
LSD = least significant difference

Table 9c. Effect of Sludge Applications on Cation Exchange Capacity, Bray P-l, Total Phosphorus, Potassium, and Total Aluminum in Soils

Rate,	Corn plots				Soybean plots			
t/a	4/24	6/13	8/13	10/21	5/21	7/18	8/29	10/21
CATION EXCHANGE CAPACITY, meq/100 g								
0	14.4	20.2	18.7	18.4	15.2	18.9	18.6	17.3
2.5	14.4	20.1	20.4	17.7	15.5	20.0	18.5	17.7
10	13.3	19.8	16.6	17.1	14.1	17.7	17.8	16.0
20	13.3	21.6	19.7	19.1	15.1	18.2	17.6	17.0
LSD 10%	NS	NS	2.1	NS	NS	NS	NS	NS
BRAY P-l, mg/kg								
0	10	13	13	13	16	26	23	19
2.5	12	11	14	14	18	34	20	25
10	15	17	17	16	18	25	22	22
20	13	19	18	20	33	18	25	27
LSD 10%	NS	4	NS	3	NS	NS	NS	NS
TOTAL PHOSPHORUS, mg/kg								
0	566	661	635	641	547	608	507	523
2.5	497	593	593	524	656	640	593	599
10	495	616	563	569	544	578	527	452
20	643	805	703	706	508	506	472	416
LSD 10%	NS	103	NS	NS	NS	NS	NS	105
POTASSIUM, mg/kg								
0	760	730	530	650	730	750	720	740
2.5	800	770	520	640	980	690	620	830
10	780	800	520	650	760	700	680	610
20	820	690	560	650	820	700	630	730
LSD 10%	NS	NS	NS	NS	110	NS	NS	NS
ALUMINUM (Total), %								
0	0.93	1.02	1.06	0.97	0.98	1.03	1.10	1.11
2.5	1.04	1.06	0.97	1.05	1.00	1.05	1.07	1.09
10	1.00	1.01	1.01	1.04	0.88	1.03	1.04	1.02
20	0.97	1.08	1.08	1.05	1.02	1.01	1.01	1.09
LSD 10%	0.07	NS	0.06	0.04	NS	NS	NS	NS

Note: NS = no significant difference
LSD = least significant difference

Table 9d. Effect of Sludge Applications on Boron, Cadmium, Calcium, Chromium, and Copper in Soils

Rate, t/a	Corn plots 4/24	6/13	8/13	10/21	Soybean plots 5/21	7/18	8/29	10/21
BORON, mg/kg								
0	0.3	0.4 -	0.4	0.4	0.4	0.4	0.3	0.3
2.5	0.3	0.5	0.4	0.5	0.3	0.4	0.3	0.2
10	0.3	0.5	0.4	0.4	0.3	0.3	0.3	0.2
20	0.3	0.4	0.4	0.4	0.3	0.2	0.2	0.1
LSD 10%	NS	NS	NS	NS	NS	NS	NS	NS
CADMIUM, mg/kg								
0	1.0	<1.0	1.0	1.0	1.0	1.0	2.0	1.0
2.5	<1.0	<1.0	1.0	1.0	1.0	1.0	2.0	<1.0
10	1.0	<1.0	1.0	1.0	<1.0	1.0	2.0	<1.0
20	<1.0	<1.0	1.0	1.0	3.0	1.0	2.0	<1.0
CALCIUM, %								
0	0.362	0.476	0.288	0.315	0.227	0.223	0.274	0.259
2.5	0.287	0.306	1.044	0.272	0.475	0.310	0.381	0.422
10	0.270	0.270	0.292	0.265	1.170	0.764	0.248	0.895
20	0.377	0.340	0.334	0.352	0.360	0.432	0.368	0.384
LSD 10%	NS	NS	NS	NS	NS	NS	NS	NS
CHROMIUM, mg/kg								
0	15	17	17	15	17	17	18	17
2.5	17	17	17	16	18	17	17	15
10	17	16	15	16	18	19	18	16
20	16	17	16	14	17	18	18	17
LSD 10%	NS	NS	NS	NS	NS	NS	NS	NS
COPPER, mg/kg								
0	12	13	23	12	14	16	15	14
2.5	14	12	16	13	14	14	14	13
10	13	11	14	12	14	17	14	14
20	11	12	15	11	16	15	14	14
LSD 10%	NS	NS	NS	NS	NS	NS	NS	NS

Note: NS = no significant difference
LSD = least significant difference

Table 9e. Effect of Sludge Applications on Total Iron, Lead, Magnesium, Manganese, and Nickel in Soils

Rate,	Corn plots				Soybean plots			
t/a	4/24	6/13	8/13	10/21	5/21	7/18	8/29	10/21
IRON (Total), %-								
0	1.08	1.23	1.73	1.18	1.36	1.45	1.79	1.65
2.5	1.18	1.18	1.50	1.29	1.40	1.30	1.64	1.42
10	1.16	1.17	1.46	1.28	1.36	1.58	1.70	1.66
20	1.03	1.17	1.47	1.09	1.44	1.58	1.54	1.80
LSD 10%	NS	NS	0.13	NS	NS	NS	NS	NS
LEAD, mg/kg								
0	17	14	12	20	16	16	20	16
2.5	17	18	13	19	17	19	17	17
10	19	16	15	17	17	18	19	16
20	17	17	16	19	15	13	19	15
LSD 10%	NS	NS	NS	NS	NS	2	NS	NS
MAGNESIUM, mg/kg								
0	2220	2980	1880	1940	2230	2170	2240	2320
2.5	1757	1750	9140	1660	3320	2320	2840	2670
10	1740	1650	1630	1650	10280	6370	2190	5810
20	1820	1820	1740	1730	3050	3830	2920	2890
LSD 10%	NS	NS	NS	NS	NS	NS	NS	NS
MANGANESE, mg/kg								
0	600	600	690	550	600	610	640	640
2.5	590	570	580	580	650	630	620	610
10	570	530	570	600	580	620	600	600
20	480	540	490	530	640	610	620	640
LSD 10%	NS	NS	121	NS	NS	NS	NS	NS
NICKEL, mg/kg								
0	22	24	29	27	30	29	33	33
2.5	24	21	26	27	30	26	30	30
10	22	21	24	26	31	32	32	31
20	22	23	25	25	33	30	31	31
LSD 10%	NS	NS	NS	NS	NS	NS	NS	NS

Note: NS = no significant difference
LSD = least significant difference

Table 9f. Effect of Sludge Applications on Zinc and Particle Size Distribution in Soils

Rate, t/a	Corn plots 4/24	6/13	8/13	10/21	Soybean plots 5/21	7/18	8/29	10/21
ZINC, mg/kg								
0	38	39	43	40	39	41	40	43
2.5	37	36	39	40	42	37	37	39
10	40	37	39	40	39	43	41	42
20	37	38	39	39	45	40	39	43
LSD 10% 0	NS	NS	2	NS	NS	NS	NS	NS
SAND, %								
0	3.7	2.7	1.3	2.0	1.6	2.2	1.1	0.8
2.5	4.2	2.4	1.7	2.5	1.9	2.1	1.8	1.4
10	2.3	2.5	1.9	2.5	1.6	1.6	2.0	1.5
20	3.9	3.5	2.1	2.8	1.5	1.5	1.6	1.9
LSD 10%	NS	NS	NS	NS	NS	NS	NS	NS
SILT %								
0	67.7	70.7	68.0	66.1	64.8	68.3	65.5	65.2
2.5	68.6	68.2	67.4	62.7	66.9	70.2	68.2	66.5
10	69.8	70.5	68.0	65.6	67.5	70.1	66.6	72.8
20	69.3	70.3	67.0	64.7	67.3	66.3	67.6	64.6
LSD 10%	NS	NS	NS	NS	NS	NS	NS	NS
CLAY, %								
0	28.6	26.5	30.8	31.9	33.6	29.6	33.4	33.9
2.5	27.2	29.3	30.9	34.8	31.2	27.7	30.3	32.1
10	27.9	27.0	30.1	31.9	30.9	28.3	31.4	25.7
20	26.8	26.2	31.0	32.5	31.2	32.2	30.8	33.5
LSD 10%	NS	NS	NS	1.8	NS	NS	NS	NS

Note: NS = no significant difference
LSD = least significant difference

soil study, Bugbee and Frink (1985) reported that the media aeration and moisture-holding capacity were significantly improved by alum sludge addition.

No effect on bulk density was shown as a result of alum sludge application on the six sampling dates (Table 9a). On October 21, 1986, in the corn plots, bulk density at the 10 t/a rate was significantly higher than that of the corn control plot. In the soybean plots, on July 18, 1986, bulk density in the 10 t/a plot was significantly greater than that at the control plot at a 10% confidence level. Bugbee and Frink (1985) reported that bulk density was not different among different treatments.

Since the average value of the pH is meaningless, the pH values obtained were not statistically evaluated. The medians are presented in Table 9a. In general, pH values increased with higher sludge application rates because of the higher sludge pH. This is a beneficial effect of sludge application.

Table 9b suggests that alum sludge treatment has no effect on acidity or total Kjeldahl nitrogen for either corn or soybean plots. For both ammonia nitrogen and total nitrogen in soybean plots, significant differences occurred only on August 29, 1986 among the three application rates, with no difference between treatment and control plots. On August 13, 1986, nitrate nitrogen at both the 10 and 20 t/a corn plots was significantly less than that at the control plot. In contrast, on October 21, 1986 the nitrate nitrogen at the 10 t/a corn plot was significantly greater than that at the control plot. One can still conclude that each form of nitrogen was not changed by alum sludge application for either crop.

As shown in Table 9c, cation exchange capacity (CEC), Bray P-l, and aluminum were not affected by sludge application on the soybean plots. On August 13, 1986, the average CEC at the 10 t/a corn plots was found to be significantly lower than that at the control plot. The Bray P-l levels at the 10 and 20 t/a corn plots on both June 13 and October 21 were significantly greater than those at the control plots. In fact, there were increases in plant-available Bray P-l with sludge applications for both crops. In contrast, in their potting soil amendment study, Bugbee and Frink (1985) claimed that "phosphorus deficiencies caused by the addition of dried alum sludge cannot likely be overcome by doubling the initial phosphorus fertilization." Grabarek and Krug (1987) reported that alum sludge bound phosphorus, making it unavailable or slowly available to maple and hemlock plants.

For the June 13, 1986 soil tests the average total phosphorus at the 20 t/a corn plots was significantly higher than that at the control plots (Table 9c), while on October 21, total phosphorus at the 20 t/a soybean plots was significantly less than that at the control plots. Table 9c indicates that the average potassium levels were not affected by sludge applications for either crop, except for a minor difference between the 2.5 t/a soybean plots and the control plots on May 21, 1986.

Inspection of Table 9c shows that differences in aluminum levels in the corn test plots were inconsistent. On April 24, 1986 the average soil aluminum concentration at each of the 2.5 and 10 t/a corn plots was significantly greater than at the control plots. There was no difference on June 13. Aluminum at the 2.5 t/a rate was less than that at the control plots for the August 13 tests. However, average aluminum content was significantly higher on the October 21 sampling date in all plots to which sludge had been added.

Boron, calcium, chromium, and copper levels in soils were not affected by alum sludge applications for either corn or soybeans (Table 9d). Statistical analyses on cadmium in soils were not performed because the cadmium contents in many soil samples were below detectable levels. The average cadmium concentrations for each sampling date are presented in Table 9d.

As shown in Table 9e, on August 13 the average total iron levels in the corn test plots showed a trend toward decreases at each higher sludge application rate compared with the level in the control plots. However, iron levels in soybean plots showed no significant difference with the sludge additions.

Lead levels in the corn plots were not affected by sludge application (Table 9e). However, for the July 18 soil test, lead levels significantly increased at the 2.5 and 10 t/a soybean plots and decreased at the 20 t/a soybean plots.

Table 9e also suggests that alum sludge applications had no effect on magnesium and nickel levels in any of the test plots. Manganese in the soybean plots was also not affected by the addition of alum sludge. However, on August 13 the average manganese concentration in the 20 t/a corn plots was significantly less than that in the control plots.

As indicated in Table 9f, the average zinc concentrations in both test soils generally showed no significant change with the application of sludge except for one occasion. For the August 13 soil tests the zinc levels in the sludge-treated corn plots were significantly less than those in the control plots.

It can be seen from Table 9f that particle size distribution in soils showed no significant difference with the application of sludge, with one exception. There was a shift of percent silt and clay at the 2.5 t/a corn test plots on October 21, 1986.

In the case of both corn and soybeans, soil test levels were usually not affected by the alum sludge applications. There were several differences between the treated and the control plots between sampling dates, which were due to the inherent differences in the soil characteristics of the test plots. It is impossible to have perfect uniformity among areas when working with soils. In a few instances the soil test results were changed drastically when a lump of sludge ended up in the sample. However, these instances were very rare and were most noticeable for the calcium and magnesium levels (Tables 9d and 9e).

Corn Yield and Plant Parameters

The data on corn yield and measured corn plant parameters are given in Appendix S. The results of the statistical analyses of these data are summarized in Table 10. As seen in Table 10, corn yields were found to be significantly lower in the 2.5 and 10 t/a plots than in the 0 and 20 t/a plots. The corn plant populations in the 2.5 and 10 t/a plots were smaller than those in the 0 and 20 t/a plots, but only the population at 10 t/a was significantly different from that at the 0 and 20 t/a rates. The reason for the plant population difference was unclear; it was possibly due to the inherent soil characteristics. The plant population in the plots with the highest application rate was not affected by the sludge. Small differences in plant populations can cause significant yield differences in plots.

A field study by Naylor et al. (1987) also showed that yields of corn grown on sludge-treated soil were not affected by application rates up to 20 t/a. Garcia et al. (1974) grew corn on strip-mined soil amended with anaerobically digested liquid sewage sludge at a rate of 25 t/a. They observed that growing corn of good quality on strip-mined soil is almost impossible. In contrast, other corn grown in soil to which sewage sludge had been added was well developed and the corn yield was four times as great as that of untreated corn.

Table 10 also suggests that corn test weights at the 2.5 and 10 t/a application rates were not significantly different from those at the control rate (0 t/a), but test weights for the 20 t/a plots were significantly higher than for the control plots. Corn grain moisture was not significantly affected by the alum sludge application (Table 10).

Soybean Yield and Plant Parameters

The raw data on soybean yields and soybean plant parameters are listed in Appendix S. The statistical analyses are summarized in Table 11. As shown in Table 11, soybean yields, soybean grain moisture, soybean plant height, and soybean plant populations were not significantly affected by the alum sludge application. There were some numerical differences between the treatments, but it is believed that they were not caused by the sludge applications.

Corn Grain Analysis

The data from 16 grain analyses for corn and soybeans are listed in Appendix T. The statistical analyses for grain are summarized in Table 12. Inspection of Table 12 shows that corn grain moistures in the 2.5 and 20 t/a plots were significantly higher than those in the 0 and 10 t/a plots. There were no significant differences in percent moisture between 0 and 10 t/a. Aluminum and cadmium levels in corn grain were not evaluated because some measurements were below the detectable limits.

The other 13 chemical parameters measured for corn grain showed no effects due to the alum sludge application (Table 12). However, Garcia et al. (1974) reported a significant protein enhancement of 2.5% in the grain of corn grown in soil to which sewage sludge had been added.

Table 10. Effect of Alum Sludge Applications on Corn Yields and Plant Parameters

Application rate, t/a	Corn yield, bu/a	Grain moisture, %	Test weight, lb/bu	Population, plants/a
0	221.01	15.9	54.1	25070
2.5	210.11	16.7	54.5	24390
10	203.65	16.7	55.0	23430
20	222.07	16.4	55.8	25070
LSD 10%	7.21	NS*	1.0	1490

Note: NS = no significant difference
LSD = least significant difference

Table 11. Effect of Alum Sludge Applications on Soybean Yields and Plant Parameters

Application rate, t/a	Soybean yield, bu/a	Grain moisture, %	Plant height, inches	Population, plants/a
0	40.27	13.1	36.0	136490
2.5	43.06	13.3	37.1	133000
10	40.69	13.2	36.3	128940
20	40.10	13.4	35.3	122550
LSD 10%	NS	NS	NS	NS

Note: NS = no significant difference
LSD = least significant difference

Table 12. Effect of Sludge Applications on Chemical and Physical Characteristics of Corn and Soybean Grains

Sludge rate, t/a	N	P	K	Ca	Mg	Mn	Zn	Fe	Cu	Al	Cd	Cr	Pb	Ni	Crude protein, %	Mois-ture, %
	%					mg/kg										
CORN GRAIN																
0	1.46	0.12	0.23	0.010	0.071	6.7	21	13	1.0	<10	0.10	0.27	0.33	0.17	9.12	10.95
2.5	1.45	0.11	0.23	0.011	0.074	7.3	22	13	1.3	<10	0.13	0.27	0.27	0.27	9.07	12.22
10	1.48	0.12	0.20	0.007	0.071	7.3	17	13	1.0	<10	>.l	0.20	0.33	0.13	9.23	11.05
20	1.43	0.11	0.22	0.009	0.073	7.7	15	14	1.3	<10	>.l	1.17	0.43	0.27	8.93	12.07
LSD 10%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.79
SOYBEAN GRAIN																
0	6.31	0.64	1.42	0.206	0.173	22	64	60	13	<10	0.23	0.27	1.4	8.3	39.28	8.62
2.5	6.29	0.65	1.43	0.202	0.181	22	64	62	12	<10	0.20	0.30	1.5	5.5	39.31	8.51
10	6.07	0.64	1.43	0.198	0.179	23	56	56	13	<10	0.23	0.30	1.4	6.1	37.94	7.88
20	6.20	0.63	1.41	0.201	0.183	23	51	57	12	<10	0.20	0.27	1.4	5.6	38.75	8.25
LSD 10%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Note: LSD = least significant difference
NS = no significant difference

Soybean Grain Analysis

Table 12 indicates that 15 chemical parameters examined for soybean grain were unresponsive to the alum sludge applications. Aluminum was not statistically evaluated. The data show that there were no heavy metals accumulations in the corn or soybeans from the sludge application (Table 12). In fact, nickel levels in soybean grain from the treated plots were lower than the levels in grain from the control plots.

Corn Plant Tissue

Fourteen chemical analyses were performed on the whole plant (root not included) and leaf tissue samples for each crop. The results are listed in Appendices U and V. The, statistical analyses of these data are summarized in Table 13.

As shown in Table 13, none of the 14 parameters examined for corn whole plant tissue was affected by the addition of alum sludge. Almost every heavy metal level was generally reduced instead of increased. In another field study, Kelling et al. (1977) found that sewage sludge application to soil generally increased concentrations of Cu, Zn, Cd, and Ni in the vegetative corn tissue, but, except for Zn, the incremental additions of sewage sludge had relatively little effect on the metal content of the corn grain. A field study by Garcia et al. (1974) showed that concentrations of seven heavy metals (Zn, Mn, Ca, Pb, Cr, Cd, and Hg) increased in corn grain, cobs, and husks in that order.

Soybean Plant Tissue

As with the corn plant tissue analyses, the soybean tissue analyses generally showed no effects from the addition of alum sludge except for one difference which occurred for calcium (Table 13). Average calcium concentrations in soybean plant tissues at the 20 t/a rate were significantly lower than those for the 0, 2.5, and 10 t/a plots. Inspection of Table 13 shows that heavy metals did not accumulate in the soybean plant tissues after the addition of alum sludge.

Leaf Tissue

As shown in Table 13, the 13 parameters determined for corn leaf tissues showed no differences with or without alum sludge addition. However, average cadmium in the corn leaves at 20 t/a was significantly higher than in the 0, 2.5, and 10 t/a plots.

Only eleven chemical analyses were performed for soybean leaf tissues. Ten of these parameters showed no effect from the alum sludge applications (Table 13). However, the average chromium concentration in the soybean leaves in the 20 t/a plots was significantly less than those in the 0, 2.5, and 10 t/a plots. Zinc and iron levels in the alum-sludge-treated plots

Table 13. Effect of Sludge Applications on Chemical Characteristics of Whole Plants and Leaves

Sludge rate,	N	P	K	Ca	Mg	Mn	Zn	Fe	Cu	Al	Cd	Cr	Pb	Ni
t/a	%					mg/kg								
WHOLE PLANT - Corn														
0	0.79	0.07	0.683	0.372	0.224	82	73	673	5.0	164	0.23	1.1	7.4	1.2
2.5	0.75	0.06	0.657	0.376	0.226	79	59	590	4.7	189	0.23	1.0	3.9	1.1
10	0.76	0.06	0.537	0.385	0.226	78	49	550	5.0	158	0.23	0.9	3.8	1.0
20	0.73	0.06	0.530	0.359	0.214	62	54	587	5.3	138	0.27	0.9	3.6	1.0
LSD 10%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
WHOLE PUNT - Soybeans														
0	1.25	0.13	0.35	0.951	0.315	50	27	443	7.3	184	0.40	0.77	2.1	1.8
2.5	1.26	0.11	0.36	0.942	0.301	41	23	397	6.0	179	0.37	0.77	2.1	1.9
10	1.24	0.13	0.38	0.903	0.302	47	18	430	6.7	242	0.33	0.83	2.0	2.2
20	1.25	0.12	0.37	0.825	0.268	38	35	423	6.7	189	0.33	0.93	2.0	1.5
LSD 10%	NS	NS	NS	0.050	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LEAVES - Corn														
0	2.75	0.35	1.70	0.630	0.328	117	43	223	11	31	0.33	0.53	1.6	1.1
2.5	2.50	0.33	1.63	0.623	0.296	116	61	207	11	32	0.33	0.53	1.8	1.1
10	2.66	0.35	1.79	0.682	0.309	127	42	263	12	35	0.30	0.50	2.0	1.0
20	2.67	0.33	1.76	0.624	0.309	102	36	223	11	29	0.40	0.53	2.0	1.1
LSD 10%	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LEAVES - Soybeans														
0			2.31	0.905	0.370		68	190	10	23	0.47	0.77	2.3	9.6
2.5			2.39	0.917	0.331		28	273	10	17	0.43	0.77	2.5	6.6
10			2.31	0.879	0.332		36	223	11	20	0.47	0.77	2.3	8.8
20			2.17	0.789	0.315		29	250	10	18	0.40	0.57	2.8	7.4
LSD 10%			NS	NS	NS		NS	NS	NS	NS	NS	0.14	NS	NS

Note: LSD = least significant difference; NS = no significant difference decreased and increased respectively from the levels in the control plots, although the differences were not statistically significant.

The suggested critical nutrient levels for Illinois are presented in Table 14 (University of Illinois, 1987). Lower concentrations may indicate a nutrient deficiency. A comparison of Tables 13 and 14 shows that nitrogen and potassium levels in the corn plots were lower than the recommended critical nutrient levels. However, this was not caused by alum sludge application. There were no nutrient deficiencies observed in the soybean leaf tissues.

Table 14. Suggested Critical Plant Nutrient Levels

Crop	N	P	K	Ca	Mg	S	Zn	Fe	Mn	Cu	B
	%						mg/kg				
Corn*	2.9	0.25	1.90	0.40	0.15	0.15	15	25	15	5	10
Soybeans+		0.25	2.00	0.40	0.25	0.15	15	30	20	5	25

[*] Leaf, opposite and below the ear at tassling

[+] Fully developed leaf and petiole at early podding

A comparison of heavy metals in corn grain, whole plants, and leaves (Tables 12 and 13) shows that the highest metal levels occurred in the corn plant and leaves and the lowest in the grain. Similarly, Garcia et al. (1979) studied heavy metal (Zn, Mn, Cu, Pb, Cr, Cd, and Hg) translocation for corn plants grown on strip-mined soil amended with anaerobically digested sewage sludge. Their analysis of differential metal accumulation rates in seven tissues showed that generally the highest metal levels were observed in the corn leaves and roots and the lowest in the grain and cob.

Summary

To evaluate the use of air-dried alum sludge for growing corn and soybeans, determinations were made of soil nutrients and physical characteristics, corn and soybean yields and plant parameters, and the uptake and accumulation of heavy metals and other nutrients in plant tissues and grains.

Alum sludge was applied by hand at rates of 0, 2.5, 10, and 20 t/a to 15-foot by 30-foot test plots. Treatments were applied in a completely randomized design and a randomized block design for the soybeans and corn, respectively. Each treatment was replicated three times.

The major plant nutrients and micronutrients in alum sludge from Peoria's water treatment plant were generally greater than those in the test plot soil and lower than those in sewage sludge from Peoria.

The effects of alum sludge applications on soil properties were evaluated. Soil properties examined were TS, organic matter, percent moisture, bulk density, pH, acidity, CEC, major forms of nitrogen, Bray P-l, total phosphorus, K, Al, B, Cd, Ca, Cr, Cu, Fe, Pb, Mg, Mn, Ni, Zn, and particle size distribution. The soil test data were generally not significantly affected by the alum sludge applications for either corn or soybeans. Occasional differences occurred between sludge-treated and untreated soils. However, they were never consistent for a series of four collections for each treatment.

Corn yields in the 2.5 and 10 t/a plots were significantly lower than those in the 0 and 20 t/a plots. Corn yield appeared to be related to plant populations. However, the corn yield and the plant population in the highest-rate (20-t/a) plots were not affected by the alum sludge addition. The reasons for reduced yields in the 2.5 and 10 t/a plots is unknown.

Soybean yields and soybean plant parameters were not impacted by alum sludge applications.

Nutrients and heavy metals (N, P, K, Ca, Mg, Mn, Zn, Fe, Cu, Al, Cd, Cr, Pb, Ni, crude protein, and moisture content) in grains, whole plants, and leaves were generally not significantly changed by the sludge applications. None of the nutrient levels were increased significantly by the nutrients in the sludge. The heavy metals levels were higher in the whole plants and leaves and lower in the grains.

Conclusion

In this study the application of air-dried alum sludge on corn and soybean fields did not have any beneficial or adverse effects on corn and soybeans and did not alter the soil characteristics. From this very limited one-year investigation it appears that there are no detrimental effects from the application of water treatment plant alum sludge at rates of up to 20 t/a to agricultural tracts in Illinois used for raising cash crops, particularly corn and soybeans.

On the basis of the limited data from a one-year short-term study, the following suggestions and recommendations are offered. Land application of alum sludge appears to be a viable method with no apparent environmental degradation. Applying raw liquid alum sludge seems impractical for most water treatment plants. Dewatering of alum sludge (through methods such as lagooning) is needed to reduce the cost of transportation. However, lagoons require land.

