1 of 3

**FRESH KILLS LEACHATE TREATMENT AND MINIMIZATION STUDY
VOL. I: CHARACTERISTICS AND TREATMENT ALTERNATIVES**

Final Report

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ABSTRACT

The New York City Department of Sanitation is developing a comprehensive landfill leachate management plan for the Fresh Kills Landfill. The leachate was first analyzed for conventional and priority pollutants. The leachate was well buffered at pH 7 to 8 with an alkalinity of 5,000 to 6,000 mg/L. The BOD was low, usually less than 100 mg/L, but the COD was as high as 1,800 mg/L. Ammonia concentrations were around 700 mg/L and the color resembled strong tea at 3,000 colorimetric units. Only few of the priority pollutants were present, and at extremely low concentrations. Based on the chemical characteristics of the leachate, the primary environmental impact would be on the oxygen balance of the receiving surface waters.

Several biological and physical-chemical treatment processes were evaluated for removal of ammonia, BOD/COD, and color from the leachate. Analysis of the power requirements for each combination of processes studied was made. Batch and continuous-flow laboratory-scale models of activated sludge, sequencing batch reactors, rotating biological contactors, powdered carbon added to activated sludge, chemical coagulation, and activated carbon were used in the study. The nitrification of ammonia was achieved to less than 10 mg/L at loading rates up to four times those used in municipal wastewater treatment plants. However, organics and color remained in the leachate, which proved to be biologically stable. Their removal was achieved by chemical coagulation using alum and

polymer when the pH was adjusted between 5 and 6 and then passed through activated carbon adsorption columns. This procedure reduced the organics by 85 to 90 percent as measured by COD removal.

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SUMMARY

To comply with the Resource Conservation and Recovery Act of 1976 and Part 360 of New York State Code of Rules and Regulations, the New York City Department of Sanitation is developing a comprehensive landfill leachate management plan for the Fresh Kills Landfill.

The landfill is located on the western shore of Staten Island. The 2,400-acre facility, owned and operated by the City of New York, has been receiving household wastes for disposal since 1947. The landfill is divided geographically into operating sections that reflect the sequence in which refuse was disposed of at the site. A numbering system has been used to define the four major sections at the site. Sections 2/8 and 3/4 are scheduled for early closure with a final cover to limit infiltration and, therefore, leachate generation. However, the remaining two sections, 1/9 and 6/7, will remain active and continue to generate significant volumes of leachate. It has been estimated that these two sections will generate leachate at a rate of 1.1 million gallons a day (MGD). In developing a comprehensive leachate management plan, the leachate was characterized using conventional parameters and priority pollutants, and treatment alternatives were evaluated.

Leachate characteristics were based on groundwater collected from monitoring wells located along the periphery of sections 1/9 and

6/7 and samples from the Veterans Avenue Leachate Collection System pumping station located in section 1/9. All samples were analyzed at the Environmental Engineering Laboratory at the City College of New York and at the H2M Labs, Inc., a New York State certified laboratory in Melville, New York.

Leachate characterization began with a gross measurement of the total organic matter. The most common parameters used were biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total organic carbon (TOC). The ratio of BOD to COD was taken as a measure of the relative biodegradability of the organic matter. In general, the leachate from section 1/9 is higher strength than that from section 6/7. The BOD, COD, and TOC in the leachate of section 1/9 ranged from 90 to 140 mg/L, 1,400 to 1,600 mg/L, and 440 to 560 mg/L, respectively. In section 6/7 these same parameters ranged from 50 to 120 mg/L, 650 to 710 mg/L, and 140 to 170 mg/L, respectively. The BOD concentration and the BOD to COD ratio indicated that the organic constituents of the leachate have undergone biological degradation in the landfill. This ratio is characteristic of that associated with "old" landfills.

Leachate from both sections contained significant concentrations of dissolved solids. In section 1/9 the total dissolved solids (TDS) averaged 5800 mg/L while in section 6/7 the TDS were 3,600 mg/L.

An important contaminant found in the leachate from both sections

was ammonia and organic nitrogen measured as total kjeldahl nitrogen (TKN). In section 1/9 the TKN averaged approximately 800 mg/L while in section 6/7 the TKN was 250 mg/L. The environmental impact of ammonia is due to its high oxygen demand during biological oxidation to nitrate and, as a nutrient, to its eutrophication potential when released to the surrounding tidal streams.

The leachate in both sections was alkaline, usually in the pH range of 7 to 8. Alkalinity was in the range 4800 to 6000 mg/L, an indication that the leachate was well buffered. Analysis of priority pollutants indicated that their concentrations were low and usually less than the detection limit. The volatile organic identified were toluene, ethylbenzene, xylene and acetone at concentrations below 140 ug/L; and the semivolatile were 2-methylphenol, 2,4-dimethylphenol, naphthalene and bis(2-ethylhexyl) phthalate at concentrations lower than 100 ug/L. A noticeable physical characteristic of the leachate was its strong color. This was especially noticeable in samples collected from the Veterans Avenue Leachate Collection System pumping station, where the color averaged 3,000 colorimetric units.

In summary, the leachate from the Fresh Kills Landfill can be characterized as groundwater contaminated with high concentrations of organic substances, most of which are biologically stable. The leachate is well-buffered and slightly alkaline. The ammonia

concentration is high and the color intensity resembles a strong tea. Few of the priority pollutants were present and the NYSDEC is in the process of developing discharge limits. The primary environmental impact of the leachate on the surrounding surface waters may be its potential oxygen demand and the eutrophication concerns due to ammonia and nitrates.

Leachate management planning considered two treatment alternatives, onsite and offsite treatment at an existing water pollution control plant (WPCP). The Oakwood Beach WPCP in Staten Island was identified as the most likely offsite facility. The plant is operated by the New York City Department of Environmental Protection (NYCDEP). Preliminary respiration tests showed that the leachate is compatible with the plant influent with no toxic effects at the expected mixture ratio. However, since the actual load to the plant is rapidly approaching the plant's design capacity, NYCDEP was unwilling to accept the 1.1 MGD leachate flow. Therefore, onsite treatment alternatives were developed that could produce an effluent for direct discharge into the surrounding surface waters.

To develop treatment alternatives for an onsite facility, specific technologies were first identified that were capable of removing the contaminants in the leachate. The technologies were grouped into two broad categories, biological and physical-chemical, and included the following:

Biological Treatment:

Aerobic Processes: Activated sludge, sequencing batch reactors (SBRs), rotating biological contactors (RBCs), powdered carbon added to activated sludge (PACT)

Anaerobic Processes

Physical - Chemical Treatment:

Chemical coagulation

Air stripping

Activated carbon adsorption

Chemical oxidation

These technologies were initially screened based on experience gained from operating leachate treatment facilities at other sites, and by short-term batch laboratory-scale experiments designed to test specific chemical and biological treatment reactions. Two leachate treatment facilities were visited, the Al Turi landfill in Ghoshen, New York and the GROWS, Inc. facility in Falls Township, Bucks County, Pennsylvania. At the Al Turi Landfill the leachate was treated in an anaerobic reactor followed by aerobic treatment for further BOD reduction and nitrification. The GROWS, Inc. facility uses ammonia stripping followed by biological reduction of the BOD. Both facilities have demonstrated that biological nitrification and BOD reduction is possible. Biological processes were not upset due to toxicity which concerned some investigators.

The preliminary laboratory tests were designed to assess anaerobic

treatment by measuring the biological methane potential of the leachate, biological toxicity to bacteria using large-volume respirometers, and to identify optimum coagulants and their respective chemical dosages.

As a result of the site visits, literature review, and laboratory test results, the following technologies were selected for long-term evaluation in continuous-flow reactors: (1) activated sludge, (2) SBRs, (3) RBCs, (4) PACT, (5) chemical coagulation, and (6) activated carbon adsorption.

Anaerobic processes were eliminated from further evaluation because of the low BOD and insignificant production of methane. Air stripping requires conditioning the pH to approximately 11.5. The process would require an extremely high dosage of a base due to the high alkalinity, produce large volumes of sludge, and require extensive emission control systems to comply with New York State air pollution standards. For these reasons air stripping was not considered. Chemical oxidation was eliminated since it has not been effective for high strength wastewaters. This was further demonstrated and confirmed when treatment with peroxide and ozone was assessed in a study that will be reported in Volume III.

The selected technologies were evaluated using continuous-flow bench-scale models. All models, constructed at City College, used plexiglass as the primary material, and were designed to simulate

full-scale operation. The leachate used in the evaluation was collected from the Veterans Avenue Leachate Collection System pump station. Whenever possible, vendors of specific processes were consulted to obtain additional information that would be useful in the bench-scale evaluation study. The results of each process tested is summarized below.

Activated Sludge. The activated sludge process was evaluated in a five-liter cylindrical flask with a conical bottom to permit sludge wasting. The reactor was seeded with activated sludge from the Ward's Island WPCP in New York City. Leachate was pumped continuously through the reactor at various rates to produce hydraulic retention times (HRTs) within the range of 0.6 days to 1.6 days. The experimental results indicated approximately 70 percent nitrification at an ammonia loading of 0.28 lb ammonia nitrogen per lb of MLSS per day. The inability to increase the solids in the reactor prevented a higher nitrification efficiency. A process that is better for suspended solids control is SBR, which was subsequently evaluated.

Sequencing Batch Reactors. The SBR system was constructed using a four-inch plexiglass cylinder. The total reactor was of four-liter capacity with decanting ports at 1.5-, 2-, and 3-liter volume levels. Treatment of leachate in the SBR system was evaluated over a 40-day period.

The SBR system demonstrated almost complete nitrification even when the HRT was reduced to approximately 0.8 days. There was no wasting of solids other than the loss of suspended solids during decanting. Operating at a MLSS of 4,600 to 5,400 mg/L, the solids retention time was estimated at 60 days. Though the SBR proved effective in nitrifying the ammonia, the SS in the decanted leachate were occasionally as high as 100 mg/L. Implementation of an SBR facility may require improved solids capture such as a downstream filtration process.

PACT System. Concurrently with the activated sludge study, a second, similar reactor was placed in operation. However, powdered carbon was added to the second activated-sludge reactor to simulate the PACT system. The carbon dosage was controlled at two sequential levels. The first level promoted nitrification and the second level promoted nitrification and TOC removal.

The results of the PACT system study showed almost complete nitrifications (98 to 99 percent) of ammonia in the leachate can be achieved at an HRT of 0.6 days, MLSS of 5,000 mg/L and a carbon dosage of 140 mg/L. To remove TOC the MLSS was increased to 50,000 mg/L. The maximum TOC removal achieved was 75 percent at a carbon dosage of 3,000 mg/L. To operate at this high carbon dosage rate it was necessary to increase the air supply to provide sufficient turbulence to sustain the carbon in suspension. In addition clarification of the mixed liquor required adding a polymer to

capture the SS in the clarifier.

Rotating Biological Contactors. The RBC system consisted of four stages. Each stage consisted of six discs, each spaced half an inch apart. The total surface area of the discs was 18.9 sq ft. The evaluation of the RBCs was on a continuous basis for 90 days.

The experimental results demonstrated effective nitrification at loadings as high as 1.21 lb/day/1,000 sq ft compared to loadings of 0.3 lb/day/1,000 sq ft used in wastewater applications. An important parameter that affects nitrification is the dissolved oxygen (DO) in the leachate, which may be limiting in a full-scale RBC system.

The biological processes evaluated were effective in ammonia nitrification. The leachate had sufficient alkalinity to sustain the pH above 7. However, none of the biological processes demonstrated significant reductions in TOC and color.

Chemical Coagulation. Chemical coagulation was evaluated in a series of jar tests in which different coagulants were used to reduce color and TOC in the leachate. The optimum conditions for coagulation included an initial reduction of the pH to within the range from 5 to 6 using in addition 200 mg/L alum and 300 mg/L of CAT-FLOC 8964 polymer as marketed by the Calgon Corporation. When these coagulants were added to the leachate before flocculation and

settling, they reduced color by 90 percent and TOC by 46 percent. The study indicated that additional removal of TOC would require another process such as carbon adsorption.

Activated Carbon Adsorption. Activated carbon adsorption for removing TOC from the leachate was evaluated by determining the carbon(s) adsorption isotherms and by determining breakthrough distance in dynamic column tests using four granular carbon columns in series. The isotherm tests demonstrated that adsorption capacity increases with lower-molecular-weight fractions of leachate. Decreasing the pH to 4.1 also increases the adsorption capacity from 80.1 mg TOC/gm of carbon to 132.5 mg TOC/gm of carbon. Biological pretreatment did not affect the adsorption capacity of the carbon. The isotherm test suggested that TOC removal may be achieved by initial chemical coagulation at a pH range from 5 to 6, followed directly by carbon adsorption, without adjusting the pH to neutral.

The dynamic column test was then conducted on leachate that was chemically coagulated, flocculated, settled, and sand-filtered before loading the granular carbon columns. Analysis of the breakthrough curves from the four carbon columns indicated the following operating conditions for a TOC removal of 85 percent:

Empty bed contact time	=	60 minutes.
Mass transfer zone	=	9 feet.
Carbon usage rate	=	118.6 mg TOC per gm of carbon (Calgon Carbon, Inc. - Carbon React-C)

The bench-scale studies demonstrated that biological nitrification can reduce ammonia in the leachate from an initial level of 750 to 800 mg/L to less than 10 mg/L. The leachate has sufficient alkalinity to maintain the pH above 7.5 throughout the nitrification process. However, a biological process would not significantly reduce the color or TOC of the leachate. The latter can be reduced by applying chemical coagulation and activated carbon adsorption.

The level of leachate treatment required will be ultimately determined by the discharge permit issued by the New York State Department of Environmental Conservation. Assuming that ammonia nitrification and TOC removal will be required, the treatment facility would consist of a sequence of processes, each designed to remove a category of pollutants. The first process should be biological, either an RBC or an SBR system, to nitrify the ammonia. A detailed economic analysis of the two biological processes should be part of the selection process. A preliminary analysis indicated that the RBC system may have a higher capital cost but will have much lower energy consumption. The energy needs of the RBCs are approximately one-fourth those needed to operate an SBR system, which have been estimated at 790 HP per day.

The second process should be combination of chemical coagulation-flocculation-settling, filtration, and granular carbon adsorption to remove color and TOC. The major cost involved in TOC removal is

the cost of carbon. Since most of the TOC is due to biologically stable organics, removal of TOC would not benefit the oxygen balance in the receiving water. In view of the high cost of carbon, it would be prudent to proceed with the design and construction of a biological treatment facility to nitrify ammonia and only monitor TOC in the effluent of a biological plant. The data can then be used to establish a TOC removal requirement only if adverse environmental impacts can be identified. TOC removal can be added to the facility in the future, if needed.

Leachate treatment at the Fresh Kills Landfill should be implemented in stages. The first stage should include biological oxidation of the ammonia and monitoring of the priority pollutants as well as TOC in the plant effluent. When more data are collected and if adverse environmental impacts on the receiving waters are suspected, then the facility should be upgraded.

1.0 INTRODUCTION

With the advent of the Resource Conservation and Recovery Act of 1976 and New York State's complementary regulations under Part 360 of the State Environmental Conservation Law, more stringent criteria for the siting, construction and operation of landfills were promulgated. These regulations required upgrading the Fresh Kills Landfill to appropriate standards to effectively mitigate environmental damage.

Accordingly, the New York City Department of Sanitation (NYCDOS) has made extensive environmental and operational investigations to identify and correct site deficiencies at Fresh Kills. Recognizing that leachate release from the Fresh Kills Landfill may be a major environmental concern, NYCDOS retained the services of the City College Department of Civil Engineering to characterize the chemical composition of the leachate, to estimate its generation rate, and to evaluate leachate treatment alternatives.

The leachate was characterized by conventional and priority pollutants. Leachate analyses were performed at City College and at the H2M, Labs, Inc., a New York State-certified laboratory. The leachate generation rate was estimated using hydraulic data collected from monitoring wells and from piezometers installed throughout the landfill, using mathematical models specifically formulated for the Fresh Kills Landfill. All proposed leachate treatment processes were evaluated in the Environmental Engineering

Laboratory at City College. For each process, a bench-scale model was constructed and evaluated using leachate from the Veterans Avenue Pump Station in Fresh Kills.

The results of the study are presented in three volumes:

- Volume I - Leachate Characteristics and Treatment Alternatives at the Fresh Kills Landfill;
- Volume II - Modelling, Monitoring, and Evaluation of Leachate at the Fresh Kills Landfill; and
- Volume III - Biodegradability, Nitrification and Denitrification of the Leachate from the Fresh Kills Landfill.

Volume I contains the results of the required analyses of leachate and the evaluation of biological and physical chemical processes for reducing biochemical oxygen demand (BOD), total organic carbon (TOC), chemical oxygen demand (COD), color, and ammonia-nitrogen. Volume II presents the hydraulic data collected at the Fresh Kills Landfill and the estimates of leachate generation rates. Volume III presents additional data on leachate characteristics along with the results of several attempts to increase the biodegradability of organic carbon as well as evaluation of nitrification-denitrification studies for nitrogen removal.

The following subsections present a brief description of the landfill site. The remaining sections of volume I present the results of the leachate characterization and treatability studies.

1.1 DESCRIPTION OF THE FRESH KILLS LANDFILL

The Fresh Kills Landfill is located on the western shore of Staten Island. The 2,400-acre facility, owned and operated by the City of New York, has received household wastes for disposal since 1947. The landfill currently handles approximately 17,000 tons of refuse per day on a six-day-per-week operating schedule . The Fresh Kills Landfill will be an integral part of New York City's solid waste management plan through the end of the century.

The landfill is located in a wetland area as shown in Figure 1-1. The Arthur Kill, which forms part of the western boundary of the landfill, is a tidal strait connecting Raritan Bay on the south with Newark Bay on the north. The Fresh Kills Creek and its major tributaries, Main Creek and Richmond Creek, drain the landfill and connect near the central portion of the Arthur Kill. Contaminants discharged near the central portion of the Arthur Kill are virtually trapped within the Kill by a cyclical pattern of the tides that creates little flushing action.

The landfill is divided geographically into operating sections that reflect the way in which refuse was earlier disposed of at the site. Within the operating sections, a numbering system has been developed for mounds or hills created by filling operations. The current study addresses the leachate generated in sections 1/9 and 6/7 as shown in Figure 1-1. These sections will remain active and

Figure 1-1. Vicinity Plan For Fresh Kills Landfill

will generate larger volumes of leachate than the other two sections, 2/8 and 3/4.

1.2 HYDROGEOLOGY OF THE LANDFILL SITE

Hydrogeologic conditions at the Fresh Kills Landfill were preliminarily defined in previous field investigations (1) and will be further evaluated by the IT Corporation through a recently awarded contract (July 1st, 1990). This report presents a general overview to encourage understanding the potential environmental impacts of the leachate. A more detailed description is found in Volume II.

As shown in Figure 1-2, within the weathered bedrock unit two types of bedrock were encountered on the site, Staten Island Serpentine and the Stockton Formation of the Newark Group. Groundwater occurs primarily within the bedding, joint, and fault planes that provide the pathways for groundwater flow within the bedrock. Because residual clay deposits on top of the weathered rock are impermeable, they impede the flow of water vertically into the bedrock. Above the residual clay deposits, there are several unconsolidated Cretaceous sequences. At least four distinct strata were identified: a lower sand, a lower clay, an upper sand, and an upper clay. The sand layers are considered significant water-bearing zones. The interlayered sequence of clay impedes the vertical flow of groundwater between the various water-bearing

[10] PERCENTAGE OF RECHARGE (LEACHATE) REACHING EACH AQUIFER - APPROXIMATIONS BASED UPON AVAILABLE DATA AND CONSERVATIVE ASSUMPTIONS.

Figure 1-2. Typical Geologic Cross-section Through Fresh Kills Landfill

zones.

Overlying the Cretaceous sequences are glacially derived sediments. These glacial deposits may be found at the surface, directly beneath filled material, or beneath recently deposited soils. The glacial deposits consist of glacial till, glacial sands, and glaciolacustrine clay. Recently deposited soils consist of sand, silt, and clay.

The fill materials are in direct contact with the later formations. Because no artificial linings were used to trap leachate, leachate formed within the landfill is impeded from flowing in a vertical direction only by naturally occurring impervious layers. Calculations performed by Wehran (1), indicated that more than 90 percent of the leachate generated at the Fresh Kills site moves laterally to the tidal streams. Therefore, the landfill primarily affects the surrounding surface water quality. The prime objective of this study was to develop leachate treatment alternatives to reduce such impacts on the surface waterways.

1.3 POTENTIAL IMPACT OF LEACHATE ON SURFACE WATERS

Leachate develops from the infiltration of natural precipitation as it percolates through the refuse mounds, dissolving and carrying a variety of contaminants away from the decomposing waste materials deposited in the landfill. The contaminants within the leachate

reflect the type of wastes deposited and the extent of biochemical decomposition. The environmental impacts from the uncontrolled release of leachate at some locations, have been so severe that wells located near these landfills had to be abandoned as sources of drinking water, while in other locations surface waters were rendered unfit for domestic or recreational use. To prevent additional contamination of natural water resources, State and Federal agencies have promulgated regulations to control landfills. These regulations require, in part, a New York State National Pollutant Discharge Elimination System (NPDES) permit prior to discharging the collected leachate to a surface water.

The permitting process begins with identification of the flow rate. Hydraulic water balances for the site (1) indicated that, under present, unimproved conditions, the leachate generated at each of the landfill sections is as follows:

Section 1/9	-	657,000 gallons per day (GPD)
Section 2/8	-	159,000 GPD
Section 3/4	-	246,000 GPD
Section 6/7	-	400,000 GPD

These generation rates will change after NYCDOS implements an extensive leachate control system proposed for the Fresh Kills Landfill. In sections 2/8 and 3/4, which are selected for early closure, a final cover to limit infiltration to less than one percent of that under existing conditions has been recommended. No

additional leachate mitigation actions are warranted for sections 2/8 and 3/4. However, sections 1/9 and 6/7 will remain active and will continue to generate large volumes of leachate. For those sections, perimeter cut-off walls with leachate collection and final covers are recommended. The leachate containment and collection system would be designed to collect leachate generated during future operations, to contain existing leachate within the landfill by use of a vertical cut-off wall extending from ground level down to the depth of the first naturally occurring impermeable strata, and to restrict offsite inflow of groundwater to the leachate collection lines. The system would include pumping facilities and piping for handling the leachate at an offsite or onsite treatment facility.

The second concern of the NPDES permitting process is the presence of contaminants and their impact on receiving waters. Separate categories of pollutants potentially present in leachate would manifest different impacts on receiving waters. Biodegradable organics, as measured by BOD, can potentially lower the dissolved oxygen below the water quality standards. Ammonia or ammonia precursors at high concentrations can be toxic to aquatic life and at the same time exert a high oxygen demand during natural oxidation. Refractory organic compounds and heavy metals may be toxic to aquatic life, may bioaccumulate or may concentrate in the sediments.

The actual impact of discharging the leachate to the Fresh Kills is difficult to predict because of a combination of the site-specific conditions: the volume tidal flow of poor quality water in the Arthur Kill, the lack of tidal flushing of pollutants out of the Arthur Kill, and the magnitude of other discharges into the Fresh Kills. While it is understood that reduction of contaminant loads to the Fresh Kills would minimize potential impacts of the leachate, as indicated in the previous study (1) water quality standards would not likely be attained through leachate control measures alone.

1.4 FRESH KILLS CREEK

The Fresh Kills and its two major tributaries, Main Creek and Richmond Creek, are the major surface waters that flow through the landfill site. The drainage area for the Fresh Kills-Richmond Creek-Main Creek system is estimated at 8,000 acres, of which the landfill approximately 3,000 acres, comprises 37.5 percent of the total. The headwaters of the Fresh Kills originate in wetland areas that have not been filled. All of the streams are affected by tidal action owing to their hydraulic connection to the Arthur Kill.

Figure 1-1 shows the location of the Fresh Kills Creek in relation to the two landfill sections 1/9 and 6/7. Tidal waters travel upstream approximately 14,000 feet in Main Creek and 16,000 feet in

Richmond Creek from the mouth at Arthur Kill. Fresh water input from groundwater flow and surface runoff represents the main mechanism for the net transport of contaminants into the Arthur Kill.

As a result of the Federal Clean Water Act, inland water ways have been classified according to "best uses". The usage classifications for New York saline (S) surface waters are as follows (2):

<u>Class</u>	<u>Best Use</u>
SA	The best usages of Class SA waters are shellfishing for market purposes, primary and secondary contact recreation and fishing. These waters should be suitable for fish propagation and survival.
SB	The best usages of Class SB waters are primary and secondary contact recreation and fishing. These waters shall be suitable for fish propagation and survival.
SC	The best usage of Class SC waters is fishing. These waters shall be suitable for fish propagation and survival. The water quality shall be suitable for primary and secondary contact recreation, although other factors may limit the use for these purposes.
SD	The best usage of Class SD waters is fishing. These waters should be suitable for fish survival. This classification may be given to those waters that, because of natural or man-made conditions, cannot meet the requirements for primary and secondary contact recreation and fish propagation.

The Fresh Kills and its tributaries have been classified by the New York State Department of Environmental Conservation (NYSDEC). From

the convergence of Main Creek and Richmond Creek to the mouth of Fresh Kills the classification is SD. The tidal portions of Richmond Creek and Main Creek are SC. The upper portions of both tributaries to Fresh Kills above the tidal reach, being fresh surface waters, are classified as B. Class B fresh waters are suitable for primary and secondary contact recreation and fishing. These waters should be suitable for fish propagation and survival. Arthur Kill, which interacts with Fresh Kills, is classified as SD.

Based on the characteristics of the leachate, the classification of the receiving waters and the natural purification capacity of the Fresh Kills, NYSDEC will develop discharge limits for an onsite leachate treatment facility. This report presents the analytical results used to characterize the leachate as well as the different technologies evaluated to treat the leachate.

2.0 LEACHATE CHARACTERISTICS

2.1 HISTORICAL DATA

The Fresh Kills Landfill is currently being upgraded to comply with New York State environmental regulations governing solid waste disposal. In accordance with the New York State Environmental Quality Review Act (SEQRA), an Environmental Impact Statement (EIS) was prepared in 1985 by Parsons Brinkerhoff for the Department of Sanitation.