The only no-cost disposal method is to discharge alum sludge directly into receiving waters. In Illinois direct discharge requires a permit. Currently, treatment of alum sludge is required prior to final disposal.

The results of this study indicate that air-dried alum sludge can be applied to farmland without detrimental effects. Therefore, it is felt that any suitable land disposal is a feasible alternative, because alum sludge contains few nutrients and most likely will not cause contamination of surface and ground waters.

Recommendations for Future Research

- Long-term effects of alum sludge for agricultural use should be investigated.
- Additional information is needed on the maximum alum sludge application rate feasible for many plants and root crops. In this study, the highest rate (20 t/a) generally showed no effect on corn and soybeans.
- Air-dried alum sludge needs to be ground to a powder form to eliminate clumps when the alum sludge is applied to the soil. Or it could be applied in a suspended liquid form.
- Similar studies should be conducted for lime sludge from water treatment plants, especially on land application of lime sludge, which has been practiced on Illinois farms for many years. Scientific data have not been collected for many of these applications.
- Benefits and risks of the use of combined alum sludge and wastewater sludge should be evaluated.
- Further study is needed on the land application of alum sludge for growing vegetables, wheat, rye, oats, and other crops.
- Research conducted in a greenhouse is needed to determine the best method and time of alum sludge application.
- Further study is needed with more than one water treatment plant used as a source of alum sludge.
- The possibility of using an irrigation system to apply alum sludge should be investigated.
- The rate at which the heavy metals move through the ground should be determined.

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APPENDICES

Appendix A. Sludge Survey Questionnaire

ILLINOIS WATER TREATMENT PLANT SLUDGE SURVEY (1986)

Respondent's Name:	Region:
Title:	
Facility:	County:
Address:	
	Phone: ( )

Source and Flow

	Sources	Avg. Flow (MGD)	Max. Flow
Surface			
Well			
Other			

Approximate size of the community served: ________________

Raw Water Oualitv:

	Annual Average	Approximate Range
Turbidity. NTU		
T. Alkalinity as $CaCO_3$, mg/L		
T. Hardness as $CaCO_3$, mg/L		
T. Suspended Solids, mg/L		
Total solids, mg/L		
PH		
Other		

Treatment Processes (Please check one or more, plus disinfection)

SURFACE WATER PLANT

____1. Coagulation, sedimentation, and filtration
____2. Lime softening, and filtration
____3. Coagulation, sedimentation, lime softening, and filtration
____4. Filtration:____Direct;____Pressure;____GAC
____5.____Aeration,____Desalinization
____6. Other: ________________________

GROUND WATER PLANT

____1. Fe (s Mn) removal:____Aeration;____Retention;____Pres. sand filters
___ 2. Fe removal and zeolite softening
____3. Softening:____Lime
___Lime/Soda ash
.____ Zeolite (ion exchange)
___Other
____4. Coagulation, sedimentation, and filtration
____5. Filtration:_____Rapid sand;_____Pressure

Chemicals Used

	Annual Average (mg/L or lb/d)	Approximate Range (mg/L or lb/d)
Alum		
Ferric		
Polymer		
Carbon		
(PAC)		
(GAC)		
$KMnO_4$		
Salt		
Lime		
Soda ash		
Chlorine		
Other		

Pre-sedimentation (side-channel reservoir):____Yes,____No

Basin Information

	Flocculator	Sedimentation	Pre-sedimentation and/or Secondary Sed.	Softening
Number				
Size sq. ft.				-
Depth/ft.				
Detention time at avg. flow, min.				
Sludge generated, lb/d				
or gal/d				

Filters:

Number: ______

Max. loading rate:__________gpm/sq ft

Media: Anthracite__________in.; Sand_________in.; GAC__________in.

Max. wash rate:__________gpm/sq ft.

T. Suspended solids:__________lb/sq ft. or ___________mg/L

Size, sq ft: ___________

Filter aid:________Yes (name:) :____________None

Filter run:__________ hrs/run

% Washwater to average flow:__________%

Total solids in washwater:_________lb/sq ft; or____________mg/L

Sludge Production and Disposal

Type of sludge:_____Alum sludge;____Lime sludge;____Brine wastes; or _________

Estimated total quantity:__________Dry or wet lb/d or_________gal/MG

Sludge Characteristics

	Basin sludge	Filter washwater	Brine
% solids			
PH			
TSS, mg/L			
TDS , mg/L			
Al, mg/L			
Fe, mg/L			
Ba, mg/L			
Radioactivity			
Other			

Discharge & Removal

Basin sludge discharged to:____stream;____dry creek;____storm sewer; ____lake and reservoir;_____low ground;_____impounding basin;_____sanitary sewer;_____treatment facility;_____other _______________

Flocculator sludge discharged to: _____________________

Filter washwater discharged to:_________________________

Recovery basin (recycle): _____Yes;_____No

Spent GAC disposal to:_________________; or ______ regeneration

Brine disposal to:_____________________

Methods of removing sludge from basins;_____Flushing (fire hoses, dragline or dozer) ;___Continuous removal;____Manual;____Combination of the above; ___Other ____________

Methods of removing sludge from flocculator:__________________

Sludge Treatment

Thickening:_____Gravity;____Floatation, or___Centrifuge

Stabilization and Disinfection:____Lime treatment,____Cl_2 treatment

Recycle?____Yes;____No; if yes,_____with or______without settling.

Dewatering:____Yes;____No

Appendix A. Concluded

Sludge Dewatering

	Number	Size	ib/d or ton/y generated	% solids
Drying beds				
Drying lagoons				
Centrifuge				
Vacuum filter				
Belt filter				
Filter press				
Strainers				
Freezing or heat				

Sludge Final Disposal

Composting:______Yes;_____No
Utilization for:______Cropland;_____Land reclamation;_____Fill material;
____Forests;_____Raw material recovery;_____Mixed with soil
____Fuel;_____Landscaping;_____Other

To Land:_____Landfill (___Utility owned land;____Public land;____Other private land);___Dedicated land disposal.

Sludge Disposal Limitations

A. Has your utility been ordered by a regulatory agency to stop the discharge of water treatment plant sludge into the water source within the past 15 years?____Yes___No

B. If YES to A., in your opinion, has the stopping of sludge disposal to the water source significantly improved the water quality of the water source?____Yes___No

C. If NO to B., would your utility resume sludge disposal to the water source if the regulatory barriers were removed?_________Yes____No

D. If YES to C., and your utility was allowed to resume sludge disposal to the water source, what would you estimate the annual cost savings to your utility?

$ ___________

Costs:

Total annual cost for solids handling and disposal: $ ___________
Total annual cost for the treatment plant: $__________

Remarks: (Use the back of this page)

Appendix B. Facility Information

Plant no.	Name & title of respondent	Name of facility	Address	Region	County	Phone
S101	John P. Robb Supt.	Rock Is.	1528 Third Avenue Rock Island, IL 61201	1	Rock Island	(309) 793-3486
S102	Jean Marquardt Supt.	Moline	30 18th St. Moline, IL 61265	1	Rock Island	(309) 797-0489
S103	Edwin L. Horn Division Mgr.	N. IL Wtr. Co.	120 S. Sterling St. Streator, IL 61364	1	LaSalle	(815) 672-4556
S201	Howard Peskator Dir. Wtr. Util.	Waukegan	Waukegan Water Utility Waukegan, IL 60085	2	Lake	(312) 360-9000
S202	L. R. Baur Supt.	Lk. Forest	1441 Lake Road Lake Forest, IL 60045	2	Lake	(312) 234-2600
S203	Ignatius Repp Oper.	U.S. Army	Fort Sheridan, IL 60037	2	Lake	(312) 926-2517
S204	Donald Jensen Supt.	Highland Pk.	1707 St. Johns Avenue Highland Park, IL 60035	2	Lake	(312) 432-0800 Ext. 250
S205	Ronald E. Zegers Operations Eng.	Elgin	150 Dexter Court Elgin, IL 60120	2	Kane	(312) 697-3644
S206	Steve Spriggs Foreman	Northbrook	750 Dundee Rd. Northbrook, IL 60062	2	Cook	(312) 480-0636
S207	Michael A. Moran Supt.	Glencoe	675 Village Court Glencoe, IL 60022	2	Cook	(312) 835-4111
S208	Patrick Freely Supt.	Winnetka	510 Greenbar Road Winnetka, IL 60093	2	Cook	(312) 446-2500 Ext. 24
S209	Ben Mercieri Supt.	Kenilworth	419 Richmond Rd. Kenilworth, IL 60043	2	Cook	(312) 251-1094
S210	Ray. S. Ames, Jr. Supt.	Wilmette	200 Lake Ave. Wilmette, IL 60091	2	Cook	(312) 256-3440
S211	Richard J. Figurelli Supt.	Evanston	555 Lincoln St. Evanston, IL 60201	2	Cook	(312) 866-2942
S212	G. Larsen Chief Filtration Eng.	Jardine	1000 E. Ohio Street Chicago, IL 60611	2	Cook	(312) 744-3700
S213	J. Hogan Chief Filtration Eng.	South	3300 E. Cheltenham Place Chicago, IL 60649	2	Cook	(312) 933-7105
S214	Joseph F. Donovan Plant Manager	Kankakee Water Co.	1100 Cobb Blvd. Kankankee, IL 60901	2	Kankakee	(815) 935-8803

S301	William Foster Prod. Supt.	IL-AM Wtr. Co.	123 S.W. Washington Peoria, IL 61602	3	Peoria	(309) 671-3758
S302	J.R. Lamb Supt.	Dallas City ,	Box 194 Dallas City, IL 62330	3	Hancock	(217) 852-3224
S303	Robert C. Daniels Supt.	La Harpe	P.O. Box 359 La Harpe, IL 61450	3	Hancock	(217) 659-7750
S304	Barry Cuthbert Plant Mgr.	Nauvoo	Box 85 Nauvoo, IL 62354	3	Hancock	(217) 453-2411
S305	Robert E. Allen Supt.	Hamilton	301 Woodland Dr. Hamilton, IL 62341	3	Hancock	(217) 847-3774
S306	James E. Moore Supt.	Carthage	308 Walnut St. Carthage, IL 62321	3	Hancock	(217) 357-3119
S307	Ray McKinney Supt.	Canton	R.R. 5 Canton, IL 61520	3	Fulton	(309) 647-0060
S308	Charles E. Heaton Supt.	Vermont	Box 275 Vermont, IL 61484	3	Fulton	(309) 784-5242
S309	David M. Kent Supt.	Quincy	507 Vermont St. Quincy, IL 62301	3	Adams	(217) 228-4580
S310	Randy McClure Supt.	Virginia	City Hall Virginia, IL 62691	3	Cass	(217) 452-7522
S311	John T. Cosner	Ashland	Box 170 Ashland, IL 62612	3	Cass	(217) 476-3381
S312	Kenneth Gallaher Oper.	Pittsfield	215 N. Monroe St. Pittsfield, IL 62363	3	Pike	(217) 285-2031
S313	Donald Eldridge Supt.	Waverly	P.O. Box 94 Waverly, IL 62692	3	Morgan	(217) 435-4611
S314	Paul Sperry Supt.	New Berlin	Box 357 New Berlin, IL 62670	3	Sangamon	(217) 488-6214
S315	William A. Brown Supt.	Springfield	3100 Stevenson Dr. Springfield, IL 62707	3	Sangamon	(217) 786-4047
S316	Jeff Sheffler Supt.	Loami	Box 441 Loami, IL 62661	3	Sangamon	(217) 624-5421
S317	Louis H. Bausull Oper.	Kincaid	Kincaid Water Plant Kincaid, IL 62540	3	Christian	(217) 237-2404
S318	Joe A, Marucco Supt.	Taylorville	2222 Lincoln Trail Taylorville, IL 62568	3	Christian	(217)287-1441
S319	Eddie G. Lawson Supt.	White Hall	116 E. Sherman St. White Hall, IL 62092	3	Greene	(217) 374-2355
S320		Carrollton	South Main St. Carrollton, IL 62016	3	Greene	(217) 492-3814

Appendix B. Continued

Plant no.	Name & title of respondent	Name of facility	Address	Region	County	Phone
S321	Michael C. Smith Oper.	Carlinville	R.R. 4 Carlinville, IL 62626	3	Macoupin	(217) 854-8222
S322	Raymond E. Fritz Supt., Chief Oper.	Gillespie	115 N. Macoupin Gillespie, IL 62033	3	Macoupin	(217) 839-3279
S323	Gerald Gorsich Chief Oper.	Mt. Olive	507 E. 3rd N. Mt. Olive, IL 62069	3	Macoupin	(217) 999-2651
S324	David A. Booher Supt.	Hillsboro	114 E. Wood St. Hillsboro, IL 62049	3	Montgomery	(217) 532-2163
S325	D.A. Ramsey City Engineer	Staunton	304 W. Main Staunton, IL 62088	3	Macoupin	(618) 635-2557
S401	Raymond Werner Wtr. Prod. Supt.	Highland	1115 Broadway Highland, IL 62249	4	Madison	(618) 654-9321
S402	Paul Holcmann Supt.	Sorento	Box 85 Sorento, IL 62086	4	Bond	
S403	Burel D. Goodin Supt.	Keyesport	Box 41 Keyesport, IL 62253	4	Bond	
S404	Jerry Meier Mgr.	SLM Water Coram.	R.R. 1 Box 93 Mascoutah, IL 62258	4	St. Clair	(618) 566-7100
S405	Vic Jansen Supt.	Kaskaskia Wtr. Dist.	700 S. Market New Athens, IL 62264	4	St. Clair	(618) 475-2626
S406	Gerald D. Huelskamp Oper.	Breese	900 N. 1st St. Breese, IL 62230	4	Clinton	(618) 526-7151
S407	Robert Rakers Supt.	Carlyle Mun. Utils.	1st & Franklin St. Carlyle, IL 62231	4	Clinton	(618) 594-3321
S408	Paul Mudd Supt.	Waterloo	R.R. 3 Waterloo, IL 62298	4	Monroe	(618) 939-6512
S409	James R. Aitken Supt.	Coulterville	P.O. Box 412 Coulterville, IL 62237	4	Randolph	(618) 758-2168
S410	Gene Bigham Dir. Pub. Wks.	Sparta	123 W. Broadway Sparta, IL 62286	4	Randolph	(618) 443-4712
S411	Alvin J. Myerscough Supt. .	Evansville	Route 1 Box 250 Evansville, IL 62242	4	Randolph	(618) 853-2355
S412	Walter Gilbert Supt.	Chester	1330 Swanwick St. Chester, IL 62233	4	Randolph	(618) 826-3315

S413	Jeff D. Leidner Chief Oper.	Greenville	404 S. Third Greenville, IL 62246	4	Bond	(618) 664-0131
S501	Brien Dew Util. Oper.	Van. Corr. Center	Route 51 North, Box 500 Vandalia, IL 62471	5	Fayette	(618) 283-4170 Ext. 174 or 188
S502		St. Elmo	117 W. 4th St. St. Elmo, IL 62458	5	Fayette	(618) 829-9725
S503	Ralph D. Whitt Supt. Mun. Serv.	Farina	Box 218 Farina, IL 62838	5	Fayette	(618) 245-6660
S504	Lavern Nelson Oper.	Effingham	201 Banker Effingham, IL 62401	5	Effingham	(217) 342-2011
S505	Greg R. Tomlinson Supt.	Altamont	202 N. Second Altamont, IL 62411	5	Effingham	(618) 483-6370
S506	Jack Hendrick Chief Oper.	Salem	101 S. Broadway Salem, IL 62881	5	Marion	(618) 548-0479
S507	Stan Browning City Eng.	Centralia	Rt. 51 North Central City, IL 62801	5	Marion	(618) 533-7623
S508	Tom Stanford Supt.	Louisville	Water Plant Louisville, IL 62858	5	Clay	(618) 665-3545
S509	Charles R. Peters Chief Oper.	Flora	P.O. Box 249 Flora, IL 62839	5	Clay	(618) 662-8841
S510	Dave Berry Supv.	Olney	P. 0. Box 369 Olney, IL 62450	5	Richland	(618) 392-3741
S511	Lawrence O'Bryant Oper. in Charge	Mt. Vernon	20th and Waterworks Rd. Mt. Vernon, IL 62864	5	Jefferson	(618) 242-5000 Ext. 256
S512	Raymond Garner Supt.	Wayne City	Box 66 Wayne City, IL 62895	5	Wayne	(618) 895-2166
S513	Kenny Kenshalo Oper.	Fairfield	109 N.E. Second Fairfield, IL 62837	5	Wayne	(618) 847-4241
S514	Walter L. Provine Supt.	West Salem	501 S. Broadway West Salem, IL 62476	5	Edwards	(618) 456-3547
S515	Don Wilkin Supt.	Pinckneyville	110 - 114 S. Walnut St. Pinckneyville, IL 62274	5	Perry	(618) 357-5214
S516	Irv Camden Supt.	Rend Lake Inter-City Wtr. System	P.O. Box 497 1600 Marcum Br. Rd. Benton, IL 62812	5	Franklin	(618) 439-4394
S517	James Swayze Supt.	Carbondale	P. 0. Box 2047 Carbondale, IL 62901	5	Jackson	(618) 529-1731
S518	Supt.	Marion	100 Tower Sq. City Hall Marion, IL 62959	5	Williamson	(618) 993-5533

Appendix 6. Continued

Plant no.	Name & title of respondent	Name of facility	Address	Region	County	Phone
S519	Ralph E. Gregg Supt.	Eldorado Wtr. Company	938 Veterans Drive Eldorado, IL 62930	5	Saline	(618) 273-2201
S520	Joe A. Rice Supt.	Carrier Mills Mun. Wtr. Sew.	702 N. Mill St. Carrier Mills, IL 62917	5	Saline	(618) 994-2711
S521	Lowell Cooley Util. Supt.	Dongola	Village of Dongola Dongola, IL 62926	5	Union	(618) 827-3932
S522	Claude W. Brandt Chief Oper.	Vienna Corr. Center	P.O. Box 200 Vienna, IL 62995	5	Johnson	(618) 658-8371 Ext. 686
S601	Allen Jacobsgaard Oper. in Charge	Eureka	128 N. Main St. Eureka, IL 61530	6	Woodford	(309) 467-2700
S602	Ronald S. Schultz Supt.	Bloomington	P.O. Box 1524 Bloomington, IL 61701	6	McLean	(309) 747-2455
S603	Ed Deray Supt.	Oakwood	Box 31 Oakwood, IL 61858	6	Vermilion	(217) 354-4255
S604	John C. McLane Prod. Mgr.	Inter-State Wtr. Co.	P.O. Box 907, 322 N. Gilbert St. Danville, IL 61834	6	Vermilion	(217) 442-0108
S605	Jesse Pritchett Dir. Pub. Wks.	Georgetown	Georgetown Wtr. Treatment Plant Georgetown, IL 61846	6	Vermilion	(217) 622-8609
S606	Craig M. Cummings Operations Supv.	Decatur	#1 Civic Center Plaza Decatur, IL 62523	6	Macon	(217) 424-2831
S607	Warren Brown Supt.	Paris	123 S. Central Paris, IL 61944	6	Edgar	(217) 463-4025
S608	Dale Hanner Supt.	Oakland	R.R. 2 Box 168 Oakland, IL 61943	6	Coles	(217) 346-2591
S609	David Bergman Chief Oper.	Mattoon	12th and Marshal Mattoon, IL 61938	6	Coles	(217) 234-2454
S610	Alan Alford Oper.	Charleston	520 Jackson Charleston, IL 61920	6	Coles	(217) 345-2977
S611	Vernon Greeson Supt. Wtr. & Swr.	Neoga	Box 181 Neoga, IL 62447	6	Cumberland	(217) 895-2172

G101	Jim Blair Oper.	Lena	201 Vernon Lena, IL 61048	1	Stephenson	(815) 369-2817
G102	James Barber Plant Mgr.	Freeport	230 W. Stephenson Freeport, IL 61032	1	Stephenson	(815) 233-0111
G103	Rod Nilles Engineer	S. Beloit Wtr. Gas & Elec.	7617 Mineral Point Rd. Madison, WI 53717	1	Winnebago	(603) 252-3166
G104	Dennis R. Leslie General Mgr.	N. Park PWD	1350 Turret Drive Machesney Park, IL 61111	1	Winnebago	(815) 633-5461
G105	Stephen A. Urbelis Supt.	Loves Park	5440 Walker Avenue Loves Park, IL 61111	1	Winnebago	(815) 877-1421
G106	George P. Bretrager.P.E. Supt.	Rockford	1111 Cedar Street Rockford, IL 61101	1	Winnebago	
G107	Supt.	Belvidere	210 W. Whitney Belvidere, IL 61008	1	Boone	(815) 544-3877
G108	Paul E. Hartman Pub. Wks. Supt.	Savanna	101 Main Street Savanna, IL 61074	1	Carroll	(815) 273-2251
G109	Arthur Yates Oper.	Mt. Morris	102 E. Center Mt. Morris, IL 61054	1	Ogle	(815) 734-4820
G110	George R. Salter Supt.	Polo	410 E. Wayne St. Polo, IL 61064	1	Ogle	
G1ll	Earl Fleming Supv.	Rochelle	120 N. 7th St. Rochelle, IL 61068	1	Ogle	(815) 562-4155
G112	Mr. Roach Supt. Pub. Wks.	Genoa	City Hall 113. N. Genoa Genoa, IL 60135	1	DeKalb	(8150 784-2271
G113	Syd Albrecht Supt.	Sycamore	535 DeKalb Ave. Sycamore, IL 60178	1	DeKalb	(815) 895-2548
G114	Gerald W. Bever Supt.	DeKalb	200 S. Fourth St. DeKalb, IL 60115	1	DeKalb	(815) 756-4881
G115	Dan Gilbert Supt.	Sandwich	114 E. Railroad Sandwich, IL 60548	1	DeKalb	(815) 786-6471
G116	Walter M. Heath Supt. Wtr. & Swr.	Morrison	520 W. Winfield St. or 200 West Main St. Morrison, IL 61270	1	Whiteside	(815) 772-4316
G117	Steven F. Rittenhouse Manager	Northern IL Water Corp.	P.O. Box 740 304 2nd Ave. Sterling, IL 61081	1	Whiteside	(815) 625-0017
G118	Douglas Gaumer Supt.	Rock Falls	1007 7th Ave Rock Falls, IL 61071	1	Whiteside	(815) 625-1975
G119	Christopher W. Hill Supt.	Dixon	P.O. Box 386 Dixon, IL 61021	1	Lee	(815) 288-3381

Appendix B. Continued

Plant no.	Name & title of respondent	Name of facility	Address	Region	County	Phone
G120	Supt.	Silvis	1032 1st Av. Silvis, IL 61282	1	Rock Island	(309) 792-0170
G121	Darrell Swanson Acting Supt.	Geneseo	101 S. State St. Geneseo, IL 61254	1	Henry	(309)944-2605
G122	Ronald Saunders Supt.	Orion	P.O. Box 69 Orion, IL 61273	1	Henry	(309) 526-8986
G123	Robert R. Nussear Supt. Wtr. & Swr.	Cambridge	E. Exchange St. Cambridge, IL 61238	1	Henry	(309) 937-3380
G124	Jerry Popejoy Supt.	Kewanee	200 W 3rd St.- City Hall Kewanee, IL 61443	1	Henry	
G125	Jerry Hoxworth Supt.	Galva	210 Front St. Galva, IL 61434	1	Henry	(309) 932-2616
G126	Sharon Mercer Mgr.	Princeton Mun. Wtr.	2 S. Main St. Princeton, IL 61356	1	Bureau	(815) 872-5551
G127	Francis J. Miller Supt. Wtr & Wstwtr.	Mendota	607 8th Ave. Mendota, IL 61342	1	LaSalle	(815) 539-6307
G128	David L. Stacker Supt.	LaSalle	745 Second St. LaSalle, IL 61301	1	LaSalle	(815) 223-0068
G129	William Krause Cit Engineer	Ottawa	301 W. Madison St. Ottawa, IL 61350	1	LaSalle	(815) 433-0161
G130	W. O'Brien Supt.	Seneca	116 William St. Seneca, IL 61360	1	LaSalle	(815) 357-8771
G131	Dennis Spence Supt.	Aledo	120 N. College Ave. Aledo, IL 61231	1	Mercer	(309) 582-7241
G132	Dan Ziegler Supt. Pub. Wks.	Henry	Box 196 Henry, IL 61537	1	Marshall	(309) 364-3755
G201	Ernest Bates Dir. Util.	Woodstock	1500 N. Seminary Ave. 211 W. 1st St. Woodstock, IL 60098	2	Mc Henry	(815) 338-5460
G202	Fred Batt Supt. Pub. Wks.	McHenry	1111 Green St. McHenry, IL 60050	2	Mc Henry	(815) 385-1761
G203	William Straczek Dir. Util.	Crystal Lake	121 N. Main St. P. 0. Box 597 Crystal Lake, IL 60014	2	Mc Henry	(815) 495-2020

G204	Robert F. Williams Supt. Pub. Wks.	Winthrop Harbor	830 Sheridan Rd. Winthrop Harbor, IL 60096	2	Lake	(312) 872-5275
G205	Richard Leber Supt.	Fox Lake	301 S. Rt. 59 Fox Lake, IL 60020	2	Lake	(312) 587-8393
G206	Robert B. Krause Supt. Wtr. & Swr.	Lindenhurst	2301 E. Sand Lake Rd. Lindenhurst, IL 60046	2	Lake	(312) 356-8252
G207	Kenneth J. Swanson Oper.	Round Lake Beach	1212 N. Cedar Lake Road - Round Lake Beach, IL 60073	2	Lake	(312) 546-8752
G208	Roy Wickersheim, Jr. Supt. Pub. Wks.	Grayslake	164 Hawley Grayslake, IL 60030	2	Lake	(312) 223-8860
G209	Richard P. Kruster Oper.	Wauconda	P.O. Box 785 Wauconda, IL 60084	2	Lake	(312) 526-9610
G210	Thomas Chmura Supt.	Mundelein	440 E. Hawley Mundelein, IL 60060	2	Lake	(312) 949-3271
G211	Donn N. Valentine Supt. Util.	Dundee	120 Barrington Ave. Dundee, IL 60118	2	Kane	(312) 426-2821
G212	Michael Swensek Oper.	S. Elgin	280 North Collins South Elgin, IL 60177	2	Kane	(312) 695-2742
G213	John J. Bajor, Jr. Supt.	St. Charles	2 E. Main St. St. Charles, IL 60174	2	Kane	(312) 377-4420
G214	John Edlebeck Asst. Dir. Pub. Ser.	Geneva	2 W. State Street Geneva, IL 60134	2	Kane	(312) 232-1501
G215	John Kindermann Supt. Wells	Itasca	100 N. Walnut Ave. Itasca, IL 60143	2	DuPage	(312) 773-5571
G216	Mario Grossi, Jr. Supv.	Wood Dale	269 W. Irving Wood Dale, IL 60191	2	DuPage	(312) 766-4900
G217	Robert C. Maguire Supv.	Bloomingdale	201 South Bloomingdale Rd. Blooraingdale, IL 60108	2	DuPage	(312) 893-7000
G218	Bob Hoffrage Foreman	Carol Stream	500 N. Gary Ave. Carol Stream, IL 60188	2	DuPage	(312) 665-7050
G219	Stewart McLeod Oper.	Addison	249 S. Villa Addison, IL 60101	2	DuPage	(312) 543-4100
G220	Dennis Streicher Supt. Prod.	Elmhurst	119 Schiller Elmhurst, IL 60126	2	DuPage	(312) 530-3046
G221	J. Donald Foster City Engineer	West Chicago	475 Main St. West Chicago, IL 60185	2	DuPage	
G222	Raymond P. Schnurstein Supt.	Wheaton	303 W. Wesley P.O. Box 727 Wheaton, IL 60189	2	DuPage	(312) 260-2092
G223	Floyd Wilson Pub. Wks. Supt.	Oak Brook	1200 Oak Brook Rd. Oak Brook, IL 60521	2	DuPage	(312) 654-2220