Analyses of samples collected from monitoring wells in the mounds of section 1/9 were reviewed by Parsons Brinkerhoff in preparing the EIS. These samples showed high concentrations of some conventional parameters, but relatively few priority pollutants, and those present were in the ug/L level. The mean concentrations in milligrams per liter (mg/L) for typical parameters reported were (3):

Total kjeldahl nitrogen (TKN)	741
Ammonia - nitrogen	595
Total organic carbon (TOC)	1,196
Biochemical oxygen demand (BOD)	80.8
Cadmium	0.0255
Lead	0.164
Chlorides	2,124
Total dissolved solids (TDS)	9,480
Sulfates	40.1

The data indicated high concentrations of organics as measured by TOC. However, the relatively low BOD suggested that most of the

organics were non-biodegradable.

In December 1987 the U.S. Environmental Protection Agency (EPA) conducted a sampling survey of leachate surface streams at section 1/9. These streams of leachate appeared at several locations along the base of the landfill prior to the operation of the Veterans Avenue Collection System pumping station, which was designed to collect and recirculate the leachate back to the mound for partial containment. Three surface leachate sampling points were selected and arbitrarily designated as leachate streams 001, 002, and 003. Grab samples were collected at each sampling location for analysis of all 129 parameters on the EPA Priority Pollutant List with the exception of asbestos. Table 2-1 lists the contaminants identified in the leachate.

Several organic compounds were detected within the range of the analytical detection limits. Metal concentrations were also low for most of the heavy metals. No pesticides or polychlorinated byphenols (PCBs) were detected in any of the leachate samples. The samples were not analyzed for conventional pollutants. The data, as presented in Table 2-1, are representative of the particular streams sampled on that day and should not be interpreted as representative of leachate from the entire landfill.

This brief summary of historical data on leachate characteristics suggests that the parameters of concern may be conventional, not

TABLE 2-1

**PRIORITY POLLUTANTS DETECTED
IN FRESH KILLS LANDFILL LEACHATE SAMPLES¹**

Parameter	Leachate Streams		
	001	002	003
1,2-dichlorobenzene	0.6 M	1.1 M	ND
1,4-dichlorobenzene	2.8	1.2 M	ND
2,4-dichlorophenol	12	8.7	2.0 M
Ethylbenzene	ND	15 M	ND
Fluoroanthrene	0.6 M	0.6 M	ND
Isophorone	ND	ND	0.9 M
Naphthalene	16	33	1.4 M
Acenaphthene	0.7 M	1.0 M	ND
Anthracene	0.9 M	0.9 M	ND
Phenanthrene	1.0 M	1.0 M	0.6 M
Toluene	ND	5.1 M	ND
Cyanide	4.0 M	ND	52
Silver	20 M	ND	ND
Arsenic	15	19	21
Beryllium	ND	3.0 M	3 M
Cadmium	ND	ND	8 M
Chromium	190	290	280
Copper	ND	19	310
Lead	ND	40	100 M
Nickel	100 M	100 M	160
Antimony	ND	7.6	11
Zinc	94	150	480

Notes: All concentration in microgram per liter ($\mu\text{g/L}$)

ND - Indicates that parameter was analyzed for, but not detected.

M Indicates that parameter was detected, but could not be quantified. Parameter may be present in any concentration up to the value indicated.

¹The data was obtained during an EPA sampling survey of leachate streams in section 1/9 of the Fresh Kills Landfill on December 17, 1987.

priority, pollutants. The high TKN can have pronounced effects on the oxygen balance of the Fresh Kills and can further promote eutrophication. The organic compounds present are apparently biologically stable, showing a BOD/TOC ratio of less than 0.07. The presence of low concentrations of priority pollutants does not appear to warrant treatment beyond the level required for the conventional parameters.

To develop and evaluate realistic treatment alternatives, and assure regulators and the public that priority pollutants are not a serious problem, more samples from both sections 1/9 and 6/7 were collected and analyzed to confirm the concentrations of both conventional and priority pollutants. The sample points were strategically located so that the data collected could be used to estimate the overall leachate characteristics from each section. The following sections describe the sampling effort undertaken for sections 1/9 and 6/7, the chemical analyses performed, and the evaluation of the characteristics of the leachate.

2.2 LEACHATE SAMPLING

A thorough characterization of the leachate was required prior to developing leachate management plans for sections 1/9 and 6/7 of the Fresh Kills Landfill. The process began with selection of appropriate sampling points from which representative leachate volumes could be collected for analysis. In section 1/9, the

sampling point used during the initial phase of the study was the Veterans Avenue Leachate Collection System pumping station, shown in Figure 2-1. This station was designed to collect approximately 150,000 GPD of leachate and to recirculate it back into the landfill. Its continuous operation provided convenient sampling of the leachate not only for analysis but also as the source of leachate for conducting the various bench-scale treatment technology evaluations.

The pumping station represented a single sampling point in section 1/9. Additional sampling was needed to characterize the total leachate produced in section 1/9 as well as in section 6/7. The DOS installed 20 monitoring wells in sections 1/9 and 6/7 as shown in Figures 2-1 and 2-2. The wells, located along the periphery of each section, allowed sampling of the leachate as it flowed laterally from each respective mound. All monitoring wells initially developed by the contractor were constructed of four-inch-diameter PVC pipe screened within the fill area.

Sampling from the monitoring wells began by first determining the volume of water in the well casing. Each well was then purged using a 3.5-inch outside-diameter PVC bailer until the pH, conductivity, temperature, and turbidity of the leachate stabilized; i.e. until successive readings were within a 10 percent variation. The minimum volume of leachate bailed from each well was predetermined to be three casing volumes. Field measurements

Figure 2-1. Location of Monitoring Wells in Section 1/9.

Figure 2-2. Location of Monitoring Wells in Section 6/7.

during the first sampling event showed that purging three casing volumes was sufficient to achieve stabilized conditions; this procedure was thereafter used prior to collecting samples for analysis during each subsequent sampling. After the three volumes were evacuated, 15 minutes were allowed to recharge the well prior to collecting the required leachate sample volumes. All samples were collected using a PVC bailer dedicated for each well. The sampling period commenced with the first bailer volume and ended within one hour of well purging. Samples were preserved and transported to the analytical laboratories within four to six hours following collection.

2.3 LEACHATE ANALYSIS

Leachate analyses were performed at the Environmental Engineering Laboratory of the City College of New York and at the H2M Labs, Inc., in Melville, New York. At City College the analyses performed included the conventional pollutants such as BOD, COD, TOC, TKN, ammonia, SS, and TDS. H2M Labs analyzed the leachate for priority pollutants and periodically for conventional parameters as a check of the City College analytical results. The data collected are summarized according to categories of pollutants and presented in the following sections.

2.3.1 Biochemical Oxygen Demand/Chemical Oxygen Demand/Total Organic Carbon

Characterization of any wastewater begins with a gross measurement of the total organic matter present. The three parameters used to quantify the amount of organic matter present are biochemical oxygen demand, chemical oxygen demand, and total organic carbon. The BOD test is an empirical test that measures the total oxygen required for the biochemical degradation of organic material and the oxygen used to oxidize inorganic substances such as sulfides and ferrous iron. It may also be used to measure the oxygen required to oxidize reduced forms of nitrogen unless their oxidation is prevented by an inhibitor. The test depends on the presence of a population of microorganisms, a seed, capable of aerobically metabolizing the biodegradable organic matter in the leachate. The seed sources used initially in the BOD tests of leachate were domestic wastewater, adapted microorganisms from a bench-scale activated-sludge reactor treating leachate, and "polyseed", a BOD seed inoculum manufactured by Polybac Corporation and approved by EPA. Since all three seeds produced equivalent BOD values for the leachate, the polyseed was selected and used to seed all subsequent BOD tests.

Prior to the installation of the monitoring wells, the source of leachate was the pumping station in section 1/9. Samples were periodically collected from February 1988 through January 1989 and analyzed for 5-day BOD. The results, given in Table 2-2 showed

TABLE 2-2

CHARACTERISTICS OF THE LEACHATE FROM THE VETERANS AVENUE LEACHATE COLLECTION SYSTEM

Parameter	02/17/88	05/23/88	07/23/88	10/18/88	*12/19/88	01/25/89
COD	1800	1730	1740	1850	1870	1700
TC	1948					1800
TOC	580					530
BOD ₅	140	100	100	90	98	90
BOD ₂₀						
TS		7985	7040		7400	7584
TVS		16%	16%			14%
SS	27	29	14		30	29
VSS		11	12			11
Settleable Solids (vol)		0	0	0		0
Ammonia-N	790	670	580	720	657	680
TKN		750	620	780	729	780
Chloride	2300	2296	2100	2440	1860	2180
Color (units)	3000	3500	3000	3000		3000
O-Phosphate	5	4.85	4.75	7.75	5.1	4.6
Total Alkalinity	6500	5640	5130	6220		5600
Sulfate			100			70
pH	8.5	8.4	8.0	8.0	7.7	8.25

Notes:

Concentrations in mg/L

*Analysis performed by H2M Lab., Inc.

that the BOD ranged from a maximum of 140 mg/L to a minimum of 90 mg/L with most of the values near 100 mg/L. After installation of the monitoring wells, shown in Figures 2-1 and 2-2, leachate samples drawn from them were collected and analyzed for BOD. The results are shown in Tables 2-3 and 2-4 for sections 1/9 and 6/7, respectively. The BOD, though varying significantly among the monitoring wells and sampling events in each section, nevertheless tends to be low and well within the range of domestic wastewater. For section 1/9, the average BOD appears to range from 90 to 140 mg/L while in section 6/7 the range is from 50 to 120 mg/L.

COD, used as a measure of the oxygen equivalent of the organic matter content of leachate that is susceptible to oxidation by the dichromate reflux method, was analyzed using the closed reflux colorimetric method (4). Analysis of the leachate from the Veterans Avenue Collection System pumping station showed that from February 1988 through January 1989 the COD ranged from 1,700 to 1,870 mg/L.

Results of analysis of samples from the monitoring wells in both sections are shown in Tables 2-3 and 2-4. The COD from individual monitoring wells in section 1/9 ranged from 520 to 3,060 mg/L during the three sampling events. However, the average COD of the leachate samples ranged from 1,400 to 1,600 mg/L. Similarly, the individual leachate COD values from section 6/7 ranged from 105 to 1,050 mg/L, with the average COD ranging from 640 to 710 mg/L. The

TABLE 2-3

BOD, COD and TOC in the FRESH KILLS
LANDFILL LEACHATE: SECTION 1/9

Well Number	October 1989				December 1989				March 1990			
	BOD	COD	TOC		BOD	COD	TOC		BOD	COD	TOC	
W1	69	1076	418		68	1024	207		74	890	210	
W2	51	1571	380		120	1430	420		105	1130	328	
W3	120	3110	626		162	2915	681		95	1847	866	
W4	45	494	116		240	520	112		215	539	860	
W5	222	2152	864		254	3060	941		65	2900	945	
W6												
W7	50	1133	300		57	963	261		65	900	337	
W8	71	1852	518		98	1831	565		60	1700	679	
W9	56	839	204		44	820	203		58	746	192	
W10	10	1815	587		183	1802	563		100	1980	655	
Avg.	77	1560	446		136	1596	439		109	1404	564	

Note: Concentrations in mg/L

TABLE 2-4

BOD, COD and TOC in the FRESH KILLS
LANDFILL LEACHATE: SECTION 6/7

Well Number	October 1989			December 1989			March 1990		
	BOD	COD	TOC	BOD	COD	TOC	BOD	COD	TOC
W1	214	737	260	34	760	295	34	960	190
W2	44	470	80	48	502	174	40	542	185
W4	43	203	45	6	185	34	18	180	96
W5	54	441	74	63	380	48	55	336	56
W6	196	950	145	44	580	141	40	810	167
W8	60	894	109	53	840	78	48	279	55
W9	241	1032	226	63	1050	248	83	1020	280
W10	127	934	155	56	858	218	60	840	240
AVG	122	708	137	49	645	154	48	696	171

Note: Concentrations in mg/L

soluble COD was determined to be approximately 90 percent of the total COD.

TOC is a more direct expression of total organic content than either BOD or COD. TOC is independent of the oxidation state of the organic matter and does not measure the oxygen demand of other organically bound elements that can contribute to BOD and COD. The persulfate-ultraviolet oxidation method was used to measure the TOC in the leachate. In this method, organic carbon is oxidized to carbon dioxide by persulfate in the presence of ultraviolet light. The carbon dioxide produced is then measured directly by an infrared analyzer. The organic carbon analyzer used was the Xertex-Dohrmann DC-80 recommended by Standard Methods (4).

In section 1/9 the TOC average ranged from 440 to 560 mg/L, compared to 140 to 170 in section 6/7. All the data, BOD, COD, and TOC, indicated that the organic content of the leachate in section 1/9 was more than twice the concentration in section 6/7.

The organic carbon in the leachate is composed of a variety of compounds in various oxidation states. The fraction of carbon compounds that can be oxidized further by biological processes is measured as BOD while the fraction that is chemically oxidized is measured as COD. The ratio of BOD to COD has been used traditionally as a measure of the biodegradability of the organic matter. A BOD/COD ratio of 0.67 denotes readily biodegradable

organic matter while a ratio approaching zero denotes refractory or nonbiodegradable organic matter. In the Fresh Kills Landfill leachate, the BOD/COD ratio is equal to or less than 0.1. This implies that biological treatment processes that can reduce the BOD would not significantly remove organic contaminants from the leachate as measured by either COD or TOC.

2.3.2 Solids

Matter dissolved or suspended in the leachate is referred to as solids. Dissolved solids (DS) include organic and inorganic matter found in the filtrate of a sample filtered through a standard glass fiber filter such as Whatman grade 934AH (4). The matter retained on the filter is called suspended solids (SS). This procedure, although empirical, is a convenient way to classify the total solids in the leachate.

The leachate from the pumping station and the monitoring wells was analyzed for both SS and total dissolved solids. The quantity of suspended solids in the leachate depends on the technology used to collect the leachate. For example, fine screening will minimize the SS in the collected leachate. The proposed collection system is to be passive, that is, the leachate will be collected by a peripheral drainage pipe system. Flow rates and velocities will be governed by existing hydraulic gradients, by the hydraulic conductivity of the landfill, and by local head losses induced by

the drainage system. An installed portion of the peripheral drainage system, approximately 3,000 feet, conveys the collected leachate into the Veterans Avenue Leachate Collection System pumping station. The collected leachate as sampled from February 1988 to January 1989 and analyzed for SS indicated values that range from 14 to 30 mg/L, as shown in Table 2-2. When a similar collection system is installed to intercept all the leachate from both sections of the landfill, the SS in the leachate will undoubtedly remain low within this range.

The TDS is determined after the SS have been removed from the leachate sample. Therefore, TDS concentration depends on the location from which the sample was collected, not on the method of extracting the sample from the landfill. TDS analyses on samples from the pumping station showed a range from 7,400 to 8,000 mg/L over one-year period. Table 2-5 shows the TDS at each of the monitoring wells sampled. The average TDS in section 1/9 was 5,800 mg/L, compared to that of section 6/7, 3,600 mg/L. As a reference level, it is noted that 500 mg/L TDS is desirable for drinking water while 500 to 5,000 mg/L TDS is the recommended limit for irrigation. Above 2,000 mg/L, water can be regularly used only for tolerant plants on permeable soils. The TDS in the leachate from both sections is expected to be above 2,000 mg/L.

TABLE 2-5

TOTAL DISSOLVED SOLIDS IN THE FRESH KILLS LANDFILL LEACHATE

Well Number	Section 1/9			Section 6/7		
	Oct. 1989	Dec. 1989	March 1990	Oct. 1989	Dec. 1989	March 1990
W1	4020	3575	3046	4848	4910	4600
W2	4352	4965	4324	1556	2870	2563
W3	6600	6965	6324	-----	-----	-----
W4	2304	2495	2078	6504	1085	1106
W5	12736	13210	12780	2696	1970	1856
W6	-----	-----	-----	6304	5950	4640
W7	4668	4470	4218	-----	-----	-----
W8	6220	7655	7269	2540	2710	2310
W9	2952	3685	3406	3248	4550	4683
W10	7068	7430	6538	4028	4925	5007
Avg	5658	6050	5554	3966	3621	3346

Note: Concentrations in mg/L

2.3.3 Nitrogen and Phosphorus

The principal nutrients required for growth of microorganisms in the metabolism of organic matter are nitrogen and phosphorus. Sufficient concentrations of both nutrients are required to support biological processes that may be considered for the treatment of leachate. Nutrient levels above those required to support the biological treatment process will be discharged with the process effluent. The concerns with nitrogen compounds discharged into surface waters include eutrophication, oxygen demand, toxicity caused by ammonia, and adverse health effects when nitrates are present in drinking water. Phosphorus discharge is commonly limited to control eutrophication in receiving waters. Eutrophication is the enrichment of a surface water with nutrients that results in algae blooms.

Monitoring the concentrations of both nutrients in the leachate at the pump station for a year indicated that ammonia nitrogen ranged from 600 to 800 mg/L, TKN from 600 to 800 mg/L, and phosphorus, from 4.5 to 7.8 mg/L. After the installation of the monitoring wells, samples of leachate from both sections were collected and analyzed. Table 2-6 shows the data from section 1/9 and Table 2-7 the data from section 6/7. Ammonia concentration for the three sampling events averaged 785 mg/L in section 1/9, approximately 93 percent of the TKN measured. In section 6/7, the ammonia concentration, as shown in Table 2-7, averaged 210 mg/L,

TABLE 2-6

AMMONIA-N, TKN-N AND PHOSPHOROUS (ORTHO)
IN THE FRESH KILLS LANDFILL LEACHATE: SECTION 1/9

Well Number	October 1989				December 1989				March 1990			
	NH ₃ -N	TKN-N	ORTHO-P		NH ₃ -N	TKN-N	ORTHO-P		NH ₃ -N	TKN-N	ORTHO-P	
W1	755	813	4.6		740	800	4.3		627	-----	5.2	
W2	850	898	5.7		915	980	5.3		815	-----	5.0	
W3	1350	1412	5.5		1190	1306	5.0		800	-----	5.8	
W4	240	312	ND		275	327	ND		280	-----	ND	
W5	1300	1389	68		1170	1330	6.3		850	-----	7.0	
W7	650	731	2.8		560	610	3.2		540	-----	4.0	
W8	855	913	4.1		925	940	4.3		730	-----	4.8	
W9	490	542	ND		510	560	ND		480	-----	1.3	
W10	1300	1347	3.6		1060	1135	3.8480		890	-----	3.8	
AVG	866	929	4.7		816	888	4.6		675	-----	4.6	

Note: Concentrations in mg/L

TABLE 2-7

AMMONIA-N, TKN-N AND PHOSPHOROUS (ORTHO)
IN THE FRESH KILLS LANDFILL LEACHATE: SECTION 6/7

Well Number	October 1989				December 1989				March 1990			
	NH ₃ -N	TKN-N	ORTHO-P		NH ₃ -N	TKN-N	ORTHO-P		NH ₃ -N	TKN-N	ORTHO-	
W1	450	523	1.0		200	227	0.75		250	-----	1.25	
W2	160	214	ND		110	128	ND		130	-----	ND	
W4	180	246	ND		40	48	ND		45	-----	ND	
W5	255	301	ND		50	61	ND		60	-----	0.20	
W6	500	547	0.24		165	179	ND		265	-----	0.30	
W8	285	247	ND		51	63	ND		100	-----	0.25	
W9	365	397	0.28		190	207	0.24		390	-----	0.8	
W10	390	426	ND		180	200	ND		250	-----	ND	
Avg	323	363	0.51		123	139	0.50		186	-----	0.56	

Note: Concentrations in mg/L

approximately 89 percent of the TKN measured. These data on nitrogen concentrations, although much higher in section 1/9 than 6/7, clearly indicate that ammonia is the primary form of nitrogen in the leachate.

Phosphorus in leachates and wastewaters may be found as orthophosphates, condensed phosphates (Pyro-, meta-, and other polyphosphates), and organically bound phosphates. Preliminary testing showed that orthophosphates are the predominant form of phosphorus in the Fresh Kills Landfill leachate. The results of phosphate analyses are summarized in Tables 2-6 and 2-7. Orthophosphate concentrations averaged 4.6 mg/L in the leachate of section 1/9 and 0.52 mg/L in section 6/7.

These values are low compared to medium strength wastewater, where phosphorus averages 8 mg/L. However, the nitrogen concentration is high, approximately 20 times that of domestic wastewater, which averages 40 mg/L. This concentration would affect the receiving waters in terms of both eutrophication and as a significant source of oxygen demand. The nutrient concentrations of phosphorus and nitrogen found in the leachate are sufficiently high to support biological treatment.

2.3.4 Alkalinity and pH

Alkalinity of a water sample is a measure of its acid-neutralizing

capacity. The test of alkalinity determines the sum of all the titratable bases without identifying the nature of any one base. In most treatment processes alkalinity is viewed as the buffering capacity of wastewater, which enables the water to retain a stable pH level as acid-producing reactions take place. In leachate treatment, nitrification is a biological process that produces nitric acid. The leachate must contain sufficient alkalinity to prevent the pH from dropping to acidic levels that could inhibit the process. Alkalinity measurements of the leachate from section 1/9 showed a concentration of 5,000 to 6,500 mg/L as CaCO_3 . The leachate is thus well buffered at its present pH level.

The pH, referring to the degree of acidity, is a measurement of the hydrogen ion concentration, which indicates the acidic or basic character of the leachate. In section 1/9 the pH of the leachate from the monitoring wells sampled varied from 6.9 to 8, while in section 6/7 the pH varied from 7.3 to 8.3. These data indicate that the leachate is within the basic range, slightly above seven, and well buffered at its present pH level.

2.3.5 Metals

A part of the TDS measured in the leachate and reported in section 2.3.2 is due to the presence of metals. Some of these metals may be present at concentrations that could affect selection of specific treatment processes or disposal and reuse alternatives for

the processed leachate. In a treatment facility the metals may accumulate in the sludge, thus limiting disposal options. Therefore a number of monitoring wells were selected in each landfill section as leachate sample sources for metals characterization. The selection of the monitoring wells was based on a preliminary testing of the leachate for conventional parameters and on geographic distribution within each section. Monitoring wells showing high conventional contaminant concentrations and appropriate geographic location were chosen. The samples from these monitoring wells were collected and shipped directly to H2M Labs, Inc., where all the analyses were performed. Table 2-8 describes the make-up of the metals and the metals concentrations in the leachate samples from section 1/9 during the two sampling events. Table 2-9 describes values from section 6/7. The last column in each table is the arithmetic average of both sampling events. The average concentration of all metals is below the levels required by the New York City Sewer Use Regulations. Thus the concentration of heavy metals in the leachate is within the range found in municipal wastewater where the industrial flow contribution is relatively small.

Although the concentration of most heavy metals in the leachate from sections 6/7 and 1/9 is within a similar range of values, iron and lead concentrations are much higher, 34.9 mg/L vs. 13 mg/L and 1.45 mg/L vs. 0.135 mg/L, respectively.

TABLE 2-8

METAL CONCENTRATIONS IN THE FRESH KILLS LANDFILL LEACHATE: SECTION 1/9

Metals	December 1989								March 1990				Avg
	Well Number								Well Number				
	W3	W5	W8	W10	W3	W5	W8	W10	W3	W5	W8	W10	
Aluminum	1.20	0.53	0.50	12.0	0.86	0.40	3.34	7.26	0.86	0.40	3.34	7.26	3.26
Antimony	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.06	<0.060
Arsenic	0.584	0.018	0.010	0.013	0.042	0.014	0.011	0.0166	0.042	0.014	0.011	0.0166	0.0232
Barium	0.51	0.99	0.87	1.60	0.41	1.00	1.04	1.50	0.41	1.00	1.04	1.50	0.99
Beryllium	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Cadmium	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.0086
Calcium	49.8	16.7	52.4	48.7	49.8	18.0	51.9	48.5	49.8	18.0	51.9	48.5	36.2
Chromium	0.29	0.41	0.25	0.17	0.25	0.37	0.22	0.15	0.25	0.37	0.22	0.15	0.26
Cobalt	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Copper	0.02	<0.04	0.03	0.17	0.03	0.07	0.19	0.14	0.03	0.07	0.19	0.14	0.09
Iron	3.00	7.20	10.8	26.8	3.50	7.80	22.9	22.2	3.50	7.80	22.9	22.2	13.0
Lead	0.006	0.0020	0.044	0.0418	0.0231	0.193	0.30	0.45	0.0231	0.193	0.30	0.45	0.135
Magnesium	68.9	32.3	52.6	59.2	64.4	46.7	48.3	54.6	64.4	46.7	48.3	64.5	54.6
Manganese	0.19	0.04	0.10	0.40	0.19	0.04	0.23	0.19	0.19	0.04	0.23	10.34	0.19
Mercury	<0.203	<0.002	<0.002	<0.002	0.00067	0.0002	0.002	0.0007	0.00067	0.0002	0.002	0.0029	0.0007
Nickel	0.12	0.17	0.10	0.12	0.10	0.17	0.13	0.13	0.10	0.17	0.13	0.13	0.13
Potassium	522	393	418	363	520	497	436	448	520	497	436	438	448
Selenium	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Silver	<0.01	<0.01	<0.01	<0.01	0.12	0.07	0.03	0.03	0.12	0.07	0.03	0.03	0.03
Sodium	1320	3180	1670	1470	1100	4640	1700	2075	1100	4640	1700	1520	2075
Thallium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Vanadium	<0.05	0.15	0.06	<0.05	<0.05	0.15	0.06	0.05	<0.05	0.15	0.06	<0.05	0.05
Zinc	49.8	16.7	52.4	48.7	49.8	18.0	51.9	48.5	49.8	18.0	51.9	48.5	36.2