Appendix B. Continued

Plant no.	Name & title of respondent	Name of facility	Address	Region	County	Phone
G224	A.L. Poole, P.E. Dir. Wtr. & Wstwtr. Util.	Naperville	175 W. Jackson Ave. Naperville, IL 60540	2	DuPage	(312) 420-6131
G225	Joel A. Hawkins Wtr. & Swr. Supt.	Lisle	1040 Burlington Ave Lisle, IL 60532	2	DuPage	(312)968-1200
G226	John Gorisch Supt.	Downers Grove	Civic Center Downers Grove, IL 60516	2	DuPage	(312) 964-0300
G227	James J. Sangala Chief Oper.	Hinsdale	19 E. Chicago Ave. Hinsdale, IL 60521	2	DuPage	(312) 789-7051
G228	Christopher W. Kohl Oper.	Woodridge	1 Plaza Drive Woodridge, IL 60517	2	DuPage	(312) 719-4753
G229	John B. White Dir. Pub. Wks.	Streamwood	565 S. Bartlett Rd. Streamwood, IL 60103	2	Cook	(312) 289-3130
G230	Robert L. Wenger Supv.	Hanover Park	2121 W. Lake St. Hanover Park, IL 60103	2	Cook	(312) 837-3800 Ext. 307
G231	Thomas Cech Dir. Pub. Wks.	Elk Grove Village	901 Wellington Elk Grove Village, IL 60007	2	Cook	(312) 439-3900
G232	Ken Hayes Oper.	Western Springs	614 Hillgrove Ave. Western Springs, IL 60558	2	Cook	(312) 246-3656
G233	Walter Potacki Water Tech.	Hickory Hills	8020 W. 87th St. Hickory Hills, IL 60457	2	Cook	(312) 598-7855
G234	George Braker Administrator	Lemont	418 Main St. Lemont, IL 60439	2	Cook	(312) 257-6421
G235	Michael J. Conley Senior Oper.	Richton Park	4455 Sauk Trail Richton Park, IL 60471	2	Cook	(312) 481-8950
G236	Eddie Mae Ross Water Clerk	E. Chicago Heights	1343 Ellis Ave. East Chicago Heights, IL 60411	2	Cook	(312) 758-3131
G237	Daniel J. Lueder Oper. in Charge	S. Chicago Heights	2729 Jackson Ave. South Chicago Heights, IL 60411	2	Cook	(312) 755-7888
G238	John P. McGinnis City Eng., Supt.	Piano	101 W. Main Piano, IL 60545	2	Kendall	(312) 552-8275
G239	Robert Flaar Supt. Pub. Wks.	Oswego	165 Harrison Oswego, IL 60543	2	Kendall	(312) 554-3242
G240	James T. Johnson Pub. Wks. Dir.	Yorkville	610 Tower Lane Yorkville, IL 60560	2	Kendall	(312) 553-4350

G241	William Moore Supt.	Bolingbrook	375 W. Briarcliff Bolingbrook, IL 60439	2	Will	(312) 759-0450
G242	Mr. H. Countryman	Plainfield	1400 N. Division St. Plainfield, IL 60544	2	Will	
G243	Eugene Weatherford Supt. Operations	Romeoville PWD	13 Montrose Dr. Romeoville, IL 60441	2	Will	(815) 886-1878
G244	Robert. F. Anderson	Lockport Wtr. Dept.	222 E. 9th St. Lockport, IL 60441	2	Will	(815) 838-0456
G245	Mgr.	Will Cty. Water Co.	Shorewood Plaza Shorewood, IL 60435	2	Will	(815) 725-8867
G246	Lewis R. Loebe, Jr. Dir. Pub. Wks.	New Lenox	701 W. Haven Ave. New Lenox, IL 60451	2	Will	(815) 485-6452
G247	Stefan R. Sailer Supt.	Consumer IL Water Co.	25820 South Western Ave. University Park, IL 60466	2	Will	(815) 534-6511
G248	Wayne C. Milton Supt.	Wilmington	114 N. Main St. Wilmington, IL 60481	2	Will	(815) 476-2175
G249	Dennis Gribbins Supt. Pub.. Wks.	Peotone	Third and Main Streets Peotone, IL 60468	2	Will	(815) 258-3279
G250	Jim Henderson Supt.	Momence	600 W. Water St. Momence, IL 60954	2	Kankakee	(815) 472-2430
G301	LeRoy Peterson	Monmouth Water Dept.	City Hall Monmouth, IL 61462	3	Warren	(309) 734-6028
G302	Don Rees Wtr. Dist. Supt.	Galesburg	920 W. Main St. Galesburg, IL 61401	3	Knox	(309) 343-4181
G303	Larry Lawson Oper.	Abingdon PWD	City Hall Abingdon, IL 61410	3	Knox	(309) 462-3182
G304	Sid Crabel Supt. Pub. Wks.	Chillicothe	908 N. Second St. Chillicothe, IL 61523	3	Peoria	(309) 274-2020
G305	Steven W. Rettig Supt. Pub. Wks.	Peoria Heights	4901 N. Prospect Peoria Heights, IL 61614	3	Peoria	(309) 682-8622
G306	R. C. Daniels Supt.	La Harpe	P.O. Box 359 La Harpe, IL 61450	3	Hancock	(309) 659-7750
G307	Kenneth McCleery Supt.	Bushnell	138 E. Hail St. Bushnell, IL 61422	3	McDonough	(309) 772-2521
G308	Richard E. Powell Supt.	Astoria	P.O. Box 515 Astoria, IL 61501	3	Fulton	(309) 329-2990
G309	Dan Giebelhausen Supt.	E. Peoria	2232 E. Washington East Peoria, IL 61611	3	Tazewell	(309) 694-6395

Appendix. B. Continued

Plant no.	Name & title of respondent	Name of facility	Address	Region	County	Phone
G310	Vernon Attig Supt.	Washington	115 W. Jefferson Washington, IL 61571	3	Tazewell	
G311	Ron F. Ramsey Supt.	Creve Coeur	101 N. Thorncrest Creve Coeur, IL 61611	3	Tazewell	(309) 699-9505
G312	Ed Crockett Supt.	Morton	120 N. Main St. Morton, IL 61550	3	Tazewell	(309) 266-6361
G313	A.R. Snelson, Jr. Operations Mgr.	Pekin IL-AM Wtr. Co.	328 Broadway Pekin, IL 61554	3	Tazewell	(309) 346-2171
G314	Roy H. Schieferdecker Supt.	Rushville	211 Clay Rushville, IL 62681	3	Schuyler	(309) 322-6018
G315	Timothy L. Donalo Oper.	Havana	227 W. Main Havana, IL 62644	3	Mason	(309) 543-2526
G316	Joe T. Burris, Jr. Supt.	Mason City	145 S. Main St. Mason City, IL 62664	3	Mason	(217) 482-5770
G317	David Schonauer Oper.	Lincoln Wtr. Corp.	710 Delavan St. Lincoln, IL 62656	3	Logan	(217) 735-1268
G318	Sam Spears Supt.	Beardstown	101 W. 15th St. Beardstown, IL 62618	3	Cass	(217) 323-5744
G319	William B. Mann Supt.	Riverton	313 E. Jefferson Riverton, IL 62561	3	Sangamon	(217) 629-7186 629-9122
G320	Alvin Bricker Supt.	Nokomis	111 S. Pine St. Nokomis, IL 62075	3	Montgomery	(217) 563-2514
G321	Paul Weiner Supt.	Jerseyville	207 S. Jefferson Jerseyville, IL 62052	3	Jersey	(618) 498-3211
G401	E. Smith	Bethalto	203 Oak St. Bethalto, IL 62010	4	Madison	(618) 259-5941
G402	Tim Palermo Util. Mgr.	Wood River	501 W. Ferguson Wood River, IL 62095	4	Madison	(618) 254-0725
G403	Jerry J. St.John Chief Oper.	Edwardsville	Route 6 Box 142 Edwardsville, IL 62025	4	Madison	(618) 656-0610
G404	Thomas L. Sedlacek Supt.	Glen Carbon	124 School Street Glen Carbon, IL 62034	4	Madison	(618) 288-5766
G405	Bud Klausterraeier Supt.	Troy	116 E. Market St. Troy, IL 62294	4	Madison	(618) 667-9924

G406	Robert L. Johann Chief Oper.	Collinsville	1800 St. Louis Rd. Collinsville, IL 62234	4	Madison	(618) 344-0128
G501	M. Evelyn Dhom City Tres.	Newton	108 N. Van Buren St. Newton, IL 62448	5	Jasper	(618) 783-8452
G502	James Laslie Supt.	Lawrenceville	700 E. State Box 557 Lawrenceville, IL 62439	5	Lawrence v	(618) 943-2422
G503	Clarence Buchanan Foreman	Carmi	Main St. Carmi, IL 62821	5	White	(618) 382-5015
G504	Robert E. Lyerla	Anna-Jonesboro Water Comm.	P. 0. Drawer 30 Jonesboro, IL 62952	5	Union	(618) 833-5313
G505		Metropolis	106 W. 5th St. Metropolis, IL 62960	5	Massac	(618) 524-2260
G601	Stanley C. Sayre Supt. Wtr. & Swr.	Metamora	116 S. Davenport 102 N. Davenport Metamora, IL 61548	6	Woodford	(618) 367-2581
G602	James G. Dransfeldt Dir. Pub. Wks.	Dwight	Village of Dwight Dwight, IL 60420	6	Livingston	(815) 584-1578 after 4pm
G603	LeRoy E. McPherson Dir. Pub. Wks.	Fairbury	1100 S. First St. Fairbury, IL 61739	6	Livingston	(815) 692-2033
G604	F.J. Martin Util. Dir.	Normal	107 E. Mulberry St. Normal, IL 61671	6	McLean	(309) 454-2444
G605	Gary L. King Supt.	LeRoy	111 E Center LeRoy, IL 61752	6	McLean	(309) 962-3901
G606	James Lynch Supt.	Paxton	Paxton Wtr. Dept. Paxton, IL 60957	6	Ford	(217) 379-2425
G607	Thomas M. Yeadon	Farmer City	105 S. Main Farmer City, IL 61842	6	DeWitt	(309) 928-3412
G608	I. D. Weikel Supt.	Clinton	700 S. Quincy Clinton, IL 61727	6	DeWitt	(217) 935-3679
G609	Ray Gossett Supt.	Montlcello	212 N. Hamilton Monticello, IL 61856	6	Piatt	(217) 262-9186
G610	John Reale Supt. Wtr. & Wstwtr.	Rantoul	109 W. Belle St. Rantoul, IL 61866	6	Champaign	(217) 812-2710
G611	Andrew J. Kieser Prod. Mgr.	Northern IL Water Corp.	P.O. Box 718 Champaign, IL 61820	6	Champaign	(217) 352-7001
G612	Ken Newkirk Supt.	Hoopeston	229 South Market Hoopeston, IL 60942	6	Vermilion	(217) 283-5631

Appendix B. Concluded

Plant no.	Name & title of respondent	Name of facility	Address	Region	County	Phone
G613	Phil Rich Supv.	Arthur	314 W. Progress St. Arthur, IL 61911	6	Moultrie	(217) 543-2813
G614	Dale Piper Supt.	Sullivan	2 W. Harrison Sullivan, IL 61951	6	Moultrie	(217) 728-7622
G615	Steve Yeager Util. Supt.	Villa Grove	612 Front Street Villa Grove, IL 61956	6	Douglas	(217) 832-4721
G616	Clarence E. Hale Supt.	Shelbyville	110 South Morgan Shelbyville, IL 62565	6	Shelby	(217) 774-5131
G617	George Q. Smith Supt. Util.	Marshall	708 Archer Ave. Marshall, IL 62441	6	Clark	(217) 826-2112

Appendix C. Communities Purchasing Water from Other Facilities

Community/community purchased from	Name, title, and phone of respondent	Address	Region	County	Flow.mgd Avg.	Flow.mgd Maximum	Population served
Lincolnshire Highland Park	Frank Tripicchio Foreman (312) 634-5800	175 Olde Half Day Rd. Lincolnshire, IL 60069	2	Lake	0.75	2.0	4,200
Deerfield Highland Park	E. 8. Klasinski Dir. P.W.D. (312) 945-5000	850 Waukegan Rd. Deerfield, IL 60015	2	Lake	2.552	4.984	
Sleepy Hollow Elgin	Arnold Ross Supt. Pub. Wks. (312) 426-6700	1 Thorobred Ln. Sleepy Hollow, IL 60118	2	Kane			
Palatine NW Water Coram.	John M. Loete, P.E. Dir. Pub. Wks.	200 E. Wood Street Palatine, IL 60067	2	Cook			
Arlington Heights Evanston & wells	Don Renner Supt. of Util. (312) 577-5606	33 S. Arlington Heights Rd. Arlington Heights, IL 60005	2	Cook	8.0	12.5	70,000
Rolling Meadows Chicago	Dennis York Dir. Pub. Wks.	3200 Central Rd. Rolling Meadows, IL 60008	2	Cook			
Mt. Prospect Chicago	Jerry Mcintosh Supt. Wtr. & Sewer (312) 870-5640	11 S. Pine St. Mt. Prospect, IL 60056	2	Cook	4.5	10.0	56,000
Des Plaines Chicago	Kenneth Tiernan Supt. (312) 391-5490	1111 Joseph J. Schwab Rd. Des Plaines, IL 60056	2	Cook	8.0	14.0	
Northfield Winnetka	Robert E. Jorgensen	361 Happ Rd. Northfield, IL 60093	2	Cook			
Hoffman Estates Chicago	Lawrence Miller Supt. of Water (312) 882-9100	1200 N. Gannon Drive Hoffman Estates, IL 60196	2	Cook			
Glenview Wilmette	Thomas Jackson Supt. (312) 724-1700	1225 Waukegan Rd. Glenview, IL 60025	2	Cook	5.62	11.8	52,,000
Schaumburg Chicago	David G. Varner Util. Supt. (312) 894-7100	714 S. Plum Grove Rd. Schaumburg, IL 60193	2	Cook			

Appendix C. Continued

Community/community purchased from	Name, title, and phone of respondent	Address	Region	County	Flow.mgd		Population served
					Avg.	Maximum	
Morton Grove Chicago		8820 National Morton Grove, IL 60053	2	Cook			
Skokie Evanston	Frank Didier Supt. Wtr. & Sewer	5015 Davis Skokie, IL 60077	2	Cook	13.0	26.0	60,000
Park Ridge Chicago	T. Fredrickson Dir. Pub. Wks.	505 Park Place Park Ridge, IL 60068	2	Cook			
Lincolnwood Chicago	Robert McCabe Supt.	6918 N. Keelerd Lincolnwood, IL 60645	2	Cook			
Harwood Heights Chicago	Joan K. White Comptroller	7343 West Lawrence Harwood Heights, IL 60656	2	Cook			
Franklin Park Chicago	Richard Martin Water Supt. (312) 671-4800	9545 Belmont Avenue Franklin Park, IL 60131	2	Cook			
Broadview-Westchester Chicago	Robert Kotche Supt. (312) 343-5599	2222 S. 10th Ave. Broadview, IL 60153	2	Cook	4.69	7.9	52,000
Riverside Chicago	Neil Van Dyke Dir. Pub. Wks. (312) 447-2700	27 Riverside Rd. Riverside, IL 60546	2	Cook			
Cicero Chicago	Forest Musselman Project Manager (312) 930-5162	525 W. Monroe St. Chicago, IL 60606	2	Cook	13.56	14.496	61,232
Brookfield Chicago	Donald R. Miskew Supt. (312) 485-4244	8636 Brookfield Ave. Brookfield, IL 60513	2	Cook	5.4	6.6	
Stickney Chicago	Charles Bachielli Water Supv. (312) 749-4400	6535 Pershing Road Stickney, IL 60402	2	Cook	1.0	1.5	5,680
Hodgkins Chicago	Jerry Tycar Supt. (312) 579-6700	8990 Lyons Street Hodgkins, IL 60525	2	Cook	0.35	0.48	2,000
Justice-Willowsprings Chicago	Michael J. Corcoran Supt.	7000 S. Archer Justice, IL 60458	2	Cook	2.5	3.8	15,000

Hometown Chicago	Joseph J. Madden, Sr. Dir. Pub. Wks. (312) 424-7503	4331 Southwest Hwy. Hometown, IL 60456	2	Cook			
Oak Lawn Chicago	John Orr Water Supt.	5252 W. Dumke Dr. Oak Lawn, IL 60453	2	Cook			
Merrionette Park Chicago	Tony Esch Oper. (312) 597-2806	3031 W. 113th St. Merrionette Park, IL 60655	2	Cook	0.16	0.21	2,000
Alsip Chicago	Tony Esch Comm. of Water (312) 385-6902	4500 W. 123rd St. Alsip, IL 60658	2	Cook			18,000
Crestwood Chicago	Frank D. Gassmere Services Dir. (312) 371-4800	13840 S. Cicero Ave. Crestwood, IL 60445	2	Cook			
Blue Island Chicago	Theodore Aguilar Supt.	13049 Greenwood Blue Island, IL 60406	2	Cook			
Riverdale Chicago	James D. Dempsey Supt. Pub. Wks. (312) 841-2202	14101 S. Halsted Riverdale, IL 60627	2	Cook			
Posen Chicago	Ted Zmuda Supt. Pub. Wks.	2440 W. Zimny Dr. Posen, IL 60409	2	Cook			
Harvey Chicago	R. Schwartzkupf Asst. Supt. (312) 339-4200	15320 Broadway Harvey, IL 60426	2	Cook	10.0	13.0	100,000
Calumet City Chicago	Cologer A. Monestere Water Supt.	945 State St. P.O. Box 1519 Calumet City, IL 60409	2	Cook			
Homewood Harvey	Robert C. Buck Supt. Gen. Oper. (312) 798-2115	17755 S. Ashland Ave. Homewood, IL 60430	2	Cook	3.2	5.6	19,800
Oak Forest Oak Lawn	Michael Cozzo City Eng. (312) 687-4050	15440 S. Central Oak Forest, IL 60452	2	Cook	2.1	5.0	27,000
Orland Park Chicago	Rick Dime Dir of Oper. (312) 349-5430	15750 S. LaGrange Orland Park, IL 60462	2	Cook	3.5	9.0	28,000
Country Club Hills Oak Lawn	Ottmar H. Becker Admin. Asst. to Mayor (312) 798-2616	3700 W. 175th Place Country Club Hills, IL 60477	2	Cook	1.1	2.0	15,750

Appendix C. Concluded

Community/community purchased from	Name, title, and phone of respondent	Address	Region	County	Flow.mgd AYR.	Flow.mgd Maximum	Population served
Hazel Crest Chicago	Christopher J. Wuellner Dir. Pub. Wks. (312) 335-9620	3000 W. 170th PI. Hazel Crest, IL 60429	2	Cook	1.1	2.0	14,000
South Holland Chicago	George D. Budwash Village Eng. (312) 331-6700	357 E. 170th St. South Holland, IL 60473	2	Cook	0.18	0.50	3,500
Flossmoor Homewood	Burce L. Ellis Supv. Util. Div. (312) 957-4100	832 Sterling Flossmoor, IL 60422	2	Cook	1.1		9,000
Tinley Park Chicago	Thomas E. Albright Supt. Wtr. & Swr.	17355 S. 68th Ct. Tinley Park, IL 60477	2	Cook			
Glenwood Chicago	Michale Passaglia Foreman (312) 756-3790	13 S. Rebecca St. Glenwood, IL 60425	2	Cook	1.0	3.6	10,500
Olympia Fields Chicago	Frederick Keuch Dir. Pub. Wks. (312) 747-8286	20700 Governors Hwy. Olympia Fields, IL 60461	2	Cook			
Lynwood Chicago	Floyd Hefner Supt. Pub. Wks. (312) 758-6101	20636 Torrence Ave. Lynwood, IL 60411	2	Cook			4,200
Mt. Sterling Clayton-Camp Point Water Commission	Nelson J. Hester Util. Supt. (217) 773-2513	145 W. Main St.-City Hall Mt. Sterling, IL 62353	3	Brown			
Virden ADGPTV Water Comm.	John Lewis Supt. Wtr. & Street (217) 965-3711	Water Dept.-City Hall Virden, IL 62690	3	Macoupin	0.25	0.30	3,800
Coffeen Hillsboro	Luretta Satterlee City Clerk	City of Coffeen Coffeen, IL 62017	3	Montgomery			
Caseyville IL-AM E. St. Louis	G.W. Scott Supt. Pub. Wks. (618) 344-1233	10 W. Morris Caseyville, IL 62232	4	St. Clair			
Commonfield of Cahokia Pub. Wtr. Dist,* IL-AM E. St. Louis	J.S. LiVigni Manager (618) 332-3302	2525 Mousette Lane Cahokia, IL 62206	4	St. Clair			

Freeburg S-L-M Water Coram.	Howard A. Analla Coordinator (618) 539-3178	P.O. Box D Freeburg, IL 62243	4	St. Clair			
New Baden S-L-M Water Coram.	Ronald V. Renth Dir. Pub. Wks. (618) 588-3813	1 E. Hanover St. New Baden, IL 62265	4.	Clinton			2,500
Columbia IL-AM E. St. Louis	Donald S. Moore, P.E. City Eng.	512 N. Metter Columbia, IL 62236	4	Monroe	0.65	0.80	4,900
Christopher Rend Lake Intercity Water System		Christopher Water. Dept. Christopher, IL 62822	5	Franklin			
McLeansboro Rend Lake Intercity Water System	W.E. Campbell Supt. (618) 643-2723	102 W. Main McLeansboro, IL 62859	5	Hamilton			
Johnston City Rend Lake Intercity Water System	Robert Colombo Supt. (618) 983-5223	500 Washington Johnston City, IL 62951	5	Williamson			3,900
Danville Inter-State Water Co.	F. Russell Mayer Supt.	P.O. Box 872 Lake Blvd PWD Danville, IL 61834	6	Vermilion			
Catlin Inter-State Water Co. Danville	Donna M. Broderick Village Clerk (217) 427-2136	109 S. Sandusky St. P. 0. Box 627 Catlin, IL 61817	6	Vermilion			
Westville Inter-State Water Co. Danville	Thomas Frankino Supt. (217) 267-7911	201 N. State St. Westville, IL 61883	6	Vermilion			
Mt. Zion Decatur	Water Dept. (217) 864-4811	400 Main St. Mt. Zion, IL 62549	6	Macon			

Appendix D. Plant Descriptions

Plant no.	Source: Surface	Source: Well	Flow, MGD: Mean	Flow, MGD: Maximum	Population served	Raw Water Quality: Turbidity, NTU	Alkalinity, mg/L	Hardness, mg/L	TSS, mg/L	Total solids, mg/L	pH	Other mg/L
SURFACE WATER SUPPLIES												
S101	Miss. R.		6.1	16	47000	14	146	184	36		7.85	Color 22
S102	Miss. R.		6.5	13	45000	16	142	174	48	280	8.0	
S103	Verm. R.		2.8	5.0	24000	0.7	205	328			7.6	
S201	L. Michigan		10.158		67700	7	107				8.1	
S202	L. Michigan		3.2	10	22000	9	110	140			8.3	
S203	L. Michigan		0.3	0.475	6000		135	141			7.9	
S204	L. Michigan		7.94	17.61	55000	10	113	141	174	190	8.0	
S205	Fox R.		7.7	11.3	75000	13.4	234	298			8.2	
		W	1.5	7.7								
S206	L. Michigan		5.8	10	31000	17.2	115	154			8.2	TDS: 200
S207	L. Michigan		1.5	5.5	9300	10	120	140			8.0	
S208	L. Michigan		3.657	7.773	17659	18.5	120	132		170	8.3	
S209	L. Michigan		0.446	1.200	2800	0.3	115	145		190	8.1	
S210	L. Michigan		10.6		78000	6.7	116	151			8.1	
S211	L. Michigan		25	50	134000	7.6	106	137			8.2	
S212	L. Michigan		578	1255/hr.	2400000	3.3	108	136	12	173	8.4	
S213	L. Michigan		426	856/hr	2000000	5.5	105	138			8.4	
S214	Kankakee R.		10.5	15.0	50000	30	169	291		382	8.05	
S301	Illinois R.		4.7	12	170000	55	180	269	425		7.9	
		W	3.9	18								
S302	Miss. R.		0.11	0.14	1400						8.0	
S303	Res.		0.72		1500	5					8.4	
		W	0.53									
S304	Miss. R.		0.12	0.36	1100	75	140	185			7.4	
S305	Miss. R.		0.28	0.46	3600	75	180	210			7.8	
S306	City lake		0.255		3000	28.9	74.5	105.4			7.31	TDS: 140
S307	L. Canton		1.4	1.6	14000	24	148	178			7.6	
S308	Lake		0.076	0.143	900	70	127	202			7.7	
S309	Miss. R.		7.5	12	50000	36.5	162.5	226.8	113.9		8.06	