Note: Concentrations in mg/L

TABLE 2-9

METAL CONCENTRATIONS IN THE FRESH KILLS LANDFILL LEACHATE: 6/7

Metals	December 1989								March 1990				Avg
	Well Number								Well Number				
	W1	W4	W6	W9	W1	W3	W6	W9	W1	W3	W6	W9	
Aluminum	6.60	6.90	6.30	0.71	4.23	0.31	17.2	10.4	6.58				
Antimony	<0.060	<0.060	<0.060	<0.060	<0.060	<0.060	<0.060	<0.060	<0.06				
Arsenic	0.014	<0.010	<0.010	<0.010	0.0118	<0.010	0.0323	0.0393	0.0122				
Barium	2.30	<5.00	0.95	0.62	2.21	<0.20	1.46	1.15	1.1				
Beryllium	<0.005	0.57	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005				
Cadmium	0.015	0.007	0.014	0.006	0.010	<0.005	0.021	0.021	0.0118				
Calcium	58.8	93.9	45.6	62.8	64.3	12.9	44.0	77.7	57.5				
Chromium	0.37	0.01	0.04	0.05	0.26	0.01	0.10	0.11	0.12				
Cobalt	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05				
Copper	0.56	0.33	0.09	0.03	0.41	0.38	0.25	0.29	0.26				
Iron	41.2	29.1	20.8	16.2	36.7	0.52	64.9	69.6	34.9				
Lead	4.930	0.071	0.174	0.0374	3.83	1.0603	0.78	0.72	1.4				
Magnesium	67.1	56.5	75.3	55.4	64.1	2.20	72.2	58.0	56.5				
Manganese	0.22	0.16	0.19	0.11	0.23	0.0008	0.57	0.46	0.25				
Mercury	0.004	0.00020	0.00050	0.0002	0.0016	2110	0.0029	0.0016	0.0011				
Nickel	0.07	<0.04	0.06	0.05	0.05	<0.04	0.17	0.12	0.07				
Potassium	233	57.0	145	270	215	55.7	180	278	183				
Selenium	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005				
Silver	<0.01	<0.01	<0.01	<0.01	0.03	<0.01	0.01	0.02	0.008				
Sodium	1590	126	1280	1010	1180	38.6	1300	1170	960				
Thallium	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01				
Vanadium	0.13	<0.05	0.06	<0.05	0.11	<0.05	0.19	<0.09	0.12				
Zinc	1.8	0.10	0.64	0.14	1.41	0.34	1.32	1.83	0.95				

Note: Concentrations in mg/L

2.3.6 Anions

All cations, positively charged ions in a solution, are balanced with anions, the negatively charged ions. Leachate samples from the selected monitoring wells were analyzed for chlorides, cyanide, fluorides, sulfides, and nitrates by H2M Labs, Inc. Table 2-10 shows the analytical results for leachate samples from monitoring wells in section 1/9, and Table 2-11 results from section 6/7. As expected, the nitrate concentration was negligible due to the anaerobic conditions in the landfill leachate. Sulfide concentrations were higher, exceeding the requirements of the New York City Sewer Use Regulations. However, the remaining anions were within the limits reported in the above regulations. In each case, chlorides are the predominant anion in the leachate samples.

2.3.7 Purgeable Organics

Purgeable organics, or volatile organic compounds, are organics that have a vapor pressure above 1 mm of Hg. Some of the leachate samples collected were analyzed for the purgeable organic compounds. Using EPA method 624, all leachate samples were tested for the compounds shown in Table 2-12. The detection limit was between 5 and 10 ug/L, as indicated. Tables 2-13 and 2-14 show only the compounds identified in the leachate from the selected monitoring wells during each of the two sampling events.

TABLE 2-10

ANIONS IN THE FRESH KILLS LANDFILL LEACHATE: SECTION 1/9

ANIONS	December 1989					March 1990				
	WELL NUMBER					WELL NUMBER				
	W3	W5	W8	W10	W3	W5	W8	W10		
CHLORIDE	1520	3560	1900	1980	160	180	1760	1640		
CYANIDE	0.020	0.022	0.026	0.043	0.014	0.017	0.018	0.019		
FLUORIDE	0.43	0.88	0.23	0.25	0.38	0.72	0.21	0.21		
SULFIDE	7.20	<0.50	5.30	6.90	3.80	3.72	3.40	3.76		
NITRATE	0.20	0.20	0.10	0.20	0.20	0.70	<0.10	<0.10		

Note: Concentrations in mg/L

TABLE 2-11

ANIONS IN THE FRESH KILLS LANDFILL LEACHATE: SECTION 6/7

ANIONS	December 1989					March 1990				
	WELL NUMBER					WELL NUMBER				
	W1	W4	W6	W9	W1	W4	W6	W9	W1	W4
CHLORIDE	1050	160	1520	800	1300	124	1520	1520		
CYANIDE	0.021	<0.01	0.019	0.024	<0.01	<0.01	0.038	0.24		
FLUORIDE	0.40	0.14	0.23	0.17	0.33	1.08	0.19	0.19		
SULFIDE	3.20	1.40	2.90	0.99	1.60	70.5	1.40	1.42		
NITRATE	0.10	0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10		

Note: Concentrations in mg/L

TABLE 2-12

TYPICAL RESULTS OF PURGEABLE ORGANICS FROM WELL W5: SECTION 1/9

PRIORITY POLLUTANT ANALYSIS - PURGEABLE ORGANICS			
Compound	Conc. ($\mu\text{g/L}$)	Compound	Conc. (mg/L)
Chloromethane	1) ND	Cis 1,3-Dichloropropene	ND
Bromomethane	1) ND	Benzene	ND
Vinyl Chloride	1) ND	2-Chloroethylvinylether	1) ND
Chloroethene	1) ND	Bromoform	ND
Methylene Chloride	ND	1,1,2,2-Tetrachloroethane	ND
Trichlorofluoromethane	ND	Tetrachloroethene	ND
1,1-Dichloroethane	ND	Toluene	140
1,1-dichloroethene	ND	Chlorobenzene	ND
1,2 Dichloroethane	ND	Ethylbenzene	ND
Chloroform	ND	1,2-Dichlorobenzene	ND
1,2-Dichloroethane	ND	1,3-Dichlorobenzene	ND
1,1,1-Trichloroethane	ND	1,4-Dichloroethene	ND
Carbon Tetrachloride	ND	Acetone	1) 40
Bromodichloroethane	ND	Carbon Disulphide	ND
1,2-Dichloropropane	ND	2-Butanone	1) ND
Trans 1,3-Dichloropropane	ND	Vinyl Acetate	1) ND
Trichlorethene	ND	4-Methyl-2-Pentanone	1) ND
Dibromochloroethane	ND	2-Hexanone	1) ND
1,1,2-Trichloromethane	ND	Xylene (Total)	130
Styrene	ND		

Notes: Quantification limit: 5 $\mu\text{g/L}$; ND - Under Quantification limit1) - Quantification limit: 10 $\mu\text{g/L}$; Date of Collected: 3/27/90; Date Analyzed: 03/29/90

John J. Molloy, P.E., Laboratory Director

TABLE 2-13

PURGEABLE ORGANICS IN THE FRESH KILLS LANDFILL LEACHATE: SECTION 1/9

Purgeable Organic Compounds	December 1989						March 1990			
	Well Number						Well Number			
	W1	W5	W8	W10	W3	W5	W8	W10	W10	W10
Vinyl Chloride	ND	10	ND	ND	ND	ND	ND	ND	ND	ND
Benzene	ND	5	ND	ND	ND	ND	ND	ND	ND	ND
Toluene	62	130	ND	13	96	140	ND	ND	2	2
Ethylbenzene	15	18	19	5	18	17	11	1	1	1
Xylene(Total)	32	60	12	6	40	130	29	ND	ND	ND
Carbon Disulphide	6	ND	ND	ND	ND	ND	ND	ND	ND	ND
1,4-Dichloroethane	ND	ND	ND	ND	19	ND	ND	ND	ND	ND
Acetone	ND	ND	ND	ND	28	40	18	6	6	6

Notes: Concentrations in µg/L

ND - Under quantification limit as given in Table 2-12

TABLE 2-14

PURGEABLE ORGANICS IN THE FRESH KILLS LANDFILLS LEACHATE: SECTION 6/7

Purgeable Organic Compounds	December 1989				March 1990			
	Well Number				Well Number			
	W1	W4	W6	W9	W1	W4	W6	W9
Chlorobenzene	ND	ND	6	ND	ND	ND	ND	ND
Ethylbenzene	ND	ND	ND	ND	ND	ND	11	ND
Acetone	ND	ND	ND	ND	ND	ND	20	45

Notes: Concentrations in $\mu\text{g/L}$

ND - Under quantification limit as given in Table 2-12

Table 2-13 shows that vinyl chloride and benzene were present only in one sample from monitoring well five in section 1/9. All the wells in this section showed low concentrations of toluene, ethylbenzene, and xylene, while carbon disulfide, 1,4-dichloroethene, and acetone were found in some of the wells. In all cases the total concentration of purgeable organics in any one sample was less than 0.3 mg/L.

Table 2-14 shows the data from section 6/7. Apparently the leachate from section 6/7 is relatively free of purgeable organics.

2.3.8 Semivolatile Organics

Analysis of semivolatile organics was performed by H2M Labs, Inc. using EPA Method 625. Tables 2-15 and 2-16 show the results from sections 1/9 and 6/7, respectively. No values are shown in the tables when concentrations are below detection limit. The four compounds present in the leachate in section 1/9 were 2-methylphenol, 2,4-dimethylphenol, naphthalene, and bis(2-ethylhexyl)phthalate. Only the last two compounds were identified in the leachate samples from section 6/7. Apparently the presence of semivolatiles is not a major concern in treatment and disposal of leachate.

TABLE 2-15

SEMI-VOLATILE ORGANICS IN THE FRESH KILLS LANDFILL LEACHATE: SECTION 1/9

Semi-Volatile	December 1989					March 1990				
	Well Number					Well Number				
	W3	W5	W8	W10	W10	W3	W5	W8	W10	
Organics										
2-Methylphenol	18	10								
2,4-Dimethylphenol	20	28	22	28						
Naphthalene	26	13	34	17		28	16	28		
Bis(2-Ethylhexyl) Phthalate						79 B*	140 B*	100	100	

TABLE 2-16

SEMI-VOLATILE ORGANICS IN THE FRESH KILLS LANDFILL LEACHATE: SECTION 6/7

Semi-Volatile	December 1989					March 1990				
	Well Number					Well Number				
	W1	W4	W6	W9	W9	W1	W4	W6	W9	
Organics										
Naphthalene	17			22				13		
Bis(2-Ethylhexyl) Phthalate						13 B*	25 B*	69	46	

Notes: Concentrations in µg/L

B* = Analyte present in the method blank

2.3.9 Color

Color in a water sample may be caused by constituents that are present in solution and/or suspension. When a sample is filtered to remove the suspended solids, then the color of the filtrate is caused by dissolved solids only, and is referred to as true color. When the sample is not filtered, then the color is referred to as apparent color. All leachate samples were first filtered; thus, in each case true color was measured.

Leachate from the pumping station was consistently a strong tea color, averaging 3,000 units over a one-year period, as shown in Table 2-2. After the installation of the monitoring wells, samples were collected around the periphery of both sections. The color, which was different in each sampling well, ranged from 250 to 3,000 colorimetric units in section 1/9, and 250 to 1,000 colorimetric units in section 6/7. The average color concentration in section 1/9 was 1,500 colorimetric units and in section 6/7, 400 colorimetric units. Apparently color in general is related to and probably caused by organic matter in the leachate. In section 6/7, both color and TOC are lower than in section 1/9.

2.3.10 Pesticides, PCBs and Dioxins

The leachate from the selected monitoring wells was analyzed for pesticides and PCBs at H2M Labs, Inc., using EPA method 608. Most

samples showed the concentrations to be below detection limits. Table 2-17 shows the list of compounds for which all leachate samples from the selected monitoring wells were analyzed and the analytical results from monitoring well five in section 1/9. The data from all samples indicated that pesticides were below the detection limits in all the wells. Trace PCBs were found only in some wells in section 1/9, namely arochlor 1254 at 9 ug/L in well three on December 13, 1989, arochlor 1260 at 1.5 ug/L in well three on March 27, 1990, arochlor 1260 at 1.2 ug/L and 1.1 ug/L in well eight on December 13, 1989 and March 27, 1990, respectively.

During the initial phase of the study, the New York City Department of Environmental Protection (DEP) had requested the leachate be analyzed for dioxin. A sample was taken from the pumping station in section 1/9 and analyzed for 2,3,7,8 - tetrachlorodibenzodioxin (2,3,7,8 - TCDD) according to the procedure outlined in EPA method 8280. The analysis was performed by TMS Analytical Services, Inc.; it was determined that TCDD was non-detected at an estimated limit of detection < 1.84 parts per trillion.

2.3.11 Coliform Bacteria

Coliform bacterial counts are used as an indicator of human waste contamination and, therefore, of the presence of pathogenic organisms. Coliform counts were estimated using the multiple-tube fermentation technique. Large variations were noted among the

TABLE 2-17

TYPICAL RESULTS OF PURGEABLE ORGANICS FROM WELL W5: SECTION 1/9

City College Sample Lab No.: 755661
 138th St. and Convent Avenue Date Collected: 03/27/90
 New York, NY 10031 Date Received : 03/27/90
 Type : Miscellaneous
 Attn: John Fillos, Ph.D Point : Freshkills Leachate
 Dept. of Civil Eng'ring. Sample FK1/9-W5
 Collected by : CL 99

ANALYTICAL RESULTS FOR PESTICIDES AND PCB'S

Compounds	Concentration (µg/L)
Lindane	<0.05
Heptachlor	<0.05
*Aldrin	<0.11
*Heptachlor epoxide	<0.14
Dieldrin	<0.10
Endrin	<0.10
P,P'-DDT	<0.10
Methoxychlor	<0.50
Toxaphene	<1.0
Chlordane	<0.50
Alpha-BHC	<0.05
Beta-BHC	<0.05
Delta-BHC	<0.05
P,P'-DDD	<0.10
P,P'-DDE	<0.10

Note:

* Signifies raised limit due to PCB interference
 Date extracted: 03/29/90
 Date analyzed : 04/03/90
 Date reported : 04/30/90

John J. Molloy, P.E.
 Laboratory Manager

TABLE 2-17 continued

TYPICAL RESULTS OF PURGEABLE ORGANICS FROM WELL W5 SECTION 1/9

City College	Sample Lab No.: 755661
138th St. and Convent Avenue	Date Collected: 03/27/90
New York, NY 10031	Date Received : 03/27/90
	Type : Miscellaneous
Attn: John Fillos, Ph.D	Point : Freshkills Leachate
Dept. of Civil Eng'ring.	Sample FK1/9-W5
	Collected by : CL 99

ANALYTICAL RESULTS FOR PESTICIDES AND PCB'S

Compounds	Concentration (µg/L)
Endosulfan I	<0.05
Endosulfan II	<0.05
Endosulfan sulfate	<0.10
Endrin aldehyde	<0.10
O,P-DDT	<0.10
Arochlor 1016	3.1
Arochlor 1221	<0.5
Arochlor 1232	<0.5
Arochlor 1242	<0.5
Arochlor 1248	<0.5
Arochlor 1254	<1.0
Arochlor 1260	1.2

* Signifies raised limit due to PCB interference

Date extracted: 03/29/90

Date analyzed : 04/03/90

Date reported : 04/30/90

John J. Molloy, P.E.
Laboratory Director

leachate samples. In section 1/9, most probable number (MPN) numbers ranged from less than 2 to greater than 2,400 per 100 ml. In two cases, where appropriate dilutions were used, the concentrations were 350 and 240 per 100 ml. Similar results were noted in the leachate from section 6/7 though none of the samples reported greater than 24,000 per 100 ml. These concentrations are relatively low when compared to municipal wastewater where coliform densities in excess of 1,000,000 per 100 ml have been reported. All coliform bacteria analyses were performed by H2M Labs, Inc.

2.4 LEACHATE CHARACTERISTICS IN SECTIONS 1/9, 6/7 AND AT THE VETERANS AVENUE LEACHATE COLLECTION SYSTEM

The leachate analyses that have been presented are based on samples collected from the monitoring wells in sections 1/9 and 6/7. The analyses for conventional pollutants shown in Tables 2-2 through 2-7 were performed at the City College of New York. Analyses shown in Tables 2-9 through 2-17 were performed by H2M Labs, Inc. The average concentration of each contaminant identified in the monitoring well samples should reflect its concentration in the leachate of the associated landfill section. Therefore, in the following section the accumulated data is combined to estimate the leachate characteristics in sections 1/9 and 6/7.

An immediate priority is to characterize of the leachate collected at the Veterans Avenue Leachate Collection System, which is currently recirculated back into section 1/9. Leachate

recirculation is scheduled to end by 1992 when offsite disposal will be implemented. The leachate disposal alternatives will depend, in part, on the characteristics of the leachate.

2.4.1 Characteristics of the Leachate in Sections 1/9 and 6/7

Values obtained from the samples collected from the monitoring wells in sections 1/9 and 6/7 are presented in Tables 2-3 through 2-17. The combined leachate flow has been estimated at 1.1 million gallons per day (MGD). To evaluate and develop leachate treatment methodologies disposal alternatives and the associated regulatory requirements for their implementation need to be defined.

Two alternatives were considered for leachate disposal: treatment of the leachate with direct discharge into the Fresh Kills and Arthur Kill; and discharge of the pretreated or untreated leachate into a sewage collection system with subsequent treatment at a local municipal wastewater treatment plant.

The first step in identifying such standards was to provide data to both DEC and the DEP for review. Although the amount of data available were limited and more data will be required to allow both agencies to define the actual discharge standards, DEC identified preliminary limits for discharging into Fresh Kills as shown in Table 2-18, which includes New York City Sewer Use Regulations. The leachate characteristics for both sections 1/9 and 6/7 are

TABLE 2-18

CHARACTERISTICS OF THE LEACHATE FROM THE FRESH KILLS LANDFILL

Parameter	Preliminary NYSDEC Discharge Limits	NYCDEP Sewer Use Regulation (mg/L)	Section 1/9 (mg/L)	Section 6/7 mg/L
BOD	45 mg/L or 85% Removal	300	111	73
COD	85% Removal	--	1520	683
TKN	Monitor	--	909	251
UOD	Monitor	--	--	--
TSS	45 mg/L or 85% Removal	350	--	--
Settleable Solids	0.2	--	--	--
Coliform	100/100ml	--	--	--
Oil & Grease	15	50	39	8.5
Aluminum	4	--	3.3	6.6
Antimony	0.6	--	<0.06	<0.06
Arsenic	0.1	--	0.023	0.012
Barium	4.0	--	0.99	1.1
Cadmium	--	2	0.09	0.012
Chloride	--	5000 Maximum	2000	1000
Chromium VI	0.1	5	<0.11	<0.02
Total Chromium	1	--	0.26	0.12
Cyanide	0.26	0.2	0.022	0.016
Copper	0.4	5	0.09	0.26

TABLE 2-18 continued

CHARACTERISTICS OF THE LEACHATE FROM THE FRESHKILLS LANDFILL

Parameter	Preliminary NYSDEC Discharge Limits	NYCDEP Sewer Use Regulation (mg/L)	Section 1/9 (mg/L)	Section 6/7 mg/L
Fluoride	15	10 (lbs/d)	0.41	0.34
Iron	4	--	13	34.9
Lead	0.2	2	0.135	1.45
Manganese	2	--	0.19	0.25
Mercury	--	0.05	0.0007	0.001
Nickel	0.8	3	0.13	0.07
Silver	0.1	--	0.03	0.008
Sulphide	4	11 (lbs/d)	4.3	1.8
Zinc	1	5	0.52	0.95
2,3-Dimethylphenol	0.06	--	0.025	ND
Ethylbenzene	0.08	--	0.013	0.001
Naphthalene	0.17	--	0.020	0.007
Pesticides	--	<0.0001	<0.00005	<0.00005
Phenols	--	1 (lb/d)	0.01	0.01
PCB's	--	0.0001	<0.0005	<0.0005
TCDD (Dioxin)	--	0	<1.84ppt	--
TOX	0.025	--	0.155	0.11
pH	6-9	>5	7.6	7.7

Note: New York State Department of Environmental Conservation preliminary effluent limitations identified in correspondence dated August 19, 1988.

included to facilitate comparison. For most parameters the untreated leachate complies with the discharge limits. However, treatment will be required to reduce some of the leachate values before discharge into Fresh Kills.

The overall data indicates that, for many contaminants, the leachate resembles municipal wastewater; however, the major differences are the strong color, the high COD, the high ammonia and the high iron concentration. The low BOD/COD ratio indicates that the organic matter present is nonbiodegradable and, thus, will not significantly impact the DO balance of the Fresh Kills or Arthur Kill. The color, due primarily to the presence of stable organic compounds, did not decrease when BOD was biologically removed. The high ammonia concentrations would affect the oxygen balance and the eutrophication potential of the Fresh Kills. Some priority pollutants present at low concentrations, PCBs, pesticides, and dioxins that are below detection limits, are no concern. Biological treatment processes should be considered for the Fresh Kills Landfill leachate to nitrify the ammonia, and physical-chemical treatment if significant COD reduction is required.

2.4.2 Characteristics of the Leachate from the Veterans Avenue Leachate Collection System

The Veterans Avenue Leachate Collection System collects

approximately 150,000 GPD. The leachate is currently pumped back into the landfill as part of an ongoing recirculation assessment study. The characteristics of this leachate are based on samples collected from the pump station. Leachate used in bench-scale treatability studies at City College was collected from the same pump station. Thus, the data on conventional pollutants and priority pollutants for the leachate from the Veterans Avenue Leachate Collection System cover a longer span of time than the data from the recently installed monitoring wells.

The leachate from the pump station has a characteristic strong tea color caused by soluble matter. A musty odor noticeable at the pump station, quickly dissipates. Odor was never a problem in the laboratory where the bench-scale experiments were conducted in reactors open to the atmosphere. The pH of the leachate was always alkaline, ranging from 7.5 to 8.3. The leachate was well buffered, with an alkalinity of 5,000 to 6,000 mg/L as calcium carbonate.

The organic contaminants, measured by BOD and COD, and nutrients, measured by nitrogen and phosphorus, were monitored for more than a year. To indicate any variations in BOD, COD, TKN, and ammonia concentration with time, these parameters were plotted in Figure 2-3. The plotted data shows that the concentrations were relatively constant throughout the year with no seasonal variations. Therefore, any treatment facility handling this leachate will experience a relatively constant influent.

Figure 2-3. BOD, COD, TKN and Ammonia in the
Leachate from the Veterans Avenue
Leachate Collection System.

Discharge permit requirements will dictate treatment procedures and operation requirements.

During this time, the leachate was also sampled intermittently and analyzed at the H2M Labs, Inc. The data, grouped and presented as Tables 2-19 to 2-21, show that the conventional pollutants of primary concern are ammonia nitrogen and COD, with heavy metal concentrations being low. Iron may be the only metal whose concentration would exceed the preliminary limits set by DEC. The other contaminants should be sufficiently treated in the selected process train, whether biological or chemical. Table 2-21 shows that the purgeable and semivolatile priority pollutants in the leachate are few and at low concentrations, so there is no apparent need for specific treatment processes to reduce their levels.

The characteristics of the leachate from the pump station are similar to those of leachate from section 1/9, but higher than those of leachate from section 6/7. Ammonia nitrogen remains the contaminant of concern since it has the potential to affect the DO balance in the receiving waters. The high COD, compared to the low BOD values, appears to be caused primarily by refractory organic matter. Heavy metal and priority pollutants, which are few and at low concentrations, do not warrant special treatment. The leachate from the Veterans Avenue Leachate Collection System pump station was therefore used in the bench-scale evaluation of potential treatment technologies.

TABLE 2-19

CONVENTIONAL CONTAMINANTS IN THE LEACHATE FROM THE PUMP STATION
OF THE VETERANS AVENUE COLLECTION SYSTEM

Parameter	Dec. 19, 1988	April 5, 1989	Jan. 11, 1990	March 29, 1990
BOD ₅	98	112	94	100
COD	1870	1840	740	400
TKN	729	726	774	873
SS	30	6318	12	10
TDS	7400	7613	7550	8380
Ammonia	657	638	703	748
Nitrate	-	-	<0.10	<0.10
Total Phos-P	5.10	5.70	5.00	7.3
Detergent (MBAS)	1.04	0.31	0.62	1.10
Oil and Grease	5.00	53.0	10.1	<5.00
Petroleum Hydrocarbon	-	-	7.60	<5.00
TOX	1.550	0.45	0.158	0.100
Chloride	1860	2080	1240	2240
Cyanide	<0.01	0.010	0.013	0.012
Fluorides	0.40	0.40	0.50	0.38
Sulfides	<0.50	<0.50	1.88	3.08
T. Coli Bacteria	12	>2400	1600	1400
Phenols	0.053	0.026	ND	ND
Vanadium	0.19	<0.05	0.12	0.14
Zinc	0.10	0.77	0.09	0.09
Cr-Vi	<0.20	<0.20	<0.02	<0.02
pH	7.70	7.20	7.50	7.70

Notes: Concentrations in mg/L
ND - Under Quantification Limit

TABLE 2-20

HEAVY METALS IN THE LEACHATE FROM THE PUMP STATION
OF THE VETERANS AVENUE COLLECTION SYSTEM

Parameter	Dec. 19, 1988	April 5, 1989	Jan. 11, 1990	March 29, 1990
Aluminum	<0.20	1.2	7.1	0.20
Antimony	<0.060	<0.060	<0.060	<0.060
Arsenic	<0.010	0.011	0.0109	0.0135
Barium	1.3	0.94	0.87	1.04
Beryllium	<0.005	<0.005	<0.005	<0.005
Cadmium	<0.005	<0.005	<0.005	<0.005
Calcium	34.0	30.6	27.6	26.0
Chromium	0.28	0.16	0.19	0.18
Cobalt	0.08	<0.05	<0.05	<0.05
Copper	<0.02	0.56	0.03	<0.02
Iron	9.60	8.00	7.70	6.81
Lead	0.027	0.005	0.034	0.017
Magnesium	48.0	37.6	39.1	41.5
Manganese	0.08	0.15	0.10	0.06
Mercury	<0.020	<0.020	<0.020	<0.020
Nickel	0.021	0.07	0.12	0.11
Potassium	420	302	317	333
Selenium	<0.005	<0.005	<0.005	<0.005
Silver	0.06	<0.01	<0.01	0.02
Sodium	2370	1840	2320	1890
Thallium	<0.010	<0.010	<0.010	<0.010
Vanadium	0.19	<0.05	0.12	0.14
Zinc	0.10	0.77	0.09	0.09
Cr-Vi	<0.20	<0.20	<0.02	<0.02
pH	7.70	7.20	7.50	7.70

Note: Concentrations in mg/L

TABLE 2-21

PURGEABLE AND SEMI-VOLATILE PRIORITY POLLUTANTS IN THE LEACHATE
FROM THE PUMP STATION OF THE VETERANS AVENUE LEACHATE COLLECTION SYSTEM

Parameter	Dec. 5, 1988	April 5, 1989	Jan. 11, 1990	March 29, 1990
Ethylbenzene	-	-	-	11
Acetone	-	-	-	54
Xylenes (Total)	8	23	19	84
Methylene Chloride	7	-	-	-
1,4-Dichlorobenzene	-	7	6	-
2-Hexnone	-	16	-	-
Bis (2-Ethylhexyl) phthalate	87	-	440 (a)	42 (b)
2,4-Dimethylphenol	22	-	-	-
Naphthalene	25	-	-	-

Note: All concentrations in mg/L

(a) - Analyte present in method blank: 72 µg/L

(b) - Analyte present in method blank: 14 µg/L

3.0 LEACHATE TREATMENT AND DISPOSAL ALTERNATIVES

The volume of leachate generated in sections 1/9 and 6/7 has been estimated at approximately 1.1 MGD as described in Volume II (5). The contaminants are primarily conventional pollutants such as BOD, COD, TKN, ammonia, and color. Priority pollutants are few and at extremely low concentrations. The level of treatment that should be applied to the Fresh Kills Landfill leachate will ultimately depend on the disposal alternative selected.