S310	Res.	0.162	0.217	1825	10	325	359			7.2	
	W	0.192	0.210								
S311	2 lakes	0.103	0.160	1340	5.92	177.8	211			7.79	
S312	Blue Cr.			4000	12	160	175			7.8	
S313	Lake	0.116	0.160	1550	25	130				7.0	
S314	Lake	0.065	0.120	850		170	168			7.4	
S315	L. Springfield	17	25	145000	12	130	200	10	260	8.2	
S316	Lake	0.06	0.10	731	11.5	116				7.5	
S317	L. Kincaid & Sangchris L.	0.30	0.30	1600	0.40	38	200			8.5	
S318	L. Taylorville	1.5	2.75	12000	33.3	150	215			7.6	Ca: 145
	W	1.0	2.50								
S319	White Hall L.	0.225	0.800	2800	35	85	144			8.0	
S320	X	0.311	0.470		4.0	260	313			6.7	
	W	0.300	0.400								
S321	L. Carlinville	0.757		5600	15	100	153	220		7.6	
S322	New & old lake	0.627	1.140	6000	60	65	140	50		7.3	
S323	Mt. Olive old res,	0.235	0.400	23000	10	106	93			7.7	
S324	L. Hillsboro	1.0	2.0	8000	30	90	125			7.4	
S325	Staunton Res.	0.43	0.74	5000	12					8.1	
S401	Silver L.	1.215	1.500	7500	60	60	75			7.9	
S402	Sorento Res.	0.063	0.080	750	0.35						
S403	Carlyle L.	0.032									
S404	Kaskaskia R.				20	100	200	30		8.0	
S405	Kaskaskia R.	0.7	1.049	7000	90	130	170			7.9	
S406	Shoal Cr. .	0.545	0.746	4000	108	150	225			7.7	
S407	Kaskaskia R.	0.700	0.850	3600	25	128	170			7.4	
S408	3 lakes	0.444	0.538		12	120	124			7.0	
S409	37-acre lake			1100	3.0	36	80			7.3	
S410	Res.	0.6	1.0	5000	7	160	180			7.5	
	Kaskaskia R.	0.5	0.75								
S411	Kaskaskia R.	0.125	0.170	850+	0.90			3.0	3.3	7.6	
S412	Miss. R.	0.750		6000	130	120	190			8.0	
S413	Gov. Bond L.	0.660	0.832								
S501	Kaskaskia R.	0.504	0.533	1100	2.6	165	220				
S502	L. Nellie	0.217	0.347	3000	8.6	84	100			7.7	
S503	Borrow Pit	0.066	0.144	600	13.8	89.5	131				
S504	Res.	1.3	1.8	11000	12	140	210		250	7.8	

Appendix D. Continued

Plant no.	Source: Surface	Source: Well	Flow, MGD: Mean	Flow, MGD: Maximum	Population served	Raw Water Quality: Turbidity, NTU	Alkalinity, mg/L	Hardness, mg/L	TSS, mg/L	Total solids, mg/L	pH	Other mg/L
S505	New Altamont Res.		0.250	0.576	2400	9.4	58	65	9		7.0	
S506	Salem Res.		1.250	1.8	8000	75	75	75			7.0	
S507	Raccoon L.		3.7	4.5	25000	75	50	105	16		7.1	
S508	Little Wabash R.				1200	50	160	324		TDS 430	7.6	
S509	Wabash R.				6000						7.5	
S510	East Fork L.		1.1	2.5	9000	2.1	52	86	150		7.5	
S511	Res. 1, 2, & 3		0.800	2.1	17200+	9.5	54	138			8.5	
S512	Skillet Fork R.		0.175	0.225	1000	15	90	190			7.7	
S513	Little Wabash R.		0.950	1.4	6000	80	120	180			7.2	
S514	Shale pit & lake		0.1	0.14	1120	0.2	56	145	22	240	8.2	
S515	Lake		0.563	0.951	3400	7.4	64	114			7.2	
S516	Lake		13.8	15.7		6.2	45	95			7.7	
S517	Cedar Creek L.		4.6	6.4	65000	9.7	37	42			6.6	
S518	City lake		1.6	2.4	18000	4.0	79	146			7.7	
S519	Eldorado Res.				2884	8.5	21	67			7.9	
S520	Res.		0.18	0.22	2000	4.3	75	74			7.8	
S521	80-acre lake		0.090	0.125	850	19	75	120			7.4	
S522	75-acre lake		0.375	1.404	1750		35	59			8.2	
S601	L. Eureka		0.524	0.570	5000	45	228	231		25	7.5	Fe: 0.22
S602	L. Bloomington & L. Evergreen		8.5	12.0	50000	19	127	229			8.1	
S603	Salt Fork R.				1600							
S604	North Fork Vermilion R.		8.5	11.0	55000	36	169				8.1	
S605	Little Vermilion R.		0.436	0.579		19.9	238				7.7	
S606	Lake Decatur		27	36	100000	36.2	192	260			8.1	
		W	0.809	5.4								
S607	Paris Twin Lakes					55	131	230			8.1	
S608	L. Oakland		0.10	0.22	1035	79	204				7.5	
S609	L. Paradise					25	160	232		290	8.0	

S610	Embarras R. to side channel		1.7		20000	23	148	200	270	250	8.0	
S611	L. Mattoon		0.123	0.153	1700	14	106	150	200		7.6	

GROUND WATER SUPPLIES

G101	#2	0.08	0.185	2400							
	#3	0.12	0.30								
G102	W	4.8	5.5	27000		331	413			7.7	
G103	W	0.168	1.6	44000		266	332		484	7.6	
	W	7.0	12.0								
G104											
G105	W	0.967	1.939	13600		325	404			7.7	Fe: 2.1
G106	W										
G107	W	4.0	5.3				410			7.7	
G108	W	0.8	2.25	4529		272	288		300	7.5	
G109	W	0.3		3000							
G110	W	0.25	0.31	2643						7.8	
G111	W	3.5	10.0	8600							
G112	W	0.48	0.53	3300							
G113	W	1.5	6.0	9200							
G114	W										
G115	W	1.0	0.9	5300							
G116	W	0.9	1.3	4600		280	305			7.5	
G117	W	1.8	5.8	17000		320	375			7.1	
G118	W	0.99	1.4	11000		216	314			7.1	
G119	W			15000							
G120	W	0.565	0.870	7100		231	261		870	7.9	
G121	W	0.65	0.95	6000			223			7.3	
G122	W	0.17		2000		377	157			7.5	
G123	W	0.225	0.728			242	183			7.7	
G124											
G125	W	0.475	0.550	3400		302	119		870	8.1	
G126	#6	0.72	1.86	8000		310	300			7.6	Fe: 3.4
G127	W	1.2	1.8	7000		299	312			7.6	
G128	W	1.8	3.8	10700		384	564		700	7.2	
G129	W	2.2	2.8	18700	2	310	300				
G130	W	0.12	0.40	2000		288	314				Fe: 0.0 Mn: 0.01

Appendix D. Continued

	Source		Flow. MGD			Raw Water Quality						
Plant no.	Surface	Well	Mean	Maximum	Population served	Turbidity, NTU	Alkalinity, mg/L	Hardness, mg/L	TSS, mg/L	Total solids, mg/L	pH	Other mg/L
G131		W	0.30	0.54	3800		387	106			7.5	
G132		W	0.425	1.5			280	366		500	7.5	
G201		W	2.4	3.2	11750	2	353	414	506		7.14	
G202		W	1.1	2.5	11000						7.4	
G203		W	2.7	3.6	18631		257	226	<1	280	8.0	
G204	Lake Cty. PWD		0.03		5400		190	157			8.0	
		Deep	0.23	0.936								
		Shallow	0.08	0.216								
G205		W	0.288	0.432	6800		385	449			7.7	
G206		W	0.441	0.961	7000		241	215		398	7.8	Conductance 201
G207		W	1.4	103	16000	4.5	222	227		358	7.7	
G208		W	0.37	0.539	6300		180	200		402	7.9	
G209		W	0.53	0.793			396	377		423	7.6	
G210		W	0.694	3.1	17300							
G211	Spring		0.153	0.336	2700		325	379	460	460	7.7	
		#2	0.016	0.473								
		#3	0.245	0.766								
G212		W	0.249	0.290	6600	16	296	357	413	410	7.9	
G213		W	0.9	1.3	20000		300	430	490		7.5	Fe: 2.1 Mn : 0.033
G214		W	2.0	3.0	10000	1.6	270	237		506	6.8	
G215		W	0.953	1.6	7200							
G216		W	1.124	1.989	11200		281	422		598	7.3	
G217		W										
G218		W										
G219		W	4.0	5.916	29000		369	638		760	7.0	
G220		W	5.3	10.8	46000		289	270	532	520	7.6	
G221		W	2.2	3.2	12700		277	363				
G222		W	4.937	10.10	47500		343	569		696	7.4	
G223		W	3.483	6.250	14000		286	264			7.3	
G224		W	8.5	14.1	72000		285	350			7.4	

G225												
G226		W	5.0	12.0	42000		355	530			7.3	TDS: 600
G227		W	2.5	4.3	16726	5.2	374	720			6.88	TDS: 814
G228		W	2.6	4.6	25100		313	650			7.2	
G229		W	1.2	5.2	24500	0.10	340				7.1	
	L. Michigan		1.4	8.1								
G230		W	2.5	4.5	30178		297	240			7.7	
G231	L. Michigan		4.0	9.5	32000							
		W	3.0	3.0								
G232		#1.2	1.218	1.944	13000	2.4	274	291	494	968	7.7	F: 1.07
		#3,4.				5.0	332	215	613	1221	7.6	F: 1.69
G233		W	0.334	0.420	13500		291	393		606	7.9	
G234		2 deep	1.29		5600							
		1 shallow	0.624									
G235		W	1.0	2.1	10100		341	547			7.6	TDS: 640
G236		W			5437							
G237		W	0.470	1.755	3800		394	545			7.5	
G238		W	0.99	1.399	5000		279	358			7.5	TDS: 410
G239		W	0.271	0.405	3360		258	223			7.7	F: 1.15
G240		W	0.38	0.6	4200		328	288				TDS: 370
G241		W	1.8	4.0	1600							
		W	0.15	0.5								
G242		W										
G243		W	1.5	1.8	16000							
G244		W	1.0		10000		268	251			7.4	TDS: 450
G245		W	0.245	0.750	5200		273	242		245	8.0	
G246		W	0.270	0.432	5800		284	796		790	7.0	
G247		W			6800		374	402		472	7.6	
G248		W	0.55	1.0	4500							
G249		W	0.35	0.9	2920		315	350			7.0	TDS: 898
G250		W	0.9	1.0	3300							
G301		W	1.4		10000							
G302		W	6.5	10.0	35500	11.0	201	224	50	280	7.4	
G303		W	1.2		3700							
G304		W	0.9	1.2	6138							
G305		W	1.0	1.5	7500	2.2	420	460	<2	470	7.3	
G306	Res.		0.072		1500		360	460			7.0	
		W	0.053									
G307		W	0.52	0.83	3700			410				Ra: 50pCi/L

Appendix D. Concluded

Plant no.	Source: Surface	Source: Well	Flow, MGD: Mean	Flow, MGD: Maximum	Population served	Raw Water Quality: Turbidity, NTU	Alkalinity, mg/L	Hardness, mg/L	TSS, mg/L	Total solids, mg/L	pH	Other mg/L
G308		W	0.12	0.16	1300		440	508		530	7.2	
G309		W	2.3	3.2	23000							
G310		W			9000		326	284		340	7.9	
G311		W	0.7	0.9			350	558		730	7.2	
G312		W	2.0	4.5	15000	8.5	423	325	420	440	7.5	
G313		W	4.4	7.1	35000	0.4	336	382	684	684	7.2	
G314		W	0.45	0.70							7.4	
G315		W			4300		160	180		220	7.8	
G316		W	0.267	0.465	2700							
G317		S. Wells	2.3	3.53	16500		280	350			7.4	
		N. Wells	0.573	0.94								
G318		W	1.6	4.0	6300	1.5	225	300			7.0	
G319		W	0.25	0.30	2860		229	295	336	340	7.8	
G320		W	0.175	0.240	3000	0.4	347	526			7.2	
G321		W	1.0	1.25	7500		380	394			7.0	
G401		W	1.5	2.2	22000		300	450		540	7.1	
G402		W	1.5	3.0	15000	<0.05					7.2	
G403		W	1.8	2.6		5.5	178	270		310	7.6	
G404		W	0.592	1.584	6500		297	405			7.4	
	Buy from Maryville		0.592	2.0								
G405		W	0.750	1.2			296	225			7.6	
G406		W	2.6	3.5	20000	6	335	523		508	7.4	
G501		W	0.518	0.518	3200			285			7.7	
G502		W	1.2	5.7	10500							
G503		W	0.85	2.8	6000	tr	148	216			7.7	
G504		W	1.2	1.6	10000	2.0	310	274			7.0	Fe: >20
G505		2	0.57		7300							
		1	no meter									
G601		W	0.249		2500							
G602		W	0.35	0.85	4200							

G603	W	0.448	0.75	3500		302	440			7.2
G604	W	3.5	6.0	38000	3	425	430			7.3
G605	W	0.194	0.346	2870			385			7.0
G606	W	0.650	0.800	5000		360	350.			
G607	W	0.2	0.3	2200						
G608	W	3.4		8000		425	302		522	7.7
G609	W	1.5	2.4	46785			239			8.16
G610	W	1.4	2.9	11000	3	330	250			7.5
G611	W	16.68	22.242	104709	0.7	340	262	342		7.7
G612	W	0.8	1.0	6400						
G613	W	0.2	0.3	2200			350			
G614	W	0.673	0.768	4500			340			
G615	W	0.3	0.4	2700		130	160			7.4
G616	W	0.637	0.813	5300						
G617	W	0.5	1.0	5000						

Appendix El. Treatment Processes - Surface Water Plants

Plant no.	Coagulation, sedimentation, & filtration	Lime softening & filtration	Coagulation, sedim., lime softening, & filtration	Filtration Direct	Filtration Pressure	PAC,* GAC	Aeration	Fluoridation	PO^4
S101	X								
S102			X			p			X
S103	X							X	
S201	X								
S202	X								
S203				X					
S204	X					P		X	
S205			X			P,G			
S206	X			X		P			
S207	X							X	
S208	X					P		X	
S209	X							X	
S210	X					P		X	
S211	X					P		X	
S212	X					G		X	
S213	X					G		X	
S214			X		X	G			
S301	X					G			
S302	X								
S303	X								
S304	X					P			
S305			X						
S306	X								
S307			X	X		P	X		X
S308			X			P		X	
S309			X			P			X
S310	X								
S311			X	X		P			
S312			X			P			X
S313			X			P			
S314		X				P			

S315		X		P		
S316		X	X	P		
S317	X					
S318		X				
S319	X					
S320		X				
S321	X		X			
S322	X			P		X
S323	X		X	G		
S324	X		X			
S325	X					X
S401	X					
S402		X				
S403	X					X
S404	X			P		
S405	X			G		
S406	X		X	P		
S407		X				
S408		X		P		
S409	X					
S410		X		P		
S411		X	X			
S412		X	X			
S413	X					
S501		X				
S502		X				
S503	X		X			X
S504	X					
S505	X					
S506	X					
S507	X					
S508	X		X	P		
S509	X			G	X	
S510	X					
S511	X					X
S512	X					
S513		X	X			
S514		X				

Appendix El. Concluded

Plant no.	Coagulation, sedimentation, & filtration	Lime softening & filtration	Coagulation, sedim., lime softening, & filtration	Filtration Direct	Filtration Pressure	PAC, GAC	Aeration	Fluoridation	PO^4
S515	X								
S516	X			X		p			
S517	X								
S518	X								
S519	X								
S520			X						
S521			X						
S522	X								
S601			X	X			X		
S602			X			G			
S603	X								
S604	X								
S605	X					p			
S606			X			p		X	X
S607	X					p			
S608	X			X					
S609			X			p			
S610			X	X		p		X	
S611			X			p		X	

PAC or P = powdered activated carbon; GAC or G = granular activated carbon.

Appendix E2. Treatment Processes - Ground Water Plants

Plant no.	Fe(Mn) Removal A	Fe(Mn) Removal R	Fe(Mn) Removal P	Fe rem. & zeolite softening	Softening Lime	Softening Lime/ soda ash	Softening Zeo- lite	Coagulation, sedimentation, & filtration	Filtration Rapid sand	Filtration Pressure	Cl^2 only	Fluori- dation	PO^4
G101											X		
G102	X	X						X	X				
G103											X	X	
G104													
G105	X	X							X			X	
G106											X	X	
G107											X	X	
G108											X	X	
G109											X	X	
G110											X		
G111											X		
G112											X	X	
G113											X		
G114											X	X	
G115			X						X			X	
G116	X											X	
G117			X							X		X	
G118			X	X				X		X			
G119											X		
G120		X											
G121											X		
G122	X	X										X	
G123	X												
G124											X		
G125	X												
G126	X	X			X			X	X			X	
G127			X						X	X		X	
G128											X		
G129											X	X	
G130	X											X	
G131											X		
G132											X	X	

Appendix E2. Continued

Plant no.	Fe(Mn) Removal*			Fe rem. & zeolite softening	Softening			Coagulation, sedimentation, & filtration	Filtration		Cl_2 only	Fluori-dation	PO_4
	A	R	P		Lime	Lime/ soda ash	Zeo-lite		Rapid sand	Pressure			
G201	X						X		X			X	
G202	X								X X				
G203							X						
G204											X		
G205			X							X		X X	
G206											X		
G207											X		
G208											X		
G209											X		
G210											X		
G211											X	X	
G212	X		X										
G213	X								X				
G21A	X												
G215											X		
G216											X		X
G217											X	X X	
G218													
G219			X										
G220											X		
G221											X	X	
G222											X		
G223											X		
G224	X		X									X	X
G225											X		
G226											X	X	
G227	X					X		X	X			X	
G228											X	X	
G229				X									
G230											X		
G231								X Have used L. Michigan water since May 1986					
G232					X			X	X				
G233											X		

G234										X		
G235										X	X	X
G236										X	X	
G237										X		
G238										X		
G239										X		
G240										X		
G241										X		
G242										X		
G243										X		
G244										X		
G245										X	X	
G246	X		X									
G247						X					X	
G248										X		
G249										X	X	
G250										X		
G301										X		
G302			X								X	
G303										X		
G304										X	X	
G305										X		X
G306	X	X	X	X			X	X				
G307	X			X								
G308	X	X	X					X				
G309			X					X				
G310		X	X			X						
G311										X	X	
G312	X	X	X			X					X	
G313										X		
G314	X							X				
G315			X						X			
G316										X		X
G317	X	X	X				X		X			
G318			X					X	X		X	
G319	X		X			X					X	
G320	X		X		X							
G321			X	X			X				X	

Appendix E2. Concluded

Plant no.	Fe(Mn) Removal			Fe rem. & zeolite softening	Softening			Coagulation, sedimentation, & filtration	Filtration		Cl$_2$ only	Fluoridation	PO$_4$
	A	R	P		Lime	Lime/soda ash	Zeolite		Rapid sand	Pressure			
G401	X	X	X	X			X			X		X	
G402					X			X	X			X	
G403				X			X			X			
G404											X	X	X
G405	X	X								X			
G406	X	X			X			X	X				
G501		X	X						X			X	
G502											X		
G503		X										X	X
G504	X				X			X	X				
G505											X	X	
G601	X	X	X	X			X					X	
G602											X		X
G603	X					X		X	X				
G604	X				X			X	X				X
G605	X	X	X	X			X			X			
G606											X		
G607											X		
G608	X		X	X						X		X	
G609	X	X	X				X	X		X			
G610	X				X			X	X				X
G611					X			X	X				X
G612	X	X	X										
G613	X	X	X	X			X						
G614					X			X	X				
G615					X				X	X			
G616											X		
G617											X		

S205		X	X		
S301	X			X	X
S303			X		
S310			X		
S320	X		X	X	

[*] A = aeration; R = retention; P = pressure sand filter.

Notes: Plants S205, 301, 303, 310, and 320 use both ground water and surface water sources.

Appendix Fl. Chemical Dosages

Plant	Alum, lb/d		$FeCl_3$, lb/d		Polymer, lb/d		Activated Carbon, lb/d		
							Granular	Powdered	
no.	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Avg.	Range
SURFACE WATER SUPPLIES									
S101	2618	750-6000			54	40-140			
S102	493		493*	163-542	19.5	16-23		174	11-423
S103	91	88-120							
S201	104	85-174							
S202	12								
S203	25								
S204	293	224-397			123	79-172		64	0-150
S205	2455	767-3836	230	76-460	0.76	0.08-3.8		821	153-3836
							276		
S206	593						1.6		
S207	100	80-120			6	4-10			
S208	225	150-300			14	9.6-22		24	6-115
S209	49						4.4		
S210	700	530-850						40	22-164
S211	1530	724-2938			76	43-155	547		142-983
S212	12540	8680-16870			1450	1350-1540	868		0-6270
S213	8940	1704-10650			1170	426-1490	732		0-17040
S214			1200	200-3000	50	0-50	10		0-500
S301	900	431-1764			71	39-118			
S302	150	100-400					6		5-8
S303	44	68-104							
S304	100	50-200						0.3	0.1-1.5
S305	25	20-30			30	15-45	6		3-9
S306	12				52.6			2.7	
S307	240	100-300						40	0-50
S308	142	50-350					5		0-8
S309			488	313-2500	41	13-281		138	0-181
S310	50	25-60							
S311	21.5	15-20					7.46		4-20
S312	17	10-18					1		0.8-1.1

S313	40						6		
S314	25								8
S315			992*	567- 1700				142	0-284
S316	15	10-20					0.5		0.2-1.5
S317	100								
S318	355	41-1140			73	33-147			
S319	305	250-350							
S320	124								
S321	190				12.6				
S322	440							5	
S323	153	100-200			3.8	2-6		5.5	3-7
S324					334	250-542			
S325	178	50-300			3.9	2-17			
S401	700	150-1500			40	20-50 (summers)			
S402	40								
S403	24	18-32							
S404	X								
S405	130	80-230							
S406	310	50-1250			2			2.3	1.3-3.5
S407	450								
S408	6	5-8					1		1-1.1
S409	100	80-115							
S410	135				2			44	
S411	56.5	45-65							
S412			86	44--142					
S413	361								
S501	36	30-50					0.82		0.01-2
S502	49	16-70							
S503	22	17-30			0.7	0.5-1.5			
S504	488	380-600						54	
S505	90	67-136							
S506	730	365-1043			16	7.8-21			
S507	1942				100				
S508	200							6	
S509	410						15		
S510	157	110-275							
S511	254	100-400							
S512	41								

Appendix Fl. Concluded

Plant	Alum, lb/d		FeCl$_3$, lb/d		Polymer, lb/d		Activated Carbon, lb/d		
							Granular	Powdered	
no.	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Avg.	Range
S513	482	100-800							
S514	25								
S515	303								
S516	2110	1070-4700			192	114-319		625	470-675
S517	56				148				
S518	555	467-600							
S519	72								
S520	200								
S521	145	90-225							
S522	172	125-219							
S601	158	90-350							
S602							X		
S603	75	50-150			0.13				
S604	2410	0-12700			59	0-125			
S605	166	100-250						3.6	0-20
S606	1890	900-14640			158	56-2252		450	338-1800
S607	667	300-1000			1 mg/L	0.5-1 mg/L	1.5 mg/L		0.5-2 mg/L
S608	X								
S609	288				15			17	
S610	5	2.2-7			0.3	0-2.5		1.3	0-5
S611	11				1		10		
GROUND WATER SUPPLIES									
G102					0.34				
G118					4.1				
G232	169	158-183							
G306	5	1-15							
G307	25								
G315					0.17				
G321	195								

G402	223					
G405					3.1	2.9-4.4
G406	175	150-190				
G504	250	210-280				
G603	60	45-75			2.6	2.2-3.4
G604	290	146-438				
G610	1035	690-1380				
G611			600	390-740		
G614	60					
G615					0.5 gpd	

Ferric sulfate is used instead of $FeCl_3$.