A leachate collection system will be implemented in each of the two sections. The four leachate disposal alternatives considered for the Fresh Kills Landfill site are:

- Alternative 1 - Offsite treatment at a local New York City water pollution control plant (WPCP).
- Alternative 2 - Onsite pretreatment with final treatment in a WPCP.
- Alternative 3 - Onsite treatment prior to discharge into Fresh Kills or Arthur Kill.
- Alternative 4 - Onsite treatment with onsite use of part of the effluent. The remaining flow to be discharged into Fresh Kills or Arthur Kill.

Alternatives one and two were considered first because they require minimum capital investment. The technical questions that had to be addressed included: (1) capacity of the WPCP to accept the additional flow of 1.1 MGD; (2) ability of the WPCP to treat the leachate; (3) compatibility of the leachate and the treatment

processes available at the WPCP; (4) presence of contaminants in the leachate that can accumulate in the sludge and disrupt current or proposed land-based sludge disposal alternatives; and (5) presence of contaminants that will not be removed, causing the plant effluent to violate the plant's discharge permit. In the case of the Fresh Kills Landfill leachate, the closest off-site treatment plant is the Oakwood Beach WPCP.

The Oakwood Beach WPCP serves the southeastern section of Staten Island. The plant is a secondary treatment facility operating in compliance with its present discharge permit. The treatment processes used include primary treatment followed by activated sludge operated in the step-aeration mode. The plant is designed to treat a wastewater flow of 39.9 MGD.

To assess whether leachate can be diverted to the Oakwood Beach WPCP, both available treatment capacity and compatibility with the treatment processes had to be considered. The relatively rapid growth of population within the plant's drainage area and major sewer connections from developments, which in the past were served by small package treatment plants, have increased the plant's hydraulic load and it is currently operating at more than 90 percent of its design capacity.

The compatibility of the leachate and the activated sludge process was demonstrated using a large-volume respirometer following the

Baltimore Inhibition Test procedures (6). The results indicated that the leachate is compatible with activated-sludge treatment at the Oakwood Beach WPCP. The level of nitrification will depend on the plant's operating conditions. Table 2-18 indicates that the leachate is in compliance with all the requirements of the New York City Sewer Use Regulations, except for sulfides. Nevertheless, DEP notified DOS that it would prefer not to accept the leachate for treatment of the Oakwood Beach WPCP. Therefore, both alternatives one and two, were eliminated from further consideration.

Onsite treatment and direct discharge into Fresh Kills or Arthur Kill represents the most viable alternatives remaining. In developing these alternatives, the available data was first presented to DEC. After evaluation, DEC determined a number of preliminary limits, which are included in Table 2-18. These limits show removal of both BOD and COD. Nitrogen as TKN would require monitoring but not removal. In addition, some of the metals, particularly iron, will require removal. As a result of communications with DOS, DEC also requested collection of additional data on leachate characteristics prior to their formulating final discharge limits. In part, the purpose of installing monitoring wells was to collect additional data to characterize the leachate and facilitate the process of developing final discharge limits by DEC.

Alternative four includes as an objective the use of the treated

leachate to satisfy nonpotable water demands at the landfill. Most criteria for water reuse, which have been developed in terms of treated domestic wastewaters, call for coliform, turbidity, BOD, and suspended solids limits. Since a potential use of the treated leachate is irrigation of the landfill cover, Table 3-1 was prepared to compare recommended limits for irrigation to the concentration of contaminants in the untreated leachate (7).

Both alternatives three and four require an onsite treatment facility. In alternative three, all of the treated leachate will be discharged into Fresh Kills. In alternative four, only that portion of the treated leachate not used at the landfill site will be discharged. Therefore, the treatment technologies selected will depend on the final discharge limits that will be imposed by DEC. At this time, reduction of BOD and COD were identified as the primary concerns. However, as additional data becomes available, ammonia may be included, with the exclusion of COD. Ammonia can place a high oxygen demand in the Fresh Kills in contrast to COD which is probably due to stable organic matter. Lacking final discharge limits, treatment trains were developed capable of removing BOD, COD, and ammonia. Further, process requirements for denitrification to remove nitrogen were explored and are reported in Volume III (8).

TABLE 3-1

RECOMMENDED LIMITS FOR POLLUTANTS IN RECLAIMED WATER USED FOR IRRIGATION*

TRACE HEAVY METALS				Fresh Kills Landfill	
Constituent	Long Term Use mg/L	Short Term Use mg/L	Remarks	Section 1/9	Section 6/7
Aluminum	5.0	20.0	Can cause non-productivity in acid soils, but soils at pH 5.5 to 8 will precipitate the ion and eliminate toxicity.	3.3	6.6
Arsenic	0.10	2.0	Toxicity to plants vary widely, ranging from 12 mg/L for Sudan Grass to less than 0.05 mg/l for rice.	0.023	0.012
Beryllium	0.10	0.5	Toxicity for plants vary widely, ranging from 5 mg/L for kale to 0.5 mg/L for bush beans		
Boron	0.75	2.0	Essential for plant growth, with optimum yields obtained at a few-tenths mg/L in nutrient solutions. Toxic to many sensitive plants (e.g., citrus plants) at 1 mg/L.		
Cadmium	0.01	0.05	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/L in nutrient solution. Conservative limits recommended.	0.09	0.012
Chromium	0.1	1.0	Not generally recognized as essential growth element. Conservative limits recommended due to lack of knowledge on toxicity on plants.	0.26	0.12
Cobalt	0.05	5.0	Toxic to tomato plants at 0.1 mg/L in nutrient solution. Tends to be inactivated neutral and alkaline soils.		
Copper	0.2	5.0	Toxic to a number of plants at 0.1 to 1.0 mg/L in nutrient solution.	0.09	0.26
Fluoride	1.0	15.0	Inactivated by neutral and alkaline soils.	0.13	0.07
Iron	5.0	20.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of essential phosphorus and molybdenum.	13	34.9
Lead	5.0	10.0	Can inhibit plant cell growth at very high concentrations	0.135	1.45
Lithium	2.5	2.5	Tolerated by most crops at up to 5 mg/L; mobile in soil. Toxic at low doses - recommended limit is 0.075 mg/L		
Manganese	0.2	2.0	Toxic to a number of crops at a few-tenths to a few mg/L in acid soils.	0.19	0.25

TABLE 3-1 continued
RECOMMENDED LIMITS FOR POLLUTANTS IN RECLAIMED WATER USED FOR IRRIGATION*

TRACE HEAVY METALS				Fresh Kills Landfill	
Constituent	Long Term Use mg/L	Short Term Use mg/L	Remarks	Section 1/9	Section 6/7
Molybdenum	0.01	0.05	Not toxic to plants at normal concentrations in soil and in water. Can be toxic to livestock if forage is grown in soils with high level of available molybdenum.		
Nickel	0.2	2.0	Toxic to a number of plants at 0.5 to 1 mg/L; reduced toxicity at neutral or alkaline pH.	0.13	0.07
Selenium	0.02	0.02	Toxic to plants at low concentrations and to livestock if forage is grown in soils with low levels of added selenium.		
Tin, Tungsten & Titanium	-	-	Effectively excluded by plants: specific tolerance levels unknown.		
Zinc	2.0	10.0	Toxic to many plants at widely varying concentrations; reduced toxicity at increased pH (6 or above) and in fine-textured organic soils.	0.52	0.95
pH	4.5 - 9		Most effects of pH on plant growth are indirect (e.g. pH effects on heavy metals toxicity described above).	7.6	7.7
Fecal Coliform Density	1,000/100 ml		Irrigation waters at or below this limit should pose no hazard to animals or man from their use or from the consumption of raw crops irrigated with the waters.		
TDS	500-5,000 mg/L		Below 500 mg/L no detrimental effects are usually noticed. Between 500 and 1,000 mg/L, TDS levels can affect sensitive plants. At 1,000 to 2,000 mg/L, TDS levels can affect many crops and careful management practices should be followed. Above 2,000 mg/L, water can be used regularly for tolerant plants on permeable soils.	5500	3700

Notes:
*For water used continuously on all soils
*For water used for a period of up to 20 years on fine textured neutral or alkaline soils.
From

4.0 TREATMENT TECHNOLOGIES

The treatment technologies evaluated for this project were capable of removing organic contaminants as well as ammonia through physical and biological means. Each treatment technology is conceptually described and its leachate treatment limits are noted. The selected technologies were tested independently in the City College laboratory facilities. The technologies are grouped into two categories in this report: biological treatment and physical-chemical treatment.

4.1 BIOLOGICAL TREATMENT

Biological treatment processes are used to treat municipal as well as industrial wastewaters. In these processes, microorganisms decompose organic matter to obtain energy and the molecular components required for growth. The microorganisms can grow as suspended solids in a reactor or as a fixed film on the surface of different types of media. In both cases the biological treatment process is followed by a settling stage (clarification) to separate the biomass from the water. The biomass that settles and thickens in the clarifier is called sludge. The sludge can be diverted to sludge-handling facilities or returned to the biological reactor to maintain a predetermined concentration of microorganisms.

The growth of microorganisms in a reactor can take place in the

presence of oxygen, an aerobic process, or in the absence of oxygen, an anaerobic process. Therefore, the biological processes are grouped into two sub-categories: aerobic and anaerobic.

4.1.1 Aerobic Processes

Aerobic biological processes can be used to effectively remove BOD and to oxidize ammonia into nitrates. In the case of leachate from the Fresh Kills Landfill the ratio of BOD/TKN varies from 0.12 to 0.34. This small ratio suggests that BOD and ammonia oxidation should occur in the same reactor concurrently with the size of the reactor dictated by the requirements for nitrification of ammonia. Therefore, the following briefly describes biological ammonia oxidation.

Ammonia oxidation is usually represented as a two-step reaction. First the ammonia is oxidized to nitrite by nitrosomona bacteria and then the intermediate product, nitrite, is converted to nitrate by nitrobacter bacteria. The stoichiometric reactions are shown in following equations:

2 of 3

The equations indicate the following important characteristics of biological oxidation of ammonia:

- Nitrosomona bacteria obtain more energy per mole of nitrogen oxidized than nitrobacter. Therefore, for equal growth rates, much more nitrite is oxidized. This is the reason why in natural waters nitrite concentrations are usually much lower than nitrate;
- Ammonia oxidation produces hydrogen ions, which can lower the pH. When net synthesis of biomass is neglected, the hydrogen ions produced can destroy 7.14 mg/L of alkalinity as calcium carbonate per mg/L of ammonia-nitrogen oxidized; and
- The stoichiometric requirement for oxygen is 4.57 mg per mg of ammonia-nitrogen oxidized.

The implications of the nitrification of leachate on treatment train design are significant. For example, if ammonia at a concentration of 700 mg/L is nitrified, approximately 5,000 mg/L of alkalinity will be destroyed and 3,200 mg/L of oxygen will be required. The alkalinity may be available in the leachate but the oxygen must be supplied through aeration, usually at a high energy demand.

4.1.1.1 Process Kinetics for Nitrification

Reaction kinetic studies have resulted in two typical rate equations that can be used in sizing biological reactors. The first equation is similar to the Michaelis-Menten relationship for enzyme reactions and is known as the Monod equation,

$$V = - \frac{dS}{dt} = \frac{US}{K_s + S}$$

where,

V = rate of substrate utilization
U = maximum rate of reaction
S = concentration of the substrate
 K_s = concentration of substrate at
which level $V = (1/2)U$

Table 4-1 shows typical values of U and K_s for each step and for the overall nitrification reaction. The relatively small values of K_s reduce the rate equation to a zero-order reaction at high ammonia concentrations, which means that the substrate utilization rate is independent of its concentration. Mathematically, this can be expressed as

$$V = k$$

where,

k = a constant, whose magnitude is a function of the reaction conditions, i.e. temperature, pH, etc.

Numerous investigators working with suspended growth and fixed-film reactors have shown that nitrification can be modeled as zero-order reactions (9,10,11). However, in the design of biological nitrification systems, where ammonia is reduced to low values compared to the value of K_s , the use of the Monod equation is suggested. This is appropriate since, at low ammonia concentrations, the nitrification rate is a function of the ammonia in the wastewater. For these conditions, the value of K_s becomes significant with respect to the concentration, S, in the above equation, and the reaction becomes first-order.

TABLE 4-1

TYPICAL KINETIC COEFFICIENTS FOR SUSPENDED GROWTH NITRIFICATION

Coefficient	Value	
	Range	Typical
Nitrosomonas: (Ammonia (NH_3) to Nitrite (NO_2^-))		
U (day^{-1})	0.3 - 2	0.7
K_s (mg/L)	0.2 - 2	0.6
Nitrobacter: (Nitrite (NO_2^-) to Nitrate (NO_3^-))		
U (day^{-1})	0.4 - 3	1.0
K_s (mg/L)	0.2 - 5	1.4
Overall Nitrification: (Ammonia (NH_3) to Nitrate (NO_3^-))		
U (day^{-1})	0.3 - 3	1.0
K_s (mg/L)	0.2 - 5	1.4

TABLE 4-2

COMPOUNDS TOXIC TO UNACCLIMATED NITRIFYING ORGANISMS

Organics	Inorganics
Thiourea	Zinc
Allyl-Thiourea	Thiocyanide (OCN^-)
8-Hydroxyquinoline	Chlorate VII (ClO_4^-)
Salicyladoxine	Copper
Histidine	Mercury
Amino Acids	Chromium
Mercaptobenzthiazole	Nickel
Perchloroethylene	Silver
Trichloroethylene	
Abietic Acid	

4.1.1.2 Process Variables

In designing and operating a nitrification process, the following process variables must be considered:

- Dissolved oxygen. The K_{O_2} tends to be about 2 mg/L. When operating a nitrification facility at a DO of 2 mg/L, the growth rate of the nitrifying microorganisms is one-half the maximum rate. Most facilities are operated at high DO concentrations, or approximately 4 mg/L;
- Alkalinity. Sufficient alkalinity must be present to buffer the reaction. Alkalinity available should exceed the ammonia to be nitrified by a factor of 7.13. If not, alkalinity should be added in the form of lime or soda ash;
- pH. The optimum pH for nitrification is in the alkaline range. The observed range is 7 to 9, with maximum activity at a pH about 8. When the pH falls below 5.5 to 5, nitrification essentially stops;
- Temperature. The optimum temperature for nitrification is about 30°C. Below 15°C the rate of nitrification drops sharply. Some researchers believe that the inhibitory effect of temperature decrease is greater for nitrobacter than for nitrosomonas;
- Inhibitors. The nitrifying organisms are sensitive to the presence of small concentrations of a number of compounds shown in Table 4-2. However a review of the literature suggests that 10 to 20 mg/L of heavy metals can be tolerated at high pH values of 7.5 to 8.0 (12); and
- Sludge Retention Time (SRT). To grow sufficient nitrifying microorganisms in a treatment process, the suggested SRT should be at least 5 to 6 days in the summer and 12 or more days in the winter. By controlling the SRT of a biological process, an operator can select the type of microbial population in the reactor and thus effect BOD removal or BOD removal and nitrification.

In any one application of nitrification, it is not possible to have all the process variables at optimum conditions. For example, if temperature is not controlled and varies with the weather, the design engineer must consider such variations so the facility will perform under the most common adverse circumstances.

4.1.1.3 Treatment Process Alternatives

Although biological nitrification can be incorporated into a treatment train in a number of ways, in all cases the operational principles remain the same. If a sufficient population of nitrifying microorganisms is presented and the process variables are maintained close to optimum conditions, nitrification will take place satisfactorily. The types of processes commonly used in the treatment of municipal and industrial wastewaters include:

- A. Activated Sludge. The process was developed in Manchester England in early 1900 and has been used for many years to stabilize wastewaters. In the activated sludge process microorganisms are brought into contact with the wastewater in an aeration tank. After a predetermined reaction time, the contents flows into a clarifier for gravity settling. A portion of the settled solids is returned to the aeration tank to maintain the required population concentration while excess amounts of sludge are removed from the process. With relatively minor modifications in the process, activated sludge will support nitrification. In general, the favored system for nitrification is plug flow with high SRT values. Since nitrosomonas is generally rate limiting, its growth rate determines the operation of activated sludge to effect nitrification.
- B. Sequencing Batch Reactors (SBRs). An SBR system uses a biological suspended growth process designed to operate in one or more tanks. Each tank containing biomass is

filled with wastewater for a preset interval of time and then operated aerobically as a batch reactor until the desired level of treatment is achieved. The air is then shut-off and the mixed liquor solids are allowed to settle in the same tank. Settling time is typically one hour. The supernatant is then withdrawn and the system is ready to receive additional wastewater. The tank is then refilled, aeration is initiated and the cycle is repeated. Excess sludge solids can be wasted from the SBR either during the aeration period or immediately after the supernatant is decanted from the reactor. Figure 4-1 shows the operating sequence of an SBR system. Nitrification rate studies in SBR systems have indicated a rate constant of 0.19 to 0.20 mg NH_3 /mg MLSS/day (13).

- C. Rotating Biological Reactors (RBCs). The RBC process is an aerobic, continuous flow system designed for municipal and industrial wastewater treatment. In its most elementary form, the RBC system consists of a series of closely spaced discs mounted on a horizontal shaft. The discs rotate at approximately 1.5 to 1.7 revolutions per minute (rpm) while one-half of their surface is immersed in wastewater. Slowly a biological film establishes itself on the disc surface. This film is responsible for the biochemical degradation of pollutants in the wastewater.

Nitrification kinetics in RBC systems have been based on media surface area and not on bacterial mass. O'Shaughnessy et al. (14) reported that nitrification by RBCs was best described by first-order kinetics for ammonia concentrations less than 4 mg/L, and zero-order for higher concentrations. The maximum ammonia utilization rate O'Shaughnessy et al. observed, was 0.2 lb/day per 1,000 sq ft.

- D. Powdered Carbon Added to Activated Sludge. A variation of the activated-sludge process that has been used in full-scale operations is the addition of powdered activated carbon (PAC) to the aeration basins. The PAC and biomass combine to form a dark sludge with good settling characteristics. Depending on the waste characteristics, mixed liquor carbon levels in the aeration basins can range from 100 mg/L to as high as 50,000 mg/L. To ensure maximum carbon capture in the secondary clarifier, a dose of liquid cationic polyelectrolyte is generally applied to the mixed liquors leaving the aeration basin. The underflow sludge from the clarifier should be 3 to 5 percent solids.

Figure 4-1. Operation of a Sequencing Batch-Reactor System.

The addition of PAC to nitrifying activated-sludge plants can improve nitrification rates. The mechanisms that have been proposed to explain PAC-enhanced nitrification include adsorption of compounds toxic to nitrifying microorganisms, enhanced nitrifier growth on the carbon's surface, and bioregeneration. The latter term refers to the apparent synergism between the adsorption and biodegradation that is often observed in systems where PAC is added.

Though there are other aerobic processes, the preceding have been studied in connection with many different types of wastewaters. Full-scale facilities have demonstrated their effectiveness with municipal and industrial wastewaters. Thus, they are being considered as alternatives for the treatment of leachate.

4.1.2 Anaerobic Processes

Historically, anaerobic processes have been used primarily in the treatment of high-strength wastewaters and sludges from municipal wastewater treatment plants. Conventional anaerobic processes require long detention times for waste stabilization. Recent modifications of anaerobic treatment processes allowing long SRTs have supported suitable kinetic rates to biodegrade organic matter in reactors of reasonable size. The new types of fermenters appear to increase resistance to the adverse effects of toxic compounds and to hydraulic and organic shockloads, and to facilitate the start-up of reactors. As a result, anaerobic treatment systems are finding broader application for many types of wastewaters.

Anaerobic reactor designs range from partially or fully mixed tank

reactors to stationary fixed-film reactors. The biochemical reactions involved in all processes are the same. Carbonaceous organic matter in wastewaters is hydrolyzed and absorbed by bacteria, which stabilize it through several steps to carbon dioxide, methane gas and a small amount of biomass production. Review of process data has resulted in the following generalizations:

- Strength and Composition of the Wastes. A wide variety of wastes have been treated anaerobically. These wastes range from dilute (400 mg/L COD) to concentrated semisolid manures. Anaerobic processes can be designed to treat soluble wastes or wastes with significant concentrations of suspended solids;
- Level of Treatment. COD removals are generally lower for anaerobic treatment than for aerobic systems. In most cases, anaerobic treatment is used to reduce the major portion of the organic load. It is then followed by aerobic treatment to bring the treated effluent into compliance with permit requirements. COD and total volatile solids removals generally range from 75 to 95 percent;
- Reactor Design Criteria. The size of the reactor is usually determined by the SRT, which is a function of the growth rate and the efficiency of the reactor in retaining the biomass. SRTs in excess of 30 to 40 days can be achieved using attached growth reactors. Organic loading rates are generally much higher than those obtained in aerobic systems. For example, the loading rate for the activated-sludge process is 50 to 150 lb COD per 1,000 cu ft per day, while in an anaerobic filter it can approach 600 to 1,000 lb COD per 1,000 cu ft per day;
- Type of Reactor. Anaerobic filters and sludge bed reactors are suitable for wastes with mostly soluble organics containing less than 50,000 mg/L COD. Fluidized or expanded bed reactors also operate best with soluble wastes. In the latter case, single high concentrations can be handled because of the inherent high recirculation rates. With intermediate waste strength and the presence

of suspended solids, the anaerobic contact process may be more effective than anaerobic filters; and

- Nutrient Requirements. The low nutrient requirement needed to support anaerobic treatment is reflected in the low sludge production, 0.02 to 0.1 gm of VSS produced per gm of COD removed. The nitrogen and phosphorus nutrient ratio to COD required for treatment is 1:30 and 1:300, respectively. The process can be stimulated by the presence of iron, nickel, cobalt and molybdenum.

A major benefit of the anaerobic process is the potential energy savings. Anaerobic filter reactors have operated at low temperatures, some below 20°C. At these low temperatures minimal methane gas is used to sustain the process. Therefore, with strong waste streams, anaerobic treatment should be a net energy producer. In addition, anaerobic filters inherently operate at high SRTs, permitting treatment of low strength wastewaters. With fixed-film reactors, which can achieve SRTs above 100, waste streams with COD concentrations as low as 400 mg/L can be handled.

Anaerobic treatment processes, therefore, were considered viable technologies to reduce the COD and TOC. The process will be coupled to an aerobic treatment process to effect additional removal that may be required by discharge limits.

4.2 PHYSICAL-CHEMICAL TREATMENT

Many types of wastewaters contain pollutants that are not amenable to biological treatment. These pollutants may be removed by chemical precipitation, by chemical oxidation or by using a mass

transfer process in which the pollutant is removed from the water phase onto a selected phase such as activated carbon. All of these nonbiological processes are included in the category of physical-chemical processes. In municipal wastewater treatment, physical-chemical processes have traditionally been used to provide tertiary treatment involving solids, nutrient and additional BOD removal. In some wastewater treatment plants, they have been used as a pretreatment process to remove contaminants that could overload existing facilities or inhibit biological growth. In industrial wastewaters or in treating contaminated groundwater from hazardous waste sites, physical-chemical process have been used to provide total treatment. Thus, different physical-chemical processes may be selected and combined to achieve a variety of treatment objectives. The following is a brief description of the physical-chemical processes considered for treating leachate.

4.2.1 Chemical Coagulation

Chemical coagulation is used for removal of nonsettleable suspended solids by gravity settling. Nonsettleable suspended solids include colloidal matter with a particle size ranging from one millimicron to one micron. The stability of colloidal suspensions depends on the relative magnitude of the forces of attraction, the Van der Waals' forces, and the forces of repulsion caused by the negative surface charges common to natural colloids. The magnitude of the repulsive forces is usually expressed as the Zeta potential. The

Zeta potential is a function of the charge of the colloidal particle and the distance through which the charge is effective. The greater the Zeta potential, the greater the repulsion forces between the colloids. Therefore, the Zeta potential is usually taken as a measure of the stability of a colloidal suspension.

Coagulation is the addition and rapid mixing of a chemical that causes destabilization of the colloidal solids and the initial aggregation of the destabilized solids. The chemistry involved in chemical coagulation is complex. Conceptually, the reaction involves:

- Reduction of the zeta potential to a level at which the attractive van der Waals' forces, in conjunction with turbulence provided, cause the particles to coalesce;
- Aggregation of particles by interparticulate bridging between reactive groups on the colloids; and
- Enmeshment of particles in the precipitate floc formed by the added coagulant.

The destabilized particles can be agitated slowly to form larger, rapidly settling floc. This latter process is called flocculation. Therefore, the two processes, chemical coagulation and flocculation, are designed to operate in series to convert nonsettleable colloidal and fine solids into settleable solids that are then removed in a sedimentation tank.

The most widely used coagulants in water and wastewater treatment

are aluminum sulfate, iron salts, and lime. Sometimes the process is enhanced by adding coagulation aids or polyelectrolytes. Table 4-3 shows chemical coagulants and their respective dosages used to treat leachate in bench-scale experiments. When raw leachate was treated, COD removal was relatively low, reaching a maximum removal of 26 percent when lime was applied to a biological process effluent. In each case sludge production was significant due to the high dosages of coagulants required.

Inorganic salts and polymers have also been used to remove humic substances from water. Humic substances have been quantified in terms of TOC and color in many water treatment processes. Limited definitive information is available concerning the details of their chemical structure. However