Appendix F2. Chemical Dosages

Plant	Lime, lb/d		Caustic soda, lb/d		Chlorine, lb/d		Fluoride, lb/d		Other		
no.	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Chemical	Mean	Range
SURFACE WATER SUPPLIES											
S101	993	0-2600			534	200-1000					
S102	6722	5963-7860			276	244-363			PO_4	103	103-108
S103					133	130-186			H_2SiF_6	87	85-90
S201					18	16-20			$KMnO_4$	2.3	2.1-2.4
S202					2.1				$KMnO_4$	0.18	
S203					7.0						
S204					18	12-21	12.2	11.7-13			
S205	15120	11510-19180	1610	0-2300	830	230-1150			$KMnO_4$	84	38-107
S206					99				$KMnO_4$	3 8	
S207					25	15-35	70	50-100	$KMnO_4$	0.5	0.1-0.7
S208					53	31-106	41	32-68			
S209					4.7		4.9				
S210			318	265-353	180	158-212	90	88-97			
S211					467	233-888	1222	306-1833			
S212	10120	5303-17840	48	0-3470	7710	5790-10120	4480	4340-5790	$KMnO_4$	11	0-682
S213	6490	3410-10650	51	0-4260	5690	3410-6390	3090	2810-3240	$KMnO_4$	7	0-30
S214	10700	7000-15000	700	0-2000	250	100-500					
S301	704	0-1174			313	196-391					
S302	60	50-150			10	7-20					
S303	6	7-15			X						
S304	50	25-75			5	3-10			$KMnO_4$	4	2-6
S305	300				20	5-35			PO_4	23	20-30
S306	30.3				22.1				$KMnO_4$	10	0-13
S307	1410	900-1600			67	30-90			$KMnO_4$	19	16-37
S308	65	25-150			6	3-12	37	33-73	PO_4	6.3	3.1-25
S309	8820	5630-10630			437	250-876			$KMnO_4$	2	2-3
S310	40	25-50			10	8-18					
S311	165	100-200			1.6						
S312	88				30	22-35	0.5	0.4-0.6			
S313	130				6						

S314	35				5				$KMnO_4$	7	
S315	13470	12760-14890			851	709-1130					
S316	7	4-9			3	1-5					
S317	250	300			30						
S318	1760	650-3520			80	40-150					
S319	143	100-150			8	7-9					
S320	27.3				5						
S321	253				95						
S322	280				60		7				
S323	74	50-100			11	3-19					
S324	125	92-192			50	35-60					
S325	95	50-250			30	8-84	17	7-30			
S401	400	100-850			80	30-160					
S402	18				6.3						
S403	8.4				2.2		1.9				
S404	X				X				$KMnO_4$	X	
S405			65	40-120	8	6-13					
S406	133	48-310			35	25-45			$KMnO_4$	0.75	
S407	200				350						
S408	49	39-62			8	7-9					
S409	80	70-100			8	6-10					
S410	511				28				$KMnO_4$	1.8	
S411	38.5	30-42			1.8	0.5-2.0					
S412	969	872-1070			49	38-59					
S501	560	530-590	71	60-80	6	2-10					
S502	45	21-55			12	11-16					
S503			18	11-57	15.3	7.3-21.8	18	13-22	$KMnO_4$	0.63	0.08-0.99
S504	380	325-434			80	70-90					
S505	5	0-25	115	73-146	15	8.9-14.6			$KMnO_4$	0.4	0-2.1
S506	209	104-313	365	209-521	104	73-125			$KMnO_4$	31.3	20.8-41.7
S507			1276		180				$KMnO_4$	40	
S508	175		8								
S509	214				33						
S510			202	0-321	50	35-69					
S511	167	100-267			40	27-67	6.7	6-8			
S512	35				6.6				$KMnO_4$	2.5	
S513	241	100-300			67	60-90					
S514	50	50			1.8	1.5-2.0					

Appendix F2. Continued

Plant	Lime, lb/d		Caustic soda, lb/d		Chlorine, lb/d		Fluoride, lb/d		Other		
no.	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Chemical	Mean	Range
S515			515						$KMnO_4$	20	
S516	4170	3860-5070			581	408-770			$NaClO_2$ NH_3	368 54	278-496 46-65
S517	11		704		207						
S518	363	334-467			36	24-53					
S519			48		25						
S520					14				$NaClO_2$	50	
S521	100	90-225			5.8	4-8					
S522	84	63-109			24	14-28					
S601	936	750-1800			19	7-56					
S602	8110				273						
S603					10	5-20					
S604	18	0-250	631	0-3440	336	178-663			NH_3	28	17-45
S605	5.7	0-13			21	14-27			$KMnO_4$	56	23-1130
S606	29270	22520-39410			585	338-901	360	270-450	PO_4	113	90-169
S607	450	300-600			140	70-200					
S608					X						
S609	3112				143				$KMnO_4$	20	
S610	2800	1340-3500			73	29-162			$KMnO_4$	4.8	0-23
S611	100				2.5		117	8-375	$KMnO_4$	3	
GROUND WATER SUPPLIES											
G101											
G102					208						
G103					17.9	12-30	60	54-72			
G104											
G105					22	8-70	56	0-94			
G106					X		X		H_2SiF_6		
G107					16.7	6.7-23.4	30	30-40	PO_4		
G108					9	8-10	10				
G109							9	9-10			

G110					2.1						
G111					37.5	35-40					
G112					10		12				
G113					24	20-30					
G114					X		X		PO_4	X	
G115					5	5	20	20-23			
G116					75 (15% soln.)		30 (25% soln.)			0.28	East Plant
G117					7.7				Na_2CO_3	8.2	West Plant
	94.8				40.9				$KMnO_4$		
G118					48.9					2	2-3
G119											
G120					34	20-45			PO_4		
G121					11	8-15					
G122					0.6		1.5				
G123					10.5						
G124											
G125					45	40-50					
G126	1921	1801-2042			60	54-66	6.6	6-7.8			
G127					35	32-36	26	22-28			
G128					30	27-38				16	
G129					3.6	1.8-18.3	18	16.5-20.2			
G130					2		1				
G131			55		19				PO_4	11600	3020-19300
G132											
G201			26	26-44	23	8-36	35	12-70	NaCl		
G202					15					3 '	2-4
G203					75					5	3-6
G204					0.02						
G205					13	10-14	0.25	0.1-0.5	PO_4 $KMnO_4$		
G206					4.4	2.0-7.3					
G207											
G208					4	2-6					
G209					2.4	2.0-2.5					
G210											
G211					4.2	3.2-4.5	16.6	10-19			
G212					12	11-13					
G213					14.6	13-16					

Appendix F2. Continued

Plant no.	Lime, lb/d Avg.	Lime, lb/d Range	Caustic soda, lb/d Avg.	Caustic soda, lb/d Range	Chlorine, lb/d Avg.	Chlorine, lb/d Range	Fluoride, lb/d Avg.	Fluoride, lb/d Range	Other Chemical	Other Mean	Other Range
G214					45						
G215					50						
G216					24	16-37					
G217					X		X		PO_4	x	
G218									$KMnO_4$	7.5	5-10
G219					15						
G220					60						
G221					22	18-26	20	17-22			
G222					148.5						
G223					58					284	0-284
G224					71		71	64-78	PO_4		
G225											
G226					80		140	120-160	Sodium Hexameta-phospate	25	
G227	8769				48		88		Na_2O SiO_2 Na_2CO_3	222 6245	
G228					33	22-44	85				
G229											
G230											
G231											
G232	1539	1354-1600			21	20-24			CO_2	85	60-94
G233											
G234											
G235					15		20.4		PO_4	10.6	
G236					9696		634.98				
G237											
G238					3	2-4					
G239					6						
G240											
G241											
G242											
G243											
G244					40	30-50					

G245			178		155				
G246									
G247			23.58		7.17		NaCl	2380	
G248									
G249			1.5	0.6-3.5	2.9	2.6-3.5	$KMnO_4$	2.0	1.2-2.9
G250			11						
G301									
G302							Nalco 110A	1.5	
G303			18	16-20					
G304			X		X				
G305			10	5-30			PO_4	10	10-20
G306	170	50-300							
G307	1024		13.1				$KMnO_4$	0.25	
G308			42				$KMnO_4$	2.5	
G309							NaCl	3500	
G310			22						
G311			10						
G312			200		11.7		$KMnO_4$	33.7	
G313			9	6-15			NaCl	9000	
G314			5						
G315			4				$KMnO_4$	2	
G316			5.3				PO_4	11.7	
G317			100				$KMnO_4$	4.8	
G318			60		32		$KMnO_4$	14.5	
G319			80		99		NaCl	750	
G320	650		3				Na_2CO_3	70	
G321	2003		26.2		27.9				
G401			25		49		NaCl	6900	
G402	2316		55		42				
G403			20	16.5-22.5			NaCl		
G404			7		24		PO_4	75	
G405			4.4	4.3-4.6			$KMnO_4$	3.1	
G406	4600	4000-5000	50	46-54					
G501			3		4.3				
G502			7.2						

Appendix F2. Concluded

Plant no.	Lime, lb/d Avg.	Lime, lb/d Range	Caustic soda, lb/d Avg.	Caustic soda, lb/d Range	Chlorine, lb/d Avg.	Chlorine, lb/d Range	Fluoride, lb/d Avg.	Fluoride, lb/d Range	Other Chemical	Other Mean	Other Range
G503					17	17-20	33	35	Sodium Hexametaphosphate	12	12-15
G504	2000	1900-2200			150	100-200					
G505					50		50				
G601					27		16		NaCl	1390	
G602									PO_4	15	
G603	897	747-1046			5	3-7.			CO_2	46	25-60
									Na_2CO_3	82	67-112
G604	11000	10200-11700			88	65-102			PO_4	5.8	
G605					4.1	3.4-4.9			NaCl	1100	975-1242
G606											
G607					340						
G608					135		11				
G609					0.3				NaCl	2114	
G610	1600	1200-2000			100	60-150	60	50-70			
G611	31860	30600-33530			1000	490-2000	570	480-640	Na_20		
									SiO_2	1030	790-1140
									H_2SO_4	5150	3120-7540
G612					241						
G613					11	10-12	84		NaCl	9860	
G614	2500				16						
G615	300				20						
G616											

Appendix G. Basin Information

Plant	No. of units					Size,	Depth,	Detention time,	Sludge generated	
no.	Pre-sedimentation	Flocculation	Sedimentation Primary	Sedimentation Secondary	Softening	sq ft	ft	min.	lb/d	gal/d
SURFACE WATER SUPPLIES										
S101		2				867	17		2644	
			2			28920	21		total	
S102		2			2	5050	18	150	15884	
			4			10100	18	300		
S103	1	4				2000	10	120	2-4 inches/y	
			4			5000	10	300	2-4 inches/y	
S201										
S202		4				3800	17	180	360	
			5			11500	17	720	730	
S203										
S204		4				1000	17	30+		1150
			4			1000	17	30+		total
				4		4000	17	240		
S205				2		14313	15.75	263		60000
					2	4418	16	165		60000
S206		4				546	15	61		
			4			2580	15	288		600
S207		2				1406	19	720		
			2			1672	30	720		
S208		6				1176	14	45		
			2			6625	14	300	600	
S209	1	1				414	14.5	30		
			1			414	14.5	30		
				1		1769	14.5	30		
S210		1				1584	14.5	83		
		2				2754	7.8	78		
		2				3195	9.4	81		
			1			4195	14.5	300	290	
			2			9491	8.5	366	870	
			2			12686	10	339	1120	
S211			4			1.8. mil. cu. ft.		600		

Appendix G. Continued

Plant no.	No. of units Pre-sedimentation	 Flocculation	Sedimentation Primary	 Secondary	 Softening	Size, sq ft	Depth, ft	Detention time, min.	Sludge generated lb/d	 gal/d
S212		16				13000	20	45		
			16			76000	32	225	56300	
S213		5	two level basins			16800	33	93		
			5 two level basins			67200	33	279	28045	
S214		3				3600	15			
			2			13600	15			150000
				2		17700	15			150000
S301		2								
			2							
S302		1				5000 gal				
			1			900	11			
S303		1						60		3000
S304		1				240	10	72		
			2	Accelators		144	10	72		
						100	10	74		
S305		1 Clarifier cone								
			same		1	531	20	43		
			1 Re. carb. basin			721		90		
S306			1			1017	15	131		
S307					2	225	20	100	4000	
S308			1			90	10	300		
S309	1			1 Presed.		18800	31	112		
					1	6624				
S310	1	1				380	12.5			
			1			796	10	340 for both		
S311		1				160	10	94		3000
			1			160	10	94		3000
					1	160	10	94		3000
S312		1				873	13	120		
			1			873	13	120		
S313		1				288	15			
			1			1444	15	480		
S314										

S315					5	2800	20	120	50000	
S316		1				133	10	94		
S317										
S318		2				1046	22	38		
			2			1046	22	60		
				2		1053	13	60		
					2	1046	22	37		
S319		1				464	14.7	102		
			1			1722	14.5	375		
S320										
S321		1					15	15		
			2				20	240		
S322	1		1 Infilco			250	18	90	792	
S323		1				31	11	60		
			1			1434	11	240		
S324		2				180	9	21		
			2 tube settlers			187	9	36		
S325		1				328	11	60		
			1			1620	11	300		
				1		1620	11	.300		
S401		1	1							
S402		1					20			
S403										
S404	1									
S405		2				169	12	30		
			2			1369	12	246		
S406		5				350	12	30		150
			2			4000	12	240		1650
S407		3				100	10	20		
			2			1176	10	20		
				1		210	10	20		
					1	25	5	5		
S408			1				12	90		
S409		1				550	9			
			1			600	9			
S410		3				900	8	67		
			2			1800	15	126		
S411			2			1200	16	3		

Appendix G. Continued

Plant no.	No. of units: Pre-sedimentation	No. of units: Flocculation	No. of units: Sedimentation Primary	No. of units: Sedimentation Secondary	No. of units: Softening	Size, sq ft	Depth, ft	Detention time, min.	Sludge generated lb/d	Sludge generated gal/d
S412		1				11250	14	75		400
			1			11250	12.5	75		466
S413										
S501	1	1				225		70		90
			1			100		120		9000
				1		144		60		40000
					1			120		
S502		1				220	12	75		
			1			264	12	90		
				1		230	12	80		
S503	1	Neptune Package Plant								
S504			3							
S505		1				836	10	25		
			1			2821	10	85		
S506		1				5674	11	53		for both
			2			20216	14	330		104000
S507		2				1160		35		
			2			7536				
				2 rapid mix		40	9.25	5.4		
S508										
S509			2			3600	12	90		
S510		2				804	25	270		
S511	1 Reg #1	1				80	8	20	4	
			2			2790	12	240	400	
				1 presed.		16acre	15			
S512	1									
S513		2				676	14	90 .		
S514		1				57.2	7	30		
			1			314	9	210		
S515			1			2520	11.5	8.1		
S516		4	1			9516	16	30		
S517		2				3850	15	90		

S518		1				210	7	60		
S519		1				378	10	13		
			1			1936	13	210		
				1		2025	11			
S520		1	1			1680	11.6	100		
S521			1			576	12	240	300	
S522		2				200	12	18.5		
			2			600	12	55		1000
S601		2				306-203	14	20		
S602					2	706				
					1	2826				
S603	1	2				3250	6			
			2			3600		45		
S604		2					10,12	45		
			1				17	330	28565 wet	
S605		1				315	5	33		
			2			850	25	216		
S606										
S607										
S608		1				240	12	240		
			1			333	12	240		
S609										
S610		2 small clarifiers				625	13	100		
		1 large clarifier				1376	13	135		
S611		1 Cochrane upflow reactor				200	13	60		
GROUND WATER SUPPLIES										
G101										
G102			1			3.6	16	360		
G126					1	776	14	60		15000
G130	1	1				30	10			
G201					7	570	5-6	628		
G227		1				637.6	14	27		1500
			1			3828	15	172		6000
					1	2374.6	16	114		112000

Appendix G. Concluded

Plant no.	No. of units Pre-sedimentation	 Flocculation	Sedimentation Primary	 Secondary	 Softening	Size, sq ft	Depth, ft	Detention time, min.	Sludge generated lb/d	 gal/d
G232			1			1600	15	80	666	
					1 spiractor		26	10	3613	
G247					4	16	8	4.75		900
G306		1				143	13.2	90		1000
G307					1					
G310					4					
G317		1				800	17	50		
G319					2	240 cu.ft.		3.5		
G321					1	1256	13	135		
G402		1	same units combined		1	26577	16	65	880	
G403			2			40500	9	404		
G406		1								
			1					120		52000
G504		1	1 upflow clarifier					60	3000	
G603		1	Walker upflow clarifier			50.24	8	37		
			1		1	706.5	15	89		
G604		1 Walker				2500	18	138		
			1			4417	16	217	22500	
G610		2				1860	12	120		12000
			2			1860	12	120		2% sol.
G611	East Plant		2			4301	18	262	37200	
					2	3217	19	207		
	West Plant		2 (2-4 mgd basins)			15600	17	939	23300	
					2	11600	17	691		
			1 (8 mgd basins)			12600	17	292	35200	
					1	15300	17	311		
G613			1		4					
G615		1				1200	15	270		

Appendix H. Filter Information

Plant no.	No. of filters	Size, each, sq ft	Maximum loading rate, gpm/sq ft	Media, inches			Maximum wash rate, gpm/sq ft	Washwater				
				Anthracite	Sand	GAC		Filter aid	Filter run, hr	Filter to total flow, %	TSS, mg/L	TS, mg/L
SURFACE WATER SUPPLIES												
S101	16	366	2.85	25			16					100
S102	8	433	2.6		30		13		80	2.0	112-165	260
S103	6	400	2	8	24		9		144	2.0		
S201	14			6	18				48-62	3.3		
S202	10	312.5	8@2 2@3	16	12		13.7		60	2.39		
S203	2	121	3.0	3	72		22.5		25	4.0		
S204	8		2									
S205	4	726	4		14	18	11.5		100	1.25		
S206	6	528	3	6	22		11.4	Cat Floc T	63	3		
S207	6		2	7	17		15		110	0.7		
S208	8	266	4@5.2	18			7		60	1.01		
			4@2.6		30		12					
S209	3	175	2	8	30		15		40	3		
S210	10	4@ 500 3@1050 3@1425	2	18	6		14		200	1.5		
S211	24	1344	3	6	28		7.7		300	1.1		
S212	192	1757	4		30		30	Polymer	52	1.6		
S213	120	1390	3		24		17.5	Polymer	48.5	1.3		
S214	17	320	2	24	24		15		96	2.5	700	730
S301	4	588			13.5	30	15		60+			
S302	2	105	1.7		36		15.24		10-11			1500
S303	2		3						25	2.5		
S304	2	148	3				5		50	7		
S305	3	180	1.3		30	24	14		30	0.04		1000
S306	3	127	2.36	18			15.7		15-20			
S307	8	203	2	12	26		15		40-90	2		250 TDS

Appendix H. Continued

Plant no.	No. of filters	Size each, sq ft	Maximum loading rate, gpm/sq ft	Media, inches: Anth-racite	Media, inches: Sand	Media, inches: GAC	Maximum wash rate, Rpm/sq ft	Filter aid	Filter run, hr	Washwater: to total flow, %	Washwater: TSS, mg/L	Washwater: TS, mg/L
S308	2	53	1.9				11.9		15-30			
S309	8		2	48	15					0.77	150	220 TDS
S310	3	60	2.08		30		15		10-40	9.0	3	30
S311	2	38.5	1.95	18			15.6		120	3.5		
S312	4	520	1.9				15		48	10		
S313	3	80	6				18.75		30-35			
S314	2	77	1.9		X		15					
S315	12	546	5	24	15		20		48-72	1-2		
S316	2	47.5	2.1	X			5.3		120	9		
S317	3				X				8			
S318	4	190	3	21	14	13	15		48			
S319	2	120	2.1		36		17.5		24	10	220	
S320	2				30		15		72			
S321	3	144	2		30		15		24-28			
S322	4	180	2-5		X		15		80			
S323	2	140	2.5		X		9.3		24	10		40 lb/sq ft
S324	2	150	5	30	12	42	17	Nalco 7766	24	6		
S325	2	200	1.1				6.25		8			
S401	5	120	4	12	12		18		16	5		
S402	2		100 gpm		X		75 gpm					
S403	No data											
S404	4								24			
S405	3	170	3.92		16	12	15.9		14	2.8		
S406	2	186	1.4	16	31		14		85	2.7	190	
S407	3	110	3.3	18	18		15		20		380	
S408	4	500	1.7		30		5.2		8-10			
S409	2	70	7.7		26		15.4		48	5		
S410	3	252	1.3	36	18		9.9		50	3		
S411	2	72	2.3		X		6.9		24			
S412	4	144	1.74	41					200			
S413	4	128	5	13	12		15.6		60		5.9	

S501	2	72		12	72	60	13.9	Infilco	15.5			
S502	2	66	2				15		17			
S503	1							WTH22H	8	12.75		
S504	4			X			10	X	48	2.3		
S505	3	96	1.0	6	24		15		84	4		
S506	7	4@105 3@144	3	17	15		3		96	1.5		
S507	6	304	2.28			24	14.8		50	3.5		
S508	2		10	6	6	24				10		
S509	4	180	2.0	19	12	12	13.9		24	6		
S510	4	480	1.01		8	24	7.8		152	2		
S511	5	686	2		30		2.5		45	2.5	35-120	180-360
S512	6	50	2							8		
S513	6	121.5	2		30		2		12-15			
S514	2	28	2		32		14		18	3		
S515	4	94.5			X		16.9		24	7		
S516	8	540	3		X			Polymer	90			
S517	12	4000	2			18	11		48	16	536	
S518	4								72	3.1	230	430
S519	4	275	1.9	4	6		16		8		160	221
S520	2	160			30		8		16			
S521	2	48	2		30		6.4		12	10		
S522	2	270	1.8		30		15		10-12	10.7		470
S601	4	81	3	18	8		15		24	3.82	1514	
S602	12		2	12	24				100	2		
S603	2	35.2	3.5	18	9	3	17	X	2-20			
S604	14	8@255 6@350	3		22		15	Polymer	24	3		
S605	3	304	2	19	12		17		48	4.2		
S606	8	524	2	18	12	N. Plant	15	Nalco 8103	60			
	16	6@542 6@528 4@702	2	6	28	S. Plant	15	Naloc 8103	60	2.1		
S607	4	180	2	22	26		16.6		24-48			
S608	3	169.5	2				15			10		
S609	7	195	3.5			X	15	X	48	2.6		
S610	4	180	3.25	18	18		13.9		48	3		
S611	2	63.5	2		36		15		35			

Appendix H. Concluded

Plant no.	No. of filters	Size each, sq ft	Maximum loading rate, gpm/sq ft	Media, inches			Maximum wash rate, gpm/sq ft	Filter aid	Washwater			
				Anthracite	Sand	GAC			Filter run, hr	to total flow, %	TSS, mg/L	TS, mg/L
GROUND WATER SUPPLIES												
G102	10	168	3.0	8	24		16.1	Aquafloc	15	5.6		
G105	6	91	2.5		30		15		72	25		
G115	4	50	3				12					
G117	4	90	10	8	24		9.1	$KMnO_4$	8	25		
G118	2	514	2	24			15	Nalco 8103	24	5		
G126	4	2037	3	18	8		10		60			
G127	1 gr.	176	7.4	60			30		144	5.4		
	1 gr.	64	4.7	48			30		144	5.4		
	1 pres.	514	2.92	12	16		15		144	5.4		
G201	8	948	7.4	36	48	24	30		24	.2.46		
G202	2 pressure		2.0	24			2.0		48			
	1 gravity		7.0	48			7.2		48			
G212	1	259	1.93	24		-	12		49	0.3	2.03	12.8
G213	4	162	2.7	30	12		3.5		56-70	1.0		500
G219	4	54.7	4	12	18		15					
G227	4	178.75	2.3	22	14		7		100	1.0		
	2	268.25										
G232	2	176	3.6		30		17		45-60	1.6		
	2	206	2.4		30		15					
G246	1	1165	2.58	24		16	10.3		83.3	9.0		
G302	8	314	5		24		19.1	Nalco 110A	24	2.2	3.0	
G306	2	50.73	3.2		33				30	2.2		
G307	2	254	2.75	18	18		5		70			
G308	1		12	12	18	12	12		10	14.2		
G309	8	84			24		11.9		8			
G310	5											
G312	10		3.0		30		15	$KMnO_4$	14-22	10.0		
G314				X	X							
G315	2	164	3.96	24			4.02	Nalco 8170	72	2.0		

G317	3	1125	2.93	X			12		48	3.0		
G318	3	357	2.0	7	30		15		24	3.3		
G319	4	176	2.74	24			12		12	17.0		
G320	2	64	4		X		23.4		16	20.0		
G321	4				X							
G401	5		2	30			10		48	1.5		
	6		2		24		10		48	1.5		
G402	4	264	1.7		30		15.2		16	10-15		
G403	10	78.5	3	24	6		13.8		48	2.7		0.85
G405	4	400	3	X			12	X	14	2.0		9.0
G406	4	396	2.5		X		14		96	3.0		
G501	2	100	2.0				18		15	3.33		
G504	4	105	3				14.3		18	5.0		
G505												
G601	6				24				24			
G603	6		2.3		30		17	Na Poly P	168	0.9		
G604	8	245	2	12	36		15			1.0	725	950
G605	4	164	3	24			10		18	9.4		
G608	6	45	3	6	22		8		12	5.5		
G609	2	400	2.5		24	17	15		180			
G610	8	160	2		25		20	Na tri-poly	60	3.0		
G611 East	1	921	4	26			12.2		24-72	1.69		
	9	180	4	26			12.2		24-72	1.69		
West	2	960	4		26		15		24	4.77		
	2	952	4	26			12			3.17		
G612	3											
G613	4											
G614	4	154	4		36		16		24	5.0		
G615	2	72			X				110	10.0		

Note: GAC = granular activated carbon; TSS = total suspended solids; TS = total solids;
TDS = total dissolved solids.

Appendix I. Basin Sludge Production and Characteristics

Plant	Type			Quantity		%	Characteristics, mg/L						
no.	Alum	Lime	Other	lb/MG	gal/MG	solids	pH	TSS	TDS	Al	Fe	Ba	Other
SURFACE WATER SUPPLIES													
S101	X			433		11.8	7.8						
S102		X		2444		0.03	8.6	156	125				
S103	X												
S201	X						6.7	77249					
S202	X			341				83.1		550	5		
S203	X												
S204	X				145	9.1	6.8	115236	700				
	Other characteristics (rag/kg dry wt): Sb < 25; As = 2.53; Cd = 0.65; Cr = 2.68; Ca = 2.68; Cu =4.21; CN < 5.0; Fe - 1380; Pb = 2.29;; Mn - 280; Hg < 0.05; Ni = 2.62; NH_3-N = 21; T. Kjeld-N = 280; C_6H_5OH < 5.0; P = 110; K = 140; Se < 0.168; Ag < 2.5; Zn - 10; PCB < 5; Al = 3190; BOD = 140 921.												
S205	X	X			13000	3.0	9	30000					
S207	X				400		6.4	15000					
S208	X			164			6.4	40000					
S209	X			269									
S210	X			171		2.24	7.6	22500			48		
S211	X							524863					
S212	X	X		97		1.3		11749			90		
	Other characteristics (mg/L): B = 0.00; Cd - 0.03; Cr = 0,.16; Cu - 0.20; CN = 0.000; Hg = 0.09; Pb - 0.56; Ni - 0.40; Zn = 0.62												
S213	X	X		66							53		
	Other characteristics (mg/L): B = 0.00; Cd = 0.00; Cr - 0,.08; Cu = 0.08; CN = 0.00; Hg = 0.03 Pb = 0.46; Ni = 0.27; Zn = 0.32												
S214	X	X		3143	28570	1.25	9.7	350	100		5		
			Filter			0.5	8.5	600	200		5		
S301	X												
S302	X	X					8.0	2300					
			Filter					1400					
S303	X						7.0						
S304	X			83			7.6						

S305		X				15	8.9				
			Filter			10	9.5	1000			
S306	X	X									
S307	X	X		2857		26	8.5				40 mg/kg
S308	X	X									
S309			Brine								
S310	X										
S311	X	X			87300	39	9.3		1300	120 both mg/kg	
S312	X	X									
S313	X										
S314	X	X									
S315		X		2941		15	10.8				
			Filter			10.8	10.0				
S316	X	X					7.9				
S317	X	X									
S318	X	X		2000		70	8.3				0.58 lb/dry ton
S319	X	X									
S320	X	X									
S321	X	X	Lagoon			22	7.1	52000	7500 mg/kg	44 mg/kg	
S322	X	X		1263							
S323	X	X					8.0				
S324		X	Polymer								
S325	X	X									
	X	X	Filter		70000		8.1	4.6			
S401	X	X									
S402	X	X									
S403	X	X									
S404	X	X									
S405	X										
S406	X	X			3300						
			Filter				7.6	190			
S407	X	X									
S408	X	X									
S409	X	X									
S410	X	X					8.2	6			
S411	X	X									
S412		X			1150		10.5				
S413	X	X									

Appendix I. Continued

Plant	Type			Quantity		%	Characteristics, mg/L						
no.	Alum	Lime	Other	lb/MG	gal/MG	solids	pH	TSS	TDS	Al	Fe	Ba	Other
S501	X	X		concentrated	930	30							
S502	X	X											
S503	X												
S504	X	X											
S505	X												
S506	X	X			83200		6.7						
			Filter				7.5			0.02	0.012		
S507	X												
S508	X	X											
S509	X	X											
S510	X												
S511	X	X		505									BOD
			Filter				8.3	83					0.5 to 5
S512	X	X											
S513	X	X											
S514	X	X											
S515	X												
S516	X	X					8.8						
S517	X	X					6.5						
			Filter				6.5	516					
S518	X	X					8.4		140				
			Filter					230					
S519	X	X					7.8						
S520	X												
S521	X	X		3333									
S522	X	X			2670								
S601	X	X				1.4	8.0	4415			0.1		
			Filter				8.0	1514			0.1		
	Inorganics (mg/L): NH_3-N = 5.0; T. Kjeld -N = 725; PO_4-P =113; PO_4 as P_2O_5 = 258												
	Metals (mg/kg.dry wt.): Cd = 3.97; Cu = 346; Pb = 101; Ni = 25.2; K = 3970; Zn = 563												
S602		X		2659									
S603	X												
S604	X			3361 wet		8							
S605	X						7.5	84.3					

S606	X	X		2625		41	9.3					56 mg/kg wet
	Metals (mg/kg dry wt): As < 0.3; Cd = 0.70; Cr^{+6} < 0.5; Cr(t) = 13; Cu - 24; Hg < 0.02; Ni = 5.9; Se < 0.6; Ag = 1.1; Zn = 14											
S607	X	X		877		26	8.0					
			Filter			7	7.9					
S608	X						7.3					
S609	X	X										
S610	X	X				30	9.1				5700	140 mg/kg Cu 14 mg/kg
S611	X	X				55	8.7				160 mg/kg	
	Metals (mg/kg dry wt): As = 5.6; Cd = 1.2; Cr^{+6} -< 0.46; Cr (t) = 8.2; Cu = 7.5; Hg < 0.04; Ni = 10; Se - 5.1; Ag - 2.6; Zn = 14											

GROUND WATER SUPPLIES

G126		X			20800	1.1	10.4					
G201			X	4833								
G203			X				4.2	330		0.01	3.6	
G227		X		L0400	47800	5.1	11.5					
	Other analyses (%): CaO = 43.7; SO_3 = 1.0; SiO_2 = 2.0; MgO = 14.5; CO_2 =31.5 mg/L.											
G232	X	X		3514		95.0		600,000				
G247			X		900				7450			
G306		X			13900							
G307	X	X										
G310			X									
G312			X		85000							
G317			Fe,Mg		100 cu yd/yr							
G320		X			500							
G321	X	X	X				8.4		219600			
G401			X		35000							
G402	X	X		567 wet								
G403			X				7.5	50	30000		2.0	Cl~ 27000
G406	X	X			20000	6.0	10.4	70.6			357	0.2
			Filter				8.5		370	0.1	0.01	1.23
G504	X	X		2500 wet								
G505												

Appendix I. Concluded

Plant	Type			Quantity		%	Characteristics, mg/L						
no.	Alum	Lime	Other	lb/MG	gal/MG	solids	pH	TSS	TDS	Al	Fe	Ba	Other
G601			Brine & Fe		11262								
G603	X	X		4353									
G604		X		6429									Spec. Gr. 1.16
			Filter					725	950				
G609			X		667								
G610	X	X			8570	2							
			Filter			1.0							
G611		X		5737		12-14	11.2						
			Filter				8.8						
G614			X										
			Filter	11144 wet		8.6							
G615		X											

Appendix J. Sludge Removal

Plant no.	From sedimentation basin					From flocculator				
	Flushing	Continuous removal	Manual	Corabi-nation	Other	Flushing	Continuous removal	Manual	Blow-down	Pumped
SURFACE WATER SUPPLIES										
S101	X		X			X				
S102	X	X						X		
S103	X					X				
S201	X									
S202	X									
S203	X					X				
S20A	X					X				
S205		X					X			
S206	X				Sludge collectors	X				
S207	X					X				
S208	X					X				
S209	X					X				
S210	X					X				
S211	X					X				
S212				X		X				
S213				X		X				
S214		X				X				
S301	X	X				X				
S302	X					X				
S303		X					X			
S304					Drag line	X	X			
S305	X				Pump to lagoon				X	
S306					Tank wagon				X	
S307	X		X			X				
S308										
S309					Dredging					X
S310				X				X		
S311					Backhoe				X	
S312					Drag line				X	
S313						X			X	

Appendix J. Continued

Plant no.	From sedimentation basin					From flocculator				
	Flushing	Continuous removal	Manual	Combination	Other	Flushing	Continuous removal	Manual	Blow-down	Pumped
S314										
S315			X							
S316			X							
S317			X		Backhoe		Gravity			
S318			X		Backhoe & trucks		Gravity			
S319	X					X				
S320										
S321			X				X	X		
S322	X					X		X		
S323	X								X	
S324		X				X				
S325	X					not needed				
S401	X		X				X			
S402										
S403										
S404	X									
S405									X	
S406	X					X				
S407	X					X				
S408										
S409	X					X				
S410	X		X			X				
S411	X									
S412	X					X				
S413										
S501				X	Concentrators	X				
S502	X									
S503	X								X	
S504		X				X				
S505					Backhoe				X	
S506	X		X			X				
S507		X								

S508										
S509	X					X				
S510		X							X	
S511	X		X			X		X		
S512					End loader	X				
S513										
S514			X							San. S
S515	X									
S516									. X	
S517									X	
S518			X			X				
S519			X					X		
S520		X							X	
S521	X									
S522		X					X			
S601					Pump to truck		X			
S602	X									X
S603			X							
S604	X		X			X				
S605										
S606				X				X		
S607		X								
S608	X					X				
S609	X								X	
S610	X								X	
S611				X						

GROUND WATER SUPPLIES

G102										
G105										
G115										
G117										
G118										
G124										
G125										
G126		X								
G127										
G130			X							

Appendix J. Concluded

Plant no.	From sedimentation basin					From flocculator				
	Flushing	Continuous removal	Manual	Combi-nation	Other	Flushing	Continuous removal	Manual	Blow-down	Pumped
G201										
G202										
G203										
G212										
G213	X		X							
G219										
G227		X	X				X	X		
G232				X	Concentrator		X			
G246										
G302										
G306	X	X					X			
G307					Backhoe					
G308										
G309										
G310										
G312					Vactor truck					
G314										
G315										
G317			X					X		
G318										
G319										
G320			X					End loader		
G321										
G401										
G402	X					X				
G403										
G405			X							
G406	X	X							Accelerator	
G501										
G503										
G504	X								Gravity	

G601	X			Vacuum truck			
G603							Gravity
G604		X			X		
G605							
G608							
G609	X						
G610			X	Drain	X		X
G611			X			X	
G612							
G613							
G61A				Vacuum truck			X
G615				Transfer to San. S			X

Appendix K. Sludge Discharge

Plant	Basin sludge discharged to								Floccu-	Filter washwater		Spent GAC		
no.	Stream	Dry creek	Storm sewer	Lake	Low ground	Imp. basin	San. sewer	Treat- ment	lator sludge	Discharged to	Recov. basin	Discharged to	Regener- ation	Brine waste
SURFACE WATER SUPPLIES														
S101	X								Centrifuge	Thickener	X			
S102							X		San. S	Rec. B	X			
S103						X			Lagoon	Lagoon				
S201							X	NSSD		Rec. B	X			
S202							X		San. S	Intake well	X			
S203							X		San. S	San. S	X			
S204								NSSD	San. S	San. S				
S205						X			Imp. B	Soft. B	X	Imp. B		
S206							X		San. S	Recycled	X			
S207							X	MSD	San. S		X			
S208							X			Plant inlet				
S209			X						Storm S		X			
S210							X		None	Recycled	X			
S211							X	MSD	Sewer-MSD		X			
S212							X	MSD	San. S		X			
S213							X	MSD	San. S		X			
S214						X			Imp. B	Plant inlet	X			
S301						X			Hld. T	Hld. T			X	
S302	X								Miss. R	Miss. R		Miss. R		
S303	X								Stream	Stream				
S304						X			Imp. B	Imp. B				
S305						X			Plant inlet	Plant inlet	X			
S306						Hld. T			Hld. T	Hld. T	X			
S307					X				Lagoon	Rec. B	X			
S308	X								Stream	Stream				
S309							X		Containment cells at San. Dist.					
S310	X								Stream	Stream				
S311						X			Imp. B	San. S				
S312						X			Lagoons	Lagoons	X			
S313						X			Imp. B		X			

S314		X						Dry creek	Dry creek			
S315					X			Imp. B	Imp. B			
S316					X			Imp. B		X		
S317					X			Sludge bed	Sludge bed			
S318	X							Lagoon	Lagoon			
S319		X						Dry creek	Dry creek			
S320										X		
S321					X			Lagoons	Lagoons	X		
S322			X					Storm S	Storm S			
S323	X							Stream	Stream			
S324						X	Rec. B	Rec. B	Rec. B	X		
S325				X					Lagoon			
S401					X			Imp. B	Imp. B			
S402		X							Dry creek			
S403												
S404					X			Imp. B	Imp. B			
S405					X			Lagoon	Lagoon			
S406					X			Imp. B	Ditch			
S407		X						River	River			
S408						X		San. S	San. S			
S409		X						Dry creek	Dry creek		Will construct a lagoon	
S410					X			Lagoon	Lagoon			
S411				Road ditch				Ditch	Ditch			
S412	River							River	River			
S413			Pond						Pond			
S501						X		Sewer	Creek bed		Disp. plant	
S502	X							Stream	Stream			
S503						X		San. S	San. S			
S504						X		San. S	San. S			
S505					X			Lagoons	Lagoons	X		
S506					X			Imp. B	Imp. B	X		
S507	X								Stream			X
S508	No data											
S509				X				Pol. P	Pol. P			
S510						X		Lagoon	Lagoon		Lic. Hauler	
S511	X								Stream			
S512					X			Imp. basin	Recycle			
S513	No data											

Appendix K. Continued

	Basin sludge discharged to									Filter washwater		Spent GAC		
Plant no.	Stream	Dry creek	Storm sewer	Lake	Low ground	Imp. basin	San. sewer	Treat-ment	Floccu-lator sludge	Discharged to	Recov. basin	Discharged to	Regener-ation	Brine waste
S514							X		San. S	San. S				
S515							X		San. S.		X			
S516						X			Lagoons	Lagoons				
S517	X								Stream	Stream			X	
S518	X								Stream	Stream				
S519		X							Dry creek	Dry creek				
S520				X			X		San. S	Lake				
S521							X			San. S				
S522						X			Imp. B	Imp. B		Imp. B		
S601						X			Rec. B	Rec. B	X			
S602						X			Imp. B	Stream		Imp. B		
S603						X			Imp. B	Imp. B	X			
S604						X			Imp. B	Flocculator	X			
S605	No data													
S606						X			Lagoons	Lagoons	X			
S607	X			X					Lake	Lake				
S608	X								Stream	Stream				
S609						X			Lagoon		X			
S610						X			Imp. B	Imp. B	X			
S611						X			Imp. B	San. S				
GROUND WATER SUPPLIES														
G102										San. S				
G105										San. S				
G115	No data													
G117	No data													
G118										San. S				
G126						X				Storm S				
G127										Creek/sewer				
G130					Hauled away									

G201				X				20%	San. S
G202				X					
G203									San. S
G212							San. S		
G213				X	San. S		San. S		
G219				X			Set. B		
G227			X			Lagoon	San. S		
G232				X		San. S		X	
G246	No data								
G302				X			San S.		
G306			X			Imp. B	Imp. B	X	
G307			X				Lagoon		
G308							Imp. B		
G309	No data								
G310				X			San. S		San. S
G312				X			San. S		San. S
G314		X		X					
G315	No data								
G317					X	San. S	Hld. T		
G318				X			San. S		
G319				X			San. S		San. S
G320			X				Imp. B		
G321								X	
G401								X	San. S
G402				X	X	Lagoons	Lagoons		
G403								X	Stream
G405							Stream		
G406			X				Sewer		
G501	No data								
G504			X			Lagoon	Lagoon	X	
G601				X			San. S		San. S
G603		Gravel pit				Gravel pit	Gravel pit		
G604			X			Accumulator		X	
G605	No data								
G608	No data								
G609				X				X	San. S

Appendix K. Concluded

Plant no.	Basin sludge discharged to								Floccu-lator sludge	Filter washwater		Spent GAC		Brine waste
	Stream	Dry creek	Storm sewer	Lake	Low ground	Imp. basin	San. sewer	Treat-ment		Discharged to	Recov. basin	Discharged to	Regener-ation	
G610						X			Thickner	Thickner				
G611						X			Imp. B		X			
G612										San. S				
G613							X			San. S		San. S		San. S
G614								Thickener	Thickener	Wash tank				
G615						X	X		Lime pit	Lime pit				

Note: Imp. B = impounding basin; San. S = sanitary sewer; Storm S = storm sewer; Rec. B = recovery basin; Soft. B = softening basin; Set. B = settling basin; Hld. T = holding tank; Miss. R = Mississippi River; GAC = granular activated carbon; Pol. P = polishing pond.

Appendix L. Sludge Treatment

Plant no.	Gravity	Flocculation	Centrifuge	Stabilization & disinfection		To sewage treatment plant	Lagooning or Imp. B	Wash water recycle	Recycling with settling		Sludge dewatering
				Lime	Cl_2				Yes	No	
SURFACE WATER SUPPLIES											
S101	X		X					X			X
S102						X					
S103							X				
S201						X					
S202						X					
S203						X					
S204						X					
S205							X				
S206							X	X		X	
S207						X					
S208						X					
S209	None										
S210						X		X	X		
S211						X					
S212						X					
S213						X					
S214	X			X			X	X		X	
S301							X				X
S302	None										
S303	None										
S304							X				X
S305							X				X
S306							X	X	X water		
S307							X				
S308	None										
S309				X	X	X					X
S310	None										
S311	X						X				
S312							X				

Appendix L. Continued

Plant no.	Gravity	Flocculation	Centrifuge	Stabilization & disinfection		To sewage treatment plant	Lagooning or Imp. B	Wash water recycle	Recycling with settling		Sludge dewatering
				Lime	Cl_2				Yes	No	
S313							X				
S314	None										
S315	X						X				
S316							X				
S317							X				X
S318	X						X				X
S319	None										
S320	None										
S321							X				X
S322	None										
S323	None										
S324						X					
S325							X				
S401							X				
S402	None										
S403	No data										
S404							X				
S405							X				
S406							X				
S407	None										
S408						X					
S409	None										
S410							X				
S411	None										
S412	None										
S413	None										
S501		X			X	X					X
S502	None										
S503						X					
S504						X					
S505		X					X	X	X		X

Appendix L. Sludge Treatment

Plant no.	Gravity	Floccu-lation	Centri-fuge	Stabilization & disinfection		To sewage treatment plant	Lagooning or Imp. B	Wash water recycle	Recycling with settling		Sludge dewatering
				Lime	Cl_2				Yes	No	
SURFACE WATER SUPPLIES											
S101	X		X					X			X
S102						X					
S103							X				
S201						X					
S202						X					
S203						X					
S204						X					
S205							X				
S206							X	X		X	
S207						X					
S208						X					
S209	None										
S210						X		X	X		
S211						X					
S212						X					
S213						X					
S214	X			X			X	X		X	
S301							X				X
S302	None										
S303	None										
S304							X				X
S305							X	*			X
S306							X	X	X water		
S307							X				
S308	None										
S309				X	X	X					X
S310	None										
S311	X						X				
S312							X				

Appendix L. Concluded

Plant no.	Gravity	Floccu-lation	Centri-fuge	Stabilization & disinfection		To sewage treatment plant	Lagooning or Imp. B	Wash water recycle	Recycling with settling		Sludge dewatering
				Lime	Cl_2				Yes	No	
G130	Hauled away										
G201						X					
G202	No data										
G203						X					
G212						X					
G213	X					X	HT				
G219						X	HT				
G227	X				X	X	X	X		X	X
G232						X					
G246	None										
G302						X					
G306	X						X	X	X		
G307							X				X(evap)
G308							X				
G309	No data										
G310						X					
G312						X					
G314						X					
G315	No data										
G316											
G317			X		X		HT	X	X		X
G318						X					
G319						X					
G320	X						X				
G321	No data										
G401						X					
G402	X					X	X				
G403	None										
G404	None										
G406						X	X				

G501	No data							
G504	X		X		X	X	X	X
G601				X				
G603	X				GP			
G60A	X				X			X
G605	No data							
G609				X				
G610	X				X			
G611	X				X	X		X
G612				X				
G613				X				
G614	X				TB			
G615		X		X	LP			X

Note: Imp. B = impounding basin; HT = holding tank; RB = recovery basin; GP = gravel pit; TB = thickening basin; LP = lime pit.

Appendix M. Sludge Dewatering

Plant no.	Method								No. of units	Dewatering units		
	Drying beds	Drying lagoons	Centri- fuge	Vacuum filter	Belt filter	Filter press	Strain- ers	Freezing or heat		Size, ft	Sludge lb/d	Percent solids
SURFACE WATER SUPPLIES												
S101			X						4	4 x 2.5	7814	11.8
S103		X							1			
S201	No data											
S205		X							4	26 acres		45.0
S214	No data											
S301		X							3			
S304		X							3	60 x 20	10	2.0
S305		X							2	60 x 15 x 4	2959	15.0
S306	No data											
S307		X							2	76500 ft^3	4000	
S309	X								4			15.0
S311		X							2	30 x 100	1077	39.0
S312									3	43 x 102		
S313	No data											
S315		X							2	3 & 6 acres	125000	40.0
S316	No data											
S317	X								2			
S318	X	X							5	25 x 180	5000	80.0
S321		X							3	25 x 150 x 12		
S323	No data											
S324	No data											
S401	No data											
S404		X							4			
S405	No data											
S406		X							2	100 x 125		
S409	No data											
S412	No data											
S501		X							2			50.0

S505		X		3	7500 ft^3	175	
S506		X		3	30 x 130		
S509	No data						
S510	No data						
S512	No data						
S513	No data						
S516		X		4	90 x 200 x 12		
S522	No data						
S601		X		2	0.76 acres	5754	21.0
S602		X		3		22603	22.0
S603		X		2	20 x 30		
S604		X		3	1.1408 mil ft^3	2285	100.0
S605	No data						
S606		X		7	4560000 ft^3	13000	40-50
S609		X		3			
S610		X		3		1000 yd^3/d	30.0
S611		X		2	13 x 54	1644	

GROUND WATER SUPPLIES

G126		X		2	30 x 16 x 3		
G227		X no longer in use		1	61700 cu.yd.	26000	5.1
G307		X		2	17500 cu.ft.		
G310	X			16			
G317			X	1			
G320		X		2	30 x 75		
G402		X		2	75 x 150		
G405	X			2	1950 sq.ft.		9.0
G504		X		2			
G604	No data						
G610		X		3	75 x 150	new	
G611		X		4	260000 - 3250000	30000	50.0
G615	X			1	280 sq.ft.		

Appendix N. Sludge Final Disposal

	Utilization for										Disposed to land			
											Landfill			
Plant no.	Compost-ing	Crop-land	Land rec	Land fill	Forest	RM rec	MiX soil	Fuel	Land-scaping	Other	Own	Public	Private	Dedicated land
SURFACE WATER SUPPLIES														
S101				X									X	
S102				X									X	
S103				X							X			
S205											X			
S214		X					pH adj.					X		public land
S301	No data													
S304				X			X							
S305			X	X									X	
S306			X	X			X				X			
S307		X											X	
S309		X												
S311		X											X	
S312				X							X			
S313		Never dredged sludge												
S315		X												
S316							X							
S317										X	X			
S318	X	X					X				X	X		
S320				X							X			
S321		X												
S325		Have never dredged from lagoons												
S401				X										X
S404									X					
S405	No data													
S406				X							X	X	X	
S410		X												

S501		X	X	X	X		X			X
S505				X			X			
S506				X			X			
S509				X						X
S510						San. S		X	X	
S512				X			X			
S516				X			X			
S522		Have never dredged				X				
S601		X							X	
S602	X	X			X		X			
S603				X			X			
S604	No data									
S606		X					X			
S609		X							X	
S610		X							X	
S611		X							X	
GROUND WATER SUPPLIES										
G126	X			X			X			
G130				X			X			
G227				X			X			
G232	X	Clarifier sludge goes to GCMSD						X		
G306		X								
G307				X					X	
G308	No data									
G310		X	X							X
G312				X					X	
G317				X					X	
G320	X		X				X			
G321				X				X		
G402							X			
G406				X			X			
G504				X				X	X	

Appendix N. Concluded

Plant no.	Composting	Utilization for: Cropland	Land rec	Land fill	Forest	RM rec	Mix soil	Fuel	Landscaping	Other	Disposed to land: Landfill Own	Landfill Public	Landfill Private	Dedicated land
G603										X				
G604				X							X			
G610		X					X				X		X	
G611				X									X	
G614		X											X	
G615		X										X		

Note: Land rec. = land reclamation; Fill mat. = fill material; RM rec. = raw material recovery;
San. S = sanitary sewer; GCMSD = Greater Chicago Metropolitan Sanitary District.

Appendix 0. Sludge Disposal Limitations, Costs, and Remarks

Plant no.	A		B		C		D, $	Cost of treatment, $		Cost ratio, %	Remarks
	Yes	No	Yes	No	Yes	No		Sludge	Plant		
SURFACE WATER SUPPLIES											
S101	X			X	X		150,000	150,000	3,100,000	4.8	
S102	X			X	X		650,000	650,000	1,926,000	33.8	
S103		X						920	344,631	0.3	
S201	X			X	X		140,000	140,000			
S202	X			X	X		24,000	24,000	500,000	4.8	
S203	X		X								
S204	X			X	X		10,000	10,000	120,000	8.3	
S205	X		X						5,000,000		
S206		X						26,119			
S207		X						15,000			
S208	X		X					10,000	1,400,000	0.7	
S209	X			X	X		10,000	10,000			
S210	X			X			70,000	70,000	1,000,000	7.0	
S211	X		X						99,871		
S212	X			X			1,600,000	1,618,000	3,318,000	12.1	
S213	X			X			940,000	944,840	9,444,840	10.0	
S214	X			X		X		60,000	1,200,000	5.0	
S301	X			X	X		18,000	6,000			
S302	X			X	X			600			
S303		X									
S304	X			X	X		500	500	60,000	0.8	
S305	X			X		X		1500	25,000	6.0	
S306	X										Under construction
S307		X									
S308		X									
S309	X			X	X		145,000	145,000			
S310		X									
S311		X						500	30,000	1.7	
S312	X			X	X		800	1200			
S313		X									

Appendix 0. Continued

Plant no.	A		B		C			Cost of treatment, $		Cost ratio, %	Remarks
	Yes	No	Yes	No	Yes	No	D. $	Sludge	Plant		
S314	No data										
S315	X		X								
S316		X									
S317		X									
S318		X						20,000	1,000,000	2.0	
S319		X									
S320	X			X	X						
S321	X		X						1500		
S323	No data										
S324	No data								1500		
S325		X							140,000		
S401		X							250,000		
S402		X							25,000		
S403	No data										
S404		X									
S405		X									
S406		X						4,000	124,203	3.2	
S407	X						350,000				
S408	X			X		X					
S409	No data										
S410	X		X								
S411		X									
S412	X								970,000		
S413	No data										
S501	X		X						100,000		
S502	No data										
S503		X									
S504		X									
S505	X			X	X						
S506	X		X					12,000	400,000	3.0	
S507	X			X							
S508	No data										

S509		X							6000		
S510	X			X		X		6000	420,000	1.4	
S511	X			X	X		10,000				Planning to discharge to a San. S
S512	X		X								
S513	No data										
S514		X									
S515	X			X		X					
S516		X									
S517		X									
S518	X			X		X					
S519		X						600			
S520	X		X								
S521		X									
S522		X							108,000		
S601		X					15,000	15,000	240,800	6.2	
S602	X			X			200,000	200,000			
S603	X			X	X		2,000	2000	90,000	2.2	
S604	X			X		X	5,000	28,000	4,000,000	0.7	
S605	No data										
S606	X			X	X		300,000	300,000	1,970,000	15.2	
S607	X										
S608		X									
S609		X						8,000			
S610	X		X					22,500	480,000	4.7	
S611	X			X		X					Sludge to San. S
GROUND WATER SUPPLIES											
G105									13,500		
G126		X									
G130		X						50	17312	0.3	
G201		X							360,500		
G203		X							10,000		
G219		X									
G227		X						20,000	1,210,460	1.7	
G232		X							400,000		
G238									12,000		

Appendix 0. Concluded

Plant no.	A		B		C		D, $	Cost of treatment, $		Cost ratio, %	Remarks
	Yes	No	Yes	No	Yes	No		Sludge	Plant		
G246		X									
G247		X							400,000		
G302	X			X	X		25,000	25,000	85,000	29.4	
G305									200,000		
G307		X									
G308											
G309											
G310	X			X	X			5,000	300,000	1.7	
G312		X						2,000	85,000	2.4	
G317	X			X	X		7,000	7,000	110,000	6.4	
G318		X									
G319		X							280,972		
G320	X		X					1,800	71,540	2.5	
G321	X			X	X						
G402		X						2,000	400,000	0.5	
G403		X									
G404									109,000		
G405		X									
G406		X						200,000	850,000	23.5	
G504		X						2,783	359,100	0.8	
G505											
G601	X			X	X						
G603	X			X		X			218,000		
G604		X						75,000			
G610	X			X	X		150,000	150,000	790,000	19.0	
G611		X						68,000	1,153,890	5.9	
G612		X									
G613	X			X	X		3,000				
G614		X									
G615		X									

Note: A - Has your utility been ordered by a regulatory agency to stop the discharge of water treatment plant sludge into the water source within the past 15 years?

B - If YES to A., in your opinion, has the stopping of sludge disposal to the water source significantly improved the water quality of the water source?

C - If NO to B., would your utility resume sludge disposal to the water source if the regulatory barriers were removed?

D - If YES to C, and your utility was allowed to resume sludge disposal to the water source, what would you estimate the annual cost savings to your utility?

Appendix P. Daily Precipitation Records

Date	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1		tr		.01	.52		.01			.31		
2							.70			.04	.17	.54
3	.09	tr		.17						2.18	.01	.13
4		.60	.02	.01		.03			.15	.25		
5	tr	.23		.05		.34		tr		.01	tr	
6		.05	.13		.10	.20		.66				
7		.32	tr		.27	.25	.02	.04	.12			.57
8					.02		.06	.87			.01	.29
9							1.52			tr		.11
10			.08			.10	.19			.01		tr
11			.23		.02		.10		.70		.05	
12		tr	.02			.04	1.41		.23	.94	tr	
13			.08	.08	tr		.01	tr	tr	tr	tr	
14		.06	tr	.38	.09		.30	.31	.01	.17		
15			tr	tr	.05	.35		.01				
16				tr	.11	tr		.01				
17		.42			1.62				.02			tr
18		tr	.12		1.04			.38	.28		tr	
19			.25	tr					.65		tr	
20		tr							.73		.41	
21		tr		tr					.03		tr	
22						.05						
23		.04				.21			1.22	.01	.10	
24		.30				.02			.65	tr		
25	tr						.27		1.84	.49		
26		tr	.07	.04	.55			1.05		1.10	.03	
27		.19			.27					.10		
28	tr	tr		.13	tr	.16			.08			
29	tr			tr	.01	.01	.27		.24			
30			.03	.19	.02	1.13			2.16		tr	.01
31	tr						1.49					
Total	.09	2.21	1.03	1.06	4.69	2.89	6.35	3.33	9.11	5.61	.78	1.65
Cum. total	.09	2.30	3.33	4.39	9.08	11.97	1. .32	21.65	30.76	36.37	37.15	38.80

Appendix Q. Summary of Weather Data, 1986

	Air temperature		Relative humidity		Average soil temperature Degrees, F.				Precipitation	
	Degrees, F.		(%)	(%)	Sod		Bare soil		(Inches)	
Month	(max.)	(min.)	(max.)	(min.)	(max.)	(min.)	(max.)	(min.)	Month	Total
Jan.	34	16	91	57	28	26	29	24	0.09	0.09
Feb.	31	15	94	68	30	29	31	30	2.21	2.30
Mar.	50	31	93	52	36	33	41	35	1.03	3.33
Apr.	67	41	93	39	54	48	63	49	1.06	4.39
May	73	52	95	50	65	58	72	59	4.69	9.08
June	82	61	99	53	77	68	86	90	2.89	11.97
July	85	69	100	61	82	74	90	75	6.35	18.32
Aug.	79	57	100	52	75	68	81	66	3.33	21.65
Sep.	78	58	100	55	70	65	74	63	9.11	30.76
Oct.	63	44	100	60	59	55	61	51	5.61	36.37
Nov.	43	26	98	59	42	39	41	36	0.78	37.15
Dec.	37	24	97	64	34	33	32	31	1.65	38.80

Appendix Rl. Percent Total Solids in Soils

Date, 1986	Application Rate, t/a.	Corn Plots Rep 1	Rep 2	Rep 3	Date, 1986	Application Rate, t/a	Soybean Plots Rep 1	Rep 2	Rep 3
4/24	0	80.5	83.5	79.0	5/21	0	78.2	80.9	79.1
	2.5	81.1	79.7	80.7		2.5	78.5	79.0	82.2
	10	79.9	81.3	80.6		10	80.0	79.6	80.7
	20	78.0	80.6	80.4		20	79.8	80.4	80.0
6/13	0	80.5	80.4	78.8	7/18	0	79.1	82.6	82.9
	2.5	79.5	79.8	80.4		2.5	79.6	81.2	82.1
	10	79.7	81.4	80.2		10	81.6	82.1	81.7
	20	78.3	81.0	78.6		20	81.8	82.8	81.9
8/13	0	78.0	78.8	76.9	8/29	0	79.2	81.3	79.4
	2.5	78.3	77.9	77.6		2.5	79.4	79.4	80.8
	10	78.7	78.3	76.8		10	81.3	80.4	83.4
	20	75.6	78.4	76.9		20	80.7	81.5	81.5
10/21	0	76.8	77.9	76.4	10/21	0	78.0	81.4	79.0
	2.5	76.6	77.0	77.1		2.5	78.2	79.2	79.9
	10	76.8	76.8	77.4		10	80.6	80.2	81.2
	20	74.4	77.0	76.7		20	80.3	81.3	80.8

Appendix R2. Percent Organic Matter in Soils

Date, 1986	Application Rate, t/a	Corn Plots Rep 1	Rep 2	Rep 3	Date, 1986	Application Rate, t/a	Soybean Plots Rep 1	Rep 2	Rep 3
4/24	0	6.9	5.6	6.7	5/21	0	6.5	5.9	5.0
	2.5	7.0	6.7	6.6		2.5	5.9	5.8	4.2
	10	6.6	6.6	6.5		10	4.1	3.8	3.2
	20	7.8	6.4	6.4		20	4.1	3.5	4.3
6/13	0	6.4	5.6	6.6	7/18	0	7.1	3.4	5.2
	2.5	6.1	6.8	7.0		2.5	7.1	6.2	5.5
	10	6.5	6.3	6.6		10	3.8	4.9	4.0
	20	10.8	6.7	6.6		20	4.0	3.7	3.4
8/13	?	6.6	5.4	6.8	8/29	0	6.8	3.6	5.3
	2.5	6.7	6.5	7.5		2.5	6.7	5.8	4.8
	10	6.5	6.9	7.1		10	4.3	4.7	3.6
	20	7.9	6.5	6.8		20	4.4	3.9	4.2
10/21	0	7.1	5.8	7.1	10/21	0	6.8	3.7	5.7
	2.5	6.8	6.7	6.9		2.5	6.6	5.9	5.0
	10	6.9	6.5	6.5		10	4.2	4.9	3.8
	20	8.4	6.4	6.6		20	4.4	4.2	4.5

Appendix R3. Percent Moisture in Soils

Date, 1986	Application Rate, t/a	Corn Plots			Date, 1986	Application Rate, t/a	Soybean Plots		
		Rep 1	Rep 2	Rep 3			Rep 1	Rep 2	Rep 3
4/24	0	19.5	16.5	21.0	5/21	0	21.8	19.1	20.9
	2.5	18.9	20.3	19.3		2.5	21.5	21.0	17.8
	10	20.1	18.7	19.4		10	20.0	20.4	19.3
	20	22.0	19.4	19.6		20	20.2	19.6	20.0
6/13	0	19.5	19.6	21.2	7/18	0	20.9	17.4	17.1
	2.5	20.5	20.2	19.6		2.5	20.4	18.8	17.9
	10	20.3	18.6	19.8		10	18.4	17.9	18.3
	20	21.7	19.0	21.4		20	18.2	17.2	18.1
8/13	0	22.0	21.2	23.1	8/29	0	20.8	18.7	20.6
	2.5	21.7	22.1	22.4		2.5	20.6	20.6	19.2
	10	21.3	21.7	23.2		10	18.7	19.6	16.6
	20	24.4	21.6	23.1'		20	19.3	18.5	18.5
10/21	0	23.2	22.1	23.6	10/21	0	22.0	18.6	21.0
	2.5	23.4	23.0	22.9		2.5	21.8	20.8	20.1
	10	23.2	23.2	22.6		10	19.4	19.8	18.8*
	20	25.6	23.0	23.3		20	19.7	18.7	19.2

Appendix R4. Specific Gravity (g/cm^3) in Soils

Date, 1986	Application Rate, t/a	Corn Plots			Date, 1986	Application Rate, t/a	Soybean Plots		
		Rep 1	Rep 2	Rep 3			Rep 1	Rep 2	Rep 3
4/24	0	2.08	2.07	2.04	5/21	0	1.46	2.10	1.87
	2.5	2.01	1.99	2.09		2.5	1.76	2.03	1.88
	10	2.10	2.03	2.04		10	2.17	1.78	1.81
	20	2.00	2.12	2.04		20	2.14	2.03	1.68
6/13	0	1.56	1.35	1.66	7/18	0	1.37	1.69	1.43
	2.5	1.59	1.68	1.65		2.5	1.55	1.28	1.31
	10	1.42	1.64	1.96		10	1.67	1.76	1.81
	20	1.63	1.72	1.72		20	1.90	1.46	1.70
8/13	0	1.34	1.32	1.37	8/29	0	1.51	1.42	1.36
	2.5	1.21	1.04	1.45		2.5	1.47	1.52	1.26
	10	1.30	1.22	1.38		10	1.49	1.48	1.49
	20	1.28	1.09	1.42		20	1.45	1.42	1.44
10/21	0	1.12	1.24	1.30	10/21	0	1.32	1.50	1.28
	2.5	1.14	1.34	1.28		2.5	1.54	1.31	1.39
	10	1.24	1.39	1.33		10	1.56	1.42	1.47
	20	1.15	1.19	1.15		20	1.44	1.47	1.41

Appendix R5. pH in Soils

Date, 1986	Application Rate, t/a	Corn Plots			Date, 1986	Application Rate, t/a	Soybean Plots		
		Rep 1	Rep 2	Rep 3			Rep 1	Rep 2	Rep 3
4/24	0	5.05	5.07	7.23	5/21	0	5.30	5.92	4.86
	2.5	5.31	5.13	5.91		2.5	5.64	5.43	7.20
	10	5.37	5.36	5.72		10	5.82	5.47	7.50
	20	5.26	5.52	6.56		20	5.87	6.10	7.05
6/13	0	5.21	4.93	7.12	7/18	0	5.35	5.88	5.32
	2.5	5.26	4.98	5.75		2.5	5.67	5.40	6.74
	10	5.03	4.92	6.09		10	5.81	5.72	7.54
	20	5.62	5.23	6.15		20	5.89	5.99	7.16
8/13	0	5.17	4.92	6.42	8/29	0	5.26	5.96	5.26
	2.5	5.03	5.11	5.72		2.5	5.75	5.53	7.50
	10	5.63	5.18	5.93		10	6.25	5.76	7.75
	20	5.54	5.35	6.39		20	6.63	6.50	7.48
10/21	0	5.20	5.01	6.75	10/21	0	5.52	5.94	5.28
	2.5	5.22	5.13	5.78		2.5	5.85	5.62	7.36
	10	5.37	5.30	6.14		10	6.15	5.77	7.60
	20	5.73	5.67	6.74		20	6.12	6.36	7.39

Appendix R6. Acidity (meq/100 g) in Soils

Date, 1986	Application Rate, t/a	Corn Plots			Date, 1986	Application Rate, t/a	Soybean Plots		
		Rep 1	Rep 2	Rep 3			Rep 1	Rep 2	Rep 3
4/24	0	0.32	0.42	0.03	5/21	0	0.18	0.12	0.64
	2.5	0.34	0.35	0.13		2.5	0.13	0.19	0.07
	10	0.25	0.33	0.18		10	0.16	0.32	0.03
	20	0.20	0.26	0.12		20	0.22	0.23	0.06
6/13	0	0.24	0.71	0.04	7/18	0	0.22	0.18	0.47
	2.5	0.28	0.42	0.13		2.5	0.16	0.22	0.13
	10	0.23	0.46	0.09		10	0.19	0.18	0.05
	20	0.35	0.40	0.16		20	0.14	0.17	0.09
8/13	0	0.27	0.74	0.05	8/29	0	0.28	0.15	0.64
	2.5	0.36	0.35	0.10		2.5	0.10	0.25	0.09
	10	0.31	0.41	0.11		10	0.16	0.19	0.08
	20	0.12	0.28	0.15		20	0.26	0.07	0.08
10/21	0	0.33	0.76	0.07	10/21	0	0.23	0.11	0.74
	2.5	0.40	0.48	0.10		2.5	0.09	0.16	0.06
	10	0.24	0.35	0.05		10	0.07	0.23	0.04
	20	0.16	0.25	0.08		20	0.14	0.11	0.04

Appendix R7. Cation Exchange Capacity (meq/100 g) in Soils

Date, 1986	Application Rate, t/a	Corn Plots			Date, 1986	Application Rate, t/a	Soybean Plots		
		Rep 1	Rep 2	Rep 3			Rep 1	Rep 2	Rep 3
4/24	0	13.8	12.8	16.7	5/21	0	16.6	14.7	14.4
	2.5	14.3	13.2	15.7		2.5	16.7	15.0	14.7
	10	14.9	11.9	13.1		10	15.1	15.0	12.2
	20	14.1	11.3	14.4		20	16.4	14.5	14.3
6/13	0	19.5	19.0	22.2	7/18	0	20.1	18.1	18.6
	2.5	18.4	20.0	21.8		2.5	21.7	18.9	19.4
	10	19.9	19.2	20.2		10	17.4	19.1	16.7
	20	23.9	18.8	22.2		20	19.3	18.1	17.2
8/13	0	18.2	17.2	20.8	8/29	0	19.8	17.7	18.4
	2.5	18.9	20.6	21.6		2.5	19.9	17.8	17.7
	10	14.7	17.0	18.2		10	18.9	19.5	15.0
	20	20.8	17.8	20.6		20	18.8	17.4	16.6
10/21	0	16.4	17.0	21.7	10/21	0	18.2	16.3	17.4
	2.5	16.9	15.8	20.3		2.5	18.3	17.2	17.6
	10	16.7	15.7	18.8		10	17.2	16.6	14.3
	20	20.7	16.8	19.7		20	18.3	16.6	16.4

Appendix R8. Ammonia Nitrogen (mg/kg) in Soils

Date, 1986	Application Rate, t/a	Corn Plots			Date, 1986	Application Rate, t/a	Soybean Plots		
		Rep 1	Rep 2	Rep 3			Rep 1	Rep 2	Rep 3
4/24	0	237	193	133	5/21	0	154	47	119
	2.5	259	185	340		2.5	135	137	93
	10	171	244	406		10	68	83	43
	20	190	273	141		20	56	91	69
6/13	0	172	161	158	7/18	0	197	51	91
	2.5	153	168	159		2.5	198	176	129
	10	170	182	162		10	75	119	80
	20	217	171	160		20	69	64	72
8/13	0	188	149	180	8/29	0	138	70	108
	2.5	205	186	178		2.5	149	123	95
	10	204	181	184		10	58	77	82
	20	227	178	185		20	.61	60	94
10/21	0	185	130	142	10/21	0	166	67	112
	2.5	180	150	157		2.5	167	150	106
	10	160	154	165		10	55	107	82
	20	222	163	168		20	63	71	82

Appendix R9. Nitrate Nitrogen (mg/kg) in Soils

Date, 1986	Application Rate, t/a	Corn Plots			Date, 1986	Application Rate, t/a	Soybean Plots		
		Rep 1	Rep 2	Rep 3			Rep 1	Rep 2	Rep 3
4/24	0	40.1	20.6	10.0	5/21	0	4.1	1.4	3.4
	2.5	36.7	23.0	54.2		2.5	2.3	1.8	3.0
	10	20.1	32.1	77.4		10	1.4	1.6	3.0
	20	23.9	36.2	31.9		20	1.6	1.2	3.0
6/13	0	8.4	16.8	33.4	7/18	0	4.6	1.7	2.7
	2.5	11.9	26.5	12.3		2.5	4.3	3.2	3.0
	10	32.8	19.9	9.6		10	1.4	2.3	2.4
	20	24.3	23.4	12.8		20	1.9	2.0	3.9
8/13	0	8.1	16.7	25.5	8/29	0	3.0	1.6	2.4
	2.5	12.6	12.1	7.5		2.5	3.1	2.6	3.2
	10	8.9	7.9	8.2		10	2.3	2.0	3.8
	20	9.2	8.9	7.8		20	2.0	2.0	4.0
10/21	0	5.2	4.8	4.8	10/21	0	4.0	2.4	3.1
	2.5	5.1	5.5	4.7		2.5	3.6	3.6	4.0
	10	5.6	5.9	8.0		10	2.8	3.2	5.2
	20	4.4	4.8	4.8		20	2.9	3.4	4.2

Appendix R10. Total Kjeldahl Nitrogen (mg/kg) in Soils

Date, 1986	Application Rate, t/a	Corn Plots			Date, 1986	Application Rate, t/a	Soybean Plots		
		Rep 1	Rep 2	Rep 3			Rep 1	Rep 2	Rep 3
4/24	0	2579	1873	2278	5/21	0	1584	792	1340
	2.5	2679	2281	2364		2.5	1709	1553	1201
	10	2447	2320	2331		10	939	1160	981
	20	2914	2086	2015		20	1212	916	1016
6/13	0	2371	1936	2393	7/18	0	2776	586	1237
	2.5	2168	2194	2097		2.5	2360	1898	1536
	10	2302	2313	2062		10	938	886	1064
	20	2705	2233	2256		20	1112	1086	1069
8/13	0	2460	1975	2351	8/29	0	1621	518	1526
	2.5	2464	2280	2272		2.5	1641	1541	1462
	10	2239	2039	2345		10	583	963	1154
	20	2640	2143	2336		20	941	856	1216
10/21	0	2260	1818	2330	10/21	0	2040	849	1475
	2.5	2206	2022	2294		2.5	1978	1646	1293
	10	2368	2106	2126		10	961	1189	768
	20	2621	2108	2245		20	1031	883	1255

Appendix R11. Total Nitrogen (mg/kg) in Soils

Date, 1986	Application Rate, t/a	Corn Plots			Date, 1986	Application Rate, t/a	Soybean Plots		
		Rep 1	Rep 2	Rep 3			Rep 1	Rep 2	Rep 3
4/24	0	2856	2087	2421	5/21	0	1742	840	1462
	2.5	2675	2489	2758		2.5	1846	1692	1297
	10	2638	2596	2814		10	1008	1245	1027
	20	3128	2385	2188		20	1270	1008	1088
6/13	0	2551	2114	2584	7/18	0	2978	639	1331
	2.5	2333	2389	2268		2.5	2562	2077	1668
	10	2505	2515	2234		10	1014	1007	1146
	20	2946	2427	2429		20	1183	1152	1145
8/13	0	2656	2141	2557	8/29	0	1762	590	1636
	2.5	2682	2478	2458		2.5	1793	1667	2410
	10	2452	2228	2537		10	643	1042	1240
	20	2876	2330	2529		20	1004	918	1314
10/21	0	2450	1953	2477	10/21	0	2210	918	1590
	2.5	2391	2178	2456		2.5	2149	1800	1403
	10	2534	2266	2299		10	989	1299	855
	20	2847	2276	2418		20	1097	957	1341

Appendix R12. Bray P-1 (mg/kg) in Soils

Date, 1986	Application Rate, t/a	Corn Plots			Date, 1986	Application Rate, t/a	Soybean Plots		
		Rep 1	Rep 2	Rep 3			Rep 1	Rep 2	Rep 3
4/24	0	12	12	4.8	5/21	0	17	14	18
	2.5	18	7.1	9.4		2.5	14	18	23
	10	16	20	10		10	19	18	17
	20	13	16	11		20	25	19	54
6/13	0	15	20	4.2	7/18	0	42	18	17
	2.5	9.7	17	5.9		2.5	28	40	34
	10	13	27	11		10	20	25	29
	20	20	24	13		20	16	18	20
8/13	0	18	16	4.5	8/29	0	24	23	21
	2.5	16	17	9.8		2.5	17	15	28
	10	21	16	15		10	24	18	23
	20	21	19	15		20	33	16	26
10/21	0	17	17	4.6	10/21	0	22	17	18
	2.5	16	17	8.2		2.5	23	21	31
	10	17	21	11		10	19	28	20
	20	24	25	11		20	23	22	37

Appendix R13. Total Phosphorus (mg/kg) in Soils

		Corn Plots					Soybean Plots		
Date, 1986	Application Rate, t/a	Rep 1	Rep 2	Rep 3	Date, 1986	Application Rate, t/a	Rep 1	Rep 2	Rep 3
4/24	0	500	402	796	5/21	0	746	392	503
	2.5	508	379	603		2.5	597	730	642
	10	537	477	472		10	545	464	623
	20	618	616	696		20	491	428	606
6/13	0	645	569	770	7/18	0	700	508	617
	2.5	573	581	625		2.5	676	636	607
	10	577	626	646		10	516	505	712
	20	895	708	813		20	492	475	550
8/13	0	602	515	789	8/29	0	636	567	506
	2.5	562	574	642		2.5	573	570	636
	10	527	579	584		10	477	450	653
	20	815	640	653		20	432	452	533
10/21	0	618	533	771	10/21	0	624	506	439
	2.5	410	539	622		2.5	597	591	610
	10	587	530	589		10	530	486	341
	20	781	640	696		20	394	429	426

Appendix R14. Potassium (mg/kg) in Soils

		Corn Plots					Soybean Plots		
Date, 1986	Application Rate, t/a	Rep 1	Rep 2	Rep 3	Date, 1986	Application Rate, t/a	Rep 1	Rep 2	Rep 3
4/24	0	860	780	650	5/21	0	700	790	710
	2.5	790	800	800		2.5	860	1080	1010
	10	790	880	660		10	740	830	720
	20	800	960	690		20	820	770	860
6/13	0	610	820	750	7/18	0	1060	600	530
	2.5	720	830	760		2.5	610	840	610
	10	830	850	710		10	630	880	580
	20	670	720	670		20	760	790	540
8/13	0	700	420	480	8/29	0	760	680	730
	2.5	630	520	420		2.5	560	670	640
	10	540	460	560		10	780	670	590
	20	620	480	570		20	630	640	610
10/21	0	650	630	660	10/21	0	860	790	560
	2.5	620	670	620		2.5	800	820	880
	10	630	670	650		10	670	580	580
	20	730	600	630		20	900	720	570

Appendix R15. Aluminum (Total) (mg/kg) in Soils

Date, 1986	Application Rate, t/a	Corn Plots			Date, 1986	Application Rate, t/a	Soybean Plots		
		Rep 1	Rep 2	Rep 3			Rep 1	Rep 2	Rep 3
4/24	0	9300	9400	9300	5/21	0	9300	9300	10700
	2.5	10600	10200	10400		2.5	10200	9900	9800
	10	10500	9900	9700		10	9100	10000	7400
	20	9600	10500	9100		20	10600	9500	10400
6/13	0	10000	10100	10600	7/18.	0	10300	10100	10500
	2.5	10500	10200	11100		2.5	10200	10200	11200
	10	8500	10300	11400		10	10400	10800	9600
	20	11400	10300	10600		20	10700	10200	9500
8/13	0	11000	10000	10900	8/29	0	11300	10200	11500
	2.5	9200	9800	10200		2.5	11000	10700	10400
	10	10100	10000	10100		10	10800	11000	9500
	20	10700	10900	10900		20	10400	10100	9800
10/21	0	9600	9800	9800	10/21	0	11300	10500	11400
	2.5	10300	10600	10500		2.5	11500	10400	10700
	10	10300	10400	10400		10	9800	11800	9100
	20	10900	10500	10100		20	11300	11500	10000

Appendix R16. Boron (mg/kg) in Soils

Date, 1986	Application Rate, t/a	Corn Plots			Date, 1986	Application Rate, t/a	Soybean Plots		
		Rep 1	Rep 2	Rep 3			Rep 1	Rep 2	Rep 3
4/24	0	0.5	0.3	0.2	5/21	0	0.5	0.3	0.5
	2.5	0.4	0.3	0.2		2.5	0.4	0.2	0.3
	10	0.4	0.2	0.2		10	0.3	0.2	0.5
	20	0.4	0.2	0.3		20	0.2	0.2	0.5
6/13	0	0.5	0.4	0.4	7/18	0	0.7	0.2	0.2
	2.5	0.5	0.4	0.6		2.5	0.5	0.3	0.3
	10	0.6	0.4	0.5		10	0.3	0.2	0.3
	20	0.4	0.4	0.4		20	0.3	0.2	0.2
8/13	0	0.4	0.3	0.4	8/29	0	0.6	0.1	0.3
	2.5	0.3	0.5	0.4		2.5	0.4	0.3	0.2
	10	0.6	0.4	0.3		10	0.2	0.4	0.4
	20	0.4	0.5	0.3		20	0.2	0.2	0.3
10/21	0	0.6	0.3	0.4	10/21	0	0.4	0.2	0.3
	2.5	0.5	0.5	0.4		2.5	0.4	0.2	0.1
	10	0.5	0.4	0.2		10	0.2	0.1	0.2
	20	0.4	0.4	0.3		20	0.1	0.1	0.1

Appendix R17. Cadmium (mg/kg) in Soils

Date, 1986	Application Rate, t/a	Corn Plots Rep 1	Corn Plots Rep 2	Corn Plots Rep 3	Date, 1986	Application Rate, t/a	Soybean Plots Rep 1	Soybean Plots Rep 2	Soybean Plots Rep 3
A/24	0	1.0	2.0	<1.0	5/21	0	1.0	1.0	<1.0
	2.5	0.0	<1.0	<1.0		2.5	<1.0	2.0	1.0
	10	2.0	<1.0	<1.0		10	<1.0	<1.0	1.0
	20	1.0	<1.0	<1.0		20	6.9	<1.0	1.0
6/13	0	<1.0	<1.0	<1.0	7/18	0	<1.0	1.0	2.0
	2.5	<1.0	<1.0	<1.0		2.5	<1.0	<1.0	1.9
	10	<1.0	<1.0	<1.0		10	<1.0	<1.0	2.0
	20	<1.0	<1.0	<1.0		20	<1.0	1.9	<1.0
8/13	0	<1.0	<1.0	2.0	8/29	0	1.9	2.0	2.0
	2.5	<1.0	1.9	1.9		2.5	1.0	1.8	2.0
	10	<1.0	1.9	1.9		10	0.9	1.9	1.9
	20	<1.0	1.0	1.0		20	2.0	1.9	1.0
10/21	0	1.9	1.0	1.0	10/21	0	1.0	<1.0	1.0
	2.5	1.0	1.0	1.0		2.5	<1.0	<1.0	<1.0
	10	1.0	<1.0	1.9		10	<1.0	<1.0	<1.0
	20	1.0	1.9	1.0		20	<1.0	<1.0	<1.0

Appendix R18. Calcium (mg/kg) in Soils

Date, 1986	Application Rate, t/a	Corn Plots Rep 1	Corn Plots Rep 2	Corn Plots Rep 3	Date, 1986	Application Rate, t/a	Soybean Plots Rep 1	Soybean Plots Rep 2	Soybean Plots Rep 3
4/24	0	2490	2490	5890	5/21	0	2530	2360	1910
	2.5	2680	2600	3340		2.5	2730	2950	8560
	10	2860	2450	2800		10	2320	2050	29150
	20	3310	4520	3490		20	2590	2130	6080
6/13	0	2480	2290	9500	7/18	0	2550	2000	2150
	2.5	2800	2460	3910		2.5	2620	2260	4430
	10	2550	2460	3090		10	1940	1850	19130
	20	4320	2520	3370		20	2110	2000	8860
8/13	0	2590	2220	3840	8/29	0	2870	2640	2710
	2.5	25290	2400	3620		2.5	2130	2490	6810
	10	3090	2340	3320		10	2850	2260	2340
	20	3510	2440	4060		20	2900	2790	5340
10/21	0	2410	2240	4790	10/21	0	2590	2820	2370
	2.5	2550	2310	3310		2.5	3000	2570	7080
	10	2550	2310	3090		10	2270	2690	21900
	20	4290	2510	3760		20	2730	2960	5830

Appendix R19. Chromium (mg/kg) in Soils

Date, 1986	Application Rate, t/a	Corn Plots			Date, 1986	Application Rate, t/a	Soybean Plots		
		Rep 1	Rep 2	Rep 3			Rep 1	Rep 2	Rep 3
4/24	0	12	17	16	5/21	0	16	17	17
	2.5	15	17	19		2.5	18	18	18
	10	17	16	18		10	19	18	16
	20	17	17	15		20	21	15	16
6/13	0	16	17	17	7/18	0	15	18	18
	2.5	18	17	16		2.5	14	16	20
	10	14	15	18		10	20	19	18
	20	18	16	18		20	19	19	16
8/13	0	18	17	17	8/29	0	16	20	17
	2.5	16	16	18		2.5	17	17	16
	10	16	13	15		10	20	19	15
	20	15	16	18		20	19	17	18
10/21	0	13	16	15	10/21	0	18	18	15
	2.5	16	17	14		2.5	16	14	16
	10	15	16	16		10	15	17	15
	20	15	14	14		20	18	18	15

Appendix R20. Copper (mg/kg) in Soils

Date, 1986	Application Rate, t/a	Corn Plots			Date, 1986	Application Rate, t/a	Soybean Plots		
		Rep 1	Rep 2	Rep 3			Rep 1	Rep 2.	Rep 3
4/24	0	12	12	11	5/21	0	11	17	13
	2.5	13	13	16		2.5	14	16	13
	10	17	9	13		10	16	15	11
	20	11	10	11		20	18	16	14
6/13	0	11	15	14	7/18	0	13	16	18
	2.5	12	13	12		2.5	13	12	17
	10	8	12	13		10	16	16	18
	20	12	11	13		20	15	16	15
8/13	0	15	38	15	8/29	0	16	16	12
	2.5	17	16	15		2.5	17	13	12
	10	16	13	14		10	16	15	10
	20	15	13	16		20	14	16	11
10/21	0	11	13	13	10/21	0	14	16	13
	2.5	12	14	12		2.5	13	13	14
	10	12	12	12		10	16	15	12
	20	12	11	10		20	15	16	12

Appendix R21. Iron (Total) (mg/kg) in Soils

Date, 1986	Application Rate, t/a	Corn Plots Rep 1	Rep 2	Rep 3	Date, 1986	Application Rate, t/a	Soybean Plots Rep 1	Rep 2	Rep 3
4/24	0	8900	12100	11500	5/21	0	11600	15500	13800
	2.5	12000	11700	11700		2.5	15400	14100	12400
	10	11500	10600	12700		10	15700	14500	10500
	20	9200	11400	10300		20	17000	13900	12300
6/13	0	10300	14100	12500	7/18	0	11400	15400	16600
	2.5	10900	12100	12300		2.5	12200	9600	17100
	10	9900	11900	13300		10	15500	15700	16000
	20	11700	11900	11500		20	16200	16200	15000
8/13	0	16800	18700	16500	8/29	0	16100	20500	17200
	2.5	15600	14700	14800		2.5	18000	15800	15300
	10	13900	16300	13600		10	19700	18700	12700
	20	14200	16000	13800		20	17000	18000	11300
10/21	0	10200	13000	12200	10/21	0	13300	17700	18400
	2.5	12800	13800	12000		2.5	14100	11500	17100
	10	13100	11900	13400		10	13900	20500	15500
	20	10100	11500	11100		20	18100	19800	16300

Appendix R22. Lead (mg/kg) in Soils

Date, 1986	Application Rate, t/a	Corn Plots Rep 1	Rep 2	Rep 3	Date, 1986	Application Rate, t/a	Soybean Plots Rep 1	Rep 2	Rep 3
4/24	0	16	18	18	5/21	0	19	16	13
	2.5	17	18	18		2.5	21	17	14
	10	20	19	19		10	16	17	17
	20	17	14	20		20	14	14	16
6/13	0	14	15	14	7/18	0	17	17	15
	2.5	21	17	15		2.5	18	19	20
	10	15	16	16		10	18	17	20
	20	20	14	18		20	13	12	13
8/13	0	14	10	13	8/29	0	18	21	22
	2.5	12	8	18		2.5	13	18	20
	10	15	15	15		10	16	22	19
	20	14	16	19		20	18	20	18
10/21	0	21	22	17	10/21	0	16	17	15
	2.5	21	21	15		2.5	19	17	15
	10	21	15	14		10	17	13	19
	20	23	15	18		20	16	13	15

Appendix R23. Magnesium (mg/kg) in Soils

Date, 1986	Application Rate, t/a	Corn Plots Rep 1	Rep 2	Rep 3	Date, 1986	Application Rate, t/a	Soybean Plots Rep 1	Rep 2	Rep 3
4/24	0	1520	2000	3140	5/21	0	1820	2680	2200
	2.5	1820	1670	1750		2.5	2320	2210	5440
	10	1750	1710	1750		10	2690	2440	25710
	20	1590	1930	1950		20	3030	2520	3610
6/13	0	1560	2110	5260	7/18	0	1770	2600	2150
	2.5	1730	1760	1770		2.5	1750	2080	3120
	10	1450	1740	1770		10	2590	2610	13900
	20	1840	1680	1940		20	2840	2760	5900
8/13	0	1630	1920	2100	8/29	0	2050	2690	1970
	2.5	24240	1620	1570		2.5	2130	2080	4300
	10	1620	1680	1600 ,		10	2710	2400	1450
	20	1600	1650	1970		20	2650	2370	3750
10/21	0	1450	1990	2380	10/21	0	1910	2820	2230
	2.5	1670	1680	1640		2.5	2090	1930	3990
	10	1610	1620	1720		10	2270	2390	12760
	20	1760	1620	1810		20	2820	2520	3340

Appendix R24. Manganese (mg/kg) in Soils

Date, 1986	Application Rate, t/a	Corn Plots Rep 1	Rep 2	Rep 3	Date, 1986	Application Rate, t/a	Soybean Plots Rep 1	Rep 2	Rep 3
4/24	0	500	720	590	5/21	0	600	600	590
	2.5	530	820	410		2.5	700	660	600
	10	510	560	640		10	680	580	470
	20	340	570	520		20	710	590	610
6/13	0	480	790	520	7/18	0	600	620	600
	2.5	490	720	490		2.5	670	570	660
	10	400	570	610		10	670	630	560
	20	410	610	600		20	660	580	590
8/13	0	560	830	670	8/29	0	630	650	650
	2.5	590	610	540		2.5	610	590	650
	10	520	570	630		10	670	620	520
	20	370	630	470		20	640	620	590
10/21	0	510	670	480	10/21	0	650	650	620
	2.5	440	870	440		2.5	620	600	620
	10	570	610	620		10	610	640	550
	20	410	580	600		20	720	610	580

Appendix R25. Nickel (mg/kg) in Soils

Date, 1986	Application Rate, t/a	Corn Plots			Date, 1986	Application Rate, t/a	Soybean Plots		
		Rep 1	Rep 2	Rep 3			Rep 1	Rep 2	Rep 3
4/24	0	18	23	26	5/21	0	26	32	32
	2.5	25	22	24		2.5	30	32	27
	10	22	18	27		10	33	33	27
	20	19	23	23		20	37	32	31
6/13	0	19	27	26	7/18	0	27	31	29
	2.5	21	24	18		2.5	24	23	30
	10	17	19	27		10	34	34	28
	20	19	21	29		20	34	30	26
8/13	0	27	29	30	8/29	0	28	38	32
	2.5	31	25	22		2.5	29	31	31
	10	24	25	24		10	36	36	24
	20	24	26	25		20	33	31	29
10/21	0	24	28	30	10/21	0	30	37	32
	2.5	24	29	27		2.5	29	30	30
	10	31	21	26		10	31	32	31
	20	26	24	26		20	34	33	25

Appendix R26. Zinc (mg/kg) in Soils

Date, 1986	Application Rate, t/a	Corn Plots			Date, 1986	Application Rate, t/a	Soybean Plots		
		Rep 1	Rep 2	Rep 3			Rep 1	Rep 2	Rep 3
4/24	0	40	40	33	5/21	0	35	43	38
	2.5	41	38	33		2.5	41	42	43
	10	42	40	38		10	43	39	36
	20	34	42	34		20	47	42	45
6/13	0	36	46	36	7/18	0	44	44	34
	2.5	39	37	33		2.5	38	36	37
	10	31	42	38		10	45	44	39
	20	38	39	37		20	44	41	34
8/13	0	43	44	41	8/29	0	38	44	39
	2.5	39	39	39		2.5	37	38	37
	10	40	38	39		10	46	40	36
	20	37	41	38		20	42	41	34
10/21	0	41	42	37	10/21	0	42	45	41
	2.5	42	43	36		2.5	40	37	40
	10	40	41	39		10	45	44	36
	20	39	40	39		20	46	45	37

Appendix R27. Percent Sand in Soil

Date, 1986	Application Rate, t/a	Corn Plots			Date, 1986	Application Rate, t/a	Soybean Plots		
		Rep 1	Rep 2	Rep 3			Rep 1	Rep 2	Rep 3
4/24	0	5.4	2.8	2.8	5/21	0	3.1	0.4	1.3
	2.5	7.5	3.1	1.9		2.5	3.3	1.0	1.4
	10	3.1	1.9	1.8		10	2.2	0.6	1.9
	20	5.3	4.0	2.4		20	2.0	1.1	1.3
6/13	0	2.8	2.5	2.9	7/18	0	2.9	1.6	2.0
	2.5	2.6	2.7	2.0		2.5	2.4	2.3	1.5
	10	2.1	2.5	2.9		10	0.9	1.6	2.3
	20	5.2	2.5	2.7		20	1.6	1.6	1.4
8/13	0	0.2	0.6	3.0	8/29	0	1.2	1.2	1.0
	2.5	1.2	1.3	2.5		2.5	2.9	1.1	1.5
	10	1.3	1.7	2.8		10	2.9	1.3	1.7
	20	1.9	1.4	2.9		20	2.2	0.9	1.8
10/21	0	2.7	1.4	1.8	10/21	0	1.4	0.2	0.9
	2.5	1.9	3.0	2.7		2.5	1.8	1.1	1.2
	10	2.2	4.1	1.3		10	1.4	1.0	2.2
	20	2.1	4.8	1.5		20	3.1	0.5	2.0

Appendix R28. Percent Silt in Soils

Date, 1986	Application Rate, t/a	Corn Plots			Date, 1986	Application Rate, t/a	Soybean Plots		
		Rep 1	Rep 2	Rep 3			Rep 1	Rep 2	Rep 3
4/24	0	65.4	64.9	72.9	5/21	0	65.8	64.1	64.6
	2.5	69.2	63.7	72.9		2.5	63.3	65.1	72.2
	10	68.6	71.9	68.9		10	60.9	66.5	75.2
	20	68.2	65.9	73.9		20	65.6	65.8	70.6
6/13	0	70.1	69.7	72.4	7/18	0	73.7	64.4	66.7
	2.5	64.7	70.1	69.9		2.5	69.4	69.4	71.8
	10	71.5	71.4	68.7		10	68.6	66.5	75.3
	20	67.3	72.6	71.0		20	62.9	65.5	70.4
8/13	0	70.6	66.4	66.9	8/29	0	65.5	65.3	65.6
	2.5	67.8	68.3	66.2		2.5	66.1	66.6	71.9
	10	71.7	67.2	65.1		10	59.9	65.6	74.3
	20	63.5	71.7	65.7		20	63.6	69.2	69.9
10/21	0	63.0	66.4	69.0	10/21	0	66.8	64.3	64.6
	2.5	62.7	62.8	62.6		2.5	63.7	65.8	70.0
	10	64.0	65.5	67.2		10	64.5	65.0	88.9
	20	64.3	63.3	66.6		20	56.6	68.5	68.7

Appendix R29. Percent Clay in Soils

Date, 1986	Application Rate, t/a	Corn Plots			Date, 1986	Application Rate, t/a	Soybean Plots		
		Rep 1	Rep 2	Rep 3			Rep 1	Rep 2	Rep 3
4/24	0	29.2	32.3	24.3	5/21	0	31.1	35.5	34.1
	2.5	23.3	33.2	25.2		2.5	33.4	33.9	26.4
	10	28.3	26.2	29.3		10	36.9	32.9	22.9
	20	26.5	30.1	23.7		20	32.4	33.1	28.1
6/13	0	27.1	27.8	24.7	7/18	0	23.4	34.0	31.3
	2.5	32.7	27.2	28.1		2.5	28.2	28.3	26.7
	10	26.4	26.1	28.4		10	30.5	31.9	22.4
	20	27.5	24.9	26.3		20	35.5	32.9	28.2
8/13	0	29.2	33.0	30.1	8/29	0	33.3	33.5	33.4
	2.5	31.0	30.4	31.3		2.5	31.0	32.3	26.6
	10	27.0	31.1	32.1		10	37.2	33.1	24.0
	20	34.6	26.9	31.4		20	34.2	29.9	28.3
10/21	0	34.3	32.2	29.2	10/21	0	31.8	35.5	34.5
	2.5	35.4	34.2	34.7		2.5	34.5	33.1	28.8
	10	33.8	30.4	31.5		10	34.1	34.0	8.9
	20	33.6	31.9	31.9		20	40.3	31.0	29.3

Appendix S. Crop Yields and Plant Parameters

	CORN				SOYBEANS			
Sludge rate, t/a	Yield, bu/a	% grain moisture	Test weight, lb/bu	Population, plants/a	Yield, bu/a	% grain moisture	Height, inches	Population, plants/a
0	230.77	15.8	54.3	25,560	42.06	13.1	36.8	127,200
	212.03	16.0	53.3	24,390	32.77	13.0	38.5	137,650
	220.22	16.0	54.8	25,260	45.98	13.1	32.7	144,620
2.5	215.84	16.3	54.4	23,520	50.16	13.3	36.4	130,680
	201.94	16.4	54.6	24,100	32.62	13.5	38.5	137,650
	212.55	17.4	54.6	25,560	46.41	13.1	36.3	130,680
10	211.43	17.3	54.5	24,390	35.97	13.8	36.5	139,390
	198.60	15.9	55.7	22,070	38.72	13.0	36.3	130,680
	200.92	16.8	54.8	23,810	47.38	12.9	36.2	116,740
20	225.88	15.6	55.9	25,260	43.04	13.7	35.5	128,940
	223.76	16.2	56.3	25,560	39.66	13.3	37.1	115,000
	216.55	17.4	55.3	24,390	37.62	13.3	33.3	123,710

Appendix T. Nutrients and Heavy Metals Concentrations in Grains

	Corn plots sludge applied, t/a				Soybean plots sludge applied, t/a			
Constituent	0	2.5	10	20	0	2.5	10	20
Aluminum	<10	<10	<10	<10	12	11	14	<10
Al, mg/kg	<10	<10	<10	<10	<10	14	<10	<10
	<10	<10	<10	<10	14	<10	<10	11
Cadmium	0.1	0.1	<.1	<.1	0.3	0.2	0.3	0.2
Cd, mg/kg	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2
Calcium	0.0070	0.0040	0.0040	0.0110	0.2080	0.1970	0.1970	0.2010
Ca, %	0.0090	0.0150	0.0080	0.0080	0.2080	0.2080	0.1980	0.1890
	0.0140	0.130	0.0100	0.0090	0.2030	0.2010	0.1990	0.2140
Chromium	0.2	0.2	0.1	0.2	0.1	0.2	0.2	0.2
Cr, mg/kg	0.2	0.2	0.2	0.0	0.4	0.3	0.3	0.3
	0.4	0.4	0.3	0.3	0.3	0.4	0.4	0.3
Copper	1	2	1	1	13	12	12	12
Cu, mg/kg	1	1	1	2	12	12	13	12
	1	1	1	1	13	12	13	13
Iron	16	15	14	15	64	58	57	51
Fe, mg/kg	12	14	14	14	50	63	56	54
	12	11	12	13	66	65	54	67
Lead	0.4	0.4	0.1	0.4	1.5	1.5	1.8	1.5
Pb, mg/kg	0.4	0.3	0.3	0.4	1.5	1.7	1.4	1.4
	0.2	0.1	0.6	* 0.5	1.3	1.4	1.0	1.3
Magnesium	0.075	0.075	0.062	0.067	0.172	0.169	0.167	0.176
Mg, %	0.073	0.078	0.080	0.078	0.176	0.180	0.187	0.189
	0.066	0.069	0.071	0.073	0.170	0.194	0.184	0.184
Manganese	7	7	6	8	21	20	23	22
Mn, mg/kg	7	9	8	7	22	22	23	25
	6	6	8	8	23	24	24	22
Nickel	0.1	0.0	0.1	0.1	8.1	7.3	8.9	7.9
Ni, mg/kg	0.0	0.4	0.3	0.3	8.7	7.0	6.9	5.9
	0.4	0.4	0.0	0.4	8.8	2.4	2.6	3.0
Nitrogen	1.58	1.49	1.38	1.38	6.27	6.50	6.10	6.17
N, %	1.47	1.49	1.59	1.41	6.13	6.17	6.10	6.20
	1.34	1.37	1.49	1.49	6.48	6.21	6.01	6.22
Phosphorus	0.14	0.14	0.11	0.11	0.64	0.65	0.65	0.64
P, %	0.12	0.11	0.12	0.11	0.65	0.65	0.65	0.65
	0.10	0.09	0.12	0.11	0.62	0.64	0.61	0.61
Potassium	0.23	0.24	0.18	0.21	1.41	1.39	1.33	1.42
K, %	0.24	0.22	0.24	0.24	1.45	1.38	1.50	1.40
	0.23	0.22	0.19	1.20	1.40	1.53	1.45	1.41
Zinc	<5	20	15	15	88	49	64	51
Zn, mg/kg	15	25	20	10	49	89	49	49
	44	20	15	20	54	55	54	52
Crude protein	9.86	9.30	8.63	8.64	39.20	40.60	38.14	38.59
%	9.16	9.33	9.94	8.84	38.14	38.54	38.12	38.77
	8.35	8.59	9.12	9.30	40.50	38.80	37.57	38.87
Moisture,	10.74	12.78	11.41	12.17	9.70	8.62	8.82	8.50
%	11.64	12.23	10.48	12.33	8.60	7.91	7.38	8.25
	10.47	11.64	11.25	11.81	7.55	9.00	7.44	8.00

Appendix U. Nutrients and Heavy Metals Concentrations in Whole Plants

	Corn plots sludge applied, t/a				Soybean plots sludge applied, t/a			
Constituent	0	2.5	10	20	0	2.5	10	20
Aluminum	350	369	304	156	135	172	364	195
Al, mg/kg	'71	75	85	179	188	228	226	235
	70	124	85	80	230	137	137	138
Cadmium	0.3	0.2	0.2	0.3	0.4	0.4	0.4	0.4
Cd, mg/kg	0.2	0.3	0.3	0.3	0.4	0.4	0.3	0.3
	0.2	0.2	0.2	0.2	0.4	0.3	0.3	0.3
Calcium	0.443	0.424	0.404	0.372	0.994	0.929	0.867	0.805
Ca, %	0.311	0.310	0.344	0.324	0.914	0.979	0.912	0.817
	0.362	0.393	0.406	0.380	0.944	0.919	0.930	0.854
Chromium	2.2	1.6	1.6	0.8	0.7	0.8	1.0	0.8
Cr, mg/kg	0.6	0.6	0.6	1.1	0.7	0.8	0.9	0.8
	0.5	0.7	0.6	0.7	0.9	0.7	0.6	0.6
Copper	5	4	4	6	7	6	8	7
Cu, mg/kg	5	5	6	5	8	7	7	7
	5	5	5	5	7	5	5	6
Iron	1390	890	1070	780	400	420	540	390
Fe, mg/kg	340	420	290	640	490	410	390	490
	290	460	290	340	440	360	360	390
Lead	17.0	6.9	6.4	4.0	2.3	2.3	2.1	2.0
Pb, mg/kg	2.7	2.5	2.7	4.0	2.1	1.9	2.0	2.2
	2.5	2.4	2.3	2.9	2.0	2.1	2.0	1.8
Magnesium	0.188	0.210	0.212	0.215	0.304	0.298	0.239	0.237
Mg, %	0.225	0.219	0.206	0.176	0.328	0.285	0.307	0.256
	0.288	0.248	0.259	0.250	0.312	0.319	0.359	0.311
Manganese	120	104	92	66	47	42	57	36
Mn, mg/kg	86	71	79	84	44	50	48	47
	39	63	62	37	60	31	38	33
Nickel	2.2	1.6	1.5	1.2	1.5	1.7	2.6	1.4
Ni, mg/kg	0.9	0.8	0.8	1.0	1.7	1.9	2.2	1.8
	0.6	1.0	0.8	0.8	2.3	2.1	1.7	1.3
Nitrogen	0.87	0.77	0.72	0.74	1.11	1.12	1.56	1.38
N, %	0.73	0.75	0.74	0.74	1.43	1.64	1.27	1.40
	0.78	0.73	0.82	0.70	1.22	1.01	0.90	0.98
Phosphorus	0.07	0.06	0.05	0.08	0.09	0.10	0.18	0.13
P, %	0.07	0.06	0.07	0.06	0.17	0.14	0.13	0.14
	0.06	0.05	0.05	0.05	0.12	0.09	0.08	0.10
Potassium	1.06	0.71	0.48	0.66	0.34	0.36	0.30	0.35
K, %	0.58	0.59	0.71	0.45	0.38	0.30	0.40	0.34
	0.41	0.67	0.42	0.48	0.33	0.42	0.43	0.41
Zinc	110	95	74	93	36	27	23	54
Znf mg/kg	29	26	44	45	30	31	15	30
	79	57	30	25	15	11	16	20

Appendix V. Nutrients and Heavy Metals Concentrations in Leaves

	Corn plots sludge applied, t/a				Soybean plots sludge applied, t/a			
Constituent	0	2.5	10	20	0	2.5	10	20
Aluminum	31	32	37	29	22	17	19	16
Al, mg/kg	31	34	31	32	16	14	23	20
	30	30	36	26	30	19	18	18
Cadmium	0.3	0.3	0.3	0.4	0.5	0.5	0.5	0.4
Cd, mg/kg	0.4	0.4	0.3	0.4	0.4	0.4	0.5	0.4
	0.3	0.3	0.3	0.4	0.5	0.4	0.4	0.4
Calcium	0.579	0.653	0.679	0.645	0.779	0.840	0.886	0.789
Ca, %	0.607	0.547	0.592	0.595	1.003	0.922	0.853	0.725
	0.703	0.669	0.775	0.631	0.934	0.988	0.899	0.853
Chromium	0.5	0.5	0.5	0.5	0.8	0.8	0.6	0.5
Cr, mg/kg	0.5	0.5	0.4	0.4	0.8	0.8	0.9	0.6
	0.6	0.6	0.6	0.7	0.7	0.7	0.8	0.6
Copper	11	12	12	11	10	10	10	10
Cu, mg/kg	12	10	12	12	10	10	11	9
	11	11	12	11	10	11	11	11
Iron	90	190	310	290	190	290	190	210
Fe, mg/kg	290	240	240	190	240	190	240	250
	290	190	240	190	140	340	240	290
Lead	1.4	1.7	2.2	1.6	1.8	2.0	2.2	2.9
Pb,*mg/kg	1.3	1.6	1.6	1.8	2.2	2.4	2.6	2.3
	2.0	2.0	2.1	2.6	3.0	3.2	3.1	3.4
Magnesium	0.232	0.281	0.289	0.328	0.302	0.317	0.341	0.330
Mg, %	0.320	0.258	0.251	0.273	0.462	0.338	0.324	0.269
	0.431	0.349	0.387	0.326	0.345	0.339	0.331	0.346
Manganese	137	128	149	115				
Mn, mg/kg	137	132	121	107				
	78	88	113	83				
Nickel	1.0	1.2	1.4	1.3	8.9	8.6	10.9	9.7
Ni, mg/kg	1.3	1.1	0.9	1.0	9.4	8.0	10.7	7.8
	1.0	1.1	0.6	1.0	10.5	3.2	4.7	4.6
Nitrogen	2.76	2.55	2.57	2.76				
N, %	2.84	2.13	2.86	2.72				
	2.65	2.81	2.56	2.54				
Phosphorus	0.37	0.35	0.33	0.34				
P, %	0.36	0.30	0.38	0.33				
	0.31	0.33	0.33	0.33				
Potassium	1.84	1.76	1.89	1.75	2.31	2.46	2.22	2.19
K, %	1.70	1.87	1.86	1.83	2.30	2.29	2.44	2.00
	1.55	1.25	1.63	1.71	2.32	2.41	2.26	2.31
Zinc	30	40	44	29	35	30	30	33
Zn, mg/kg	35	30	39	40	35	29	30	25
	64	113	44	40	134	25	50	30

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16. Abstract (Limit: 200 words)

The objectives of this study were to update information on the characteristics and management of wastes from water treatment plants and to assess the benefits and risks of alum sludge application to cropland. The report has three major sections: a literature review, a summary of results of a survey of Illinois water plant wastes, and a discussion of findings from a study of alum sludge for agricultural uses.

The literature survey addresses characteristics and management of sludge. It discusses background information on sources and types of wastes, and waste characteristics of coagulant sludge, lime sludge, iron and manganese sludge, brine wastes, filter wash wastewater, diatomite filter sludge, and sludge from saline water conversion. Minimizing sludge production can be achieved by chemical conservation, direct filtration, recycling, chemical substitution, and chemical recovery. Methods of waste treatment are co-treatment with sewage treatment, pre-treatment, and solids dewatering. Pre-treatment includes flow equalization, solids separation, and thickening. Dewatering can be achieved non-mechanically (lagooning, drying beds, freezing and thawing, and chemical conditioning) and mechanically (centrifugation; vacuum, pressure, and belt filtration; and pellet flocculation). Land application is usually used as an ultimate sludge disposal method. The literature review section discusses laws and regulations (PL 92-500, PL 94-580, PL 93-523) regarding waste disposal from water treatment plants.

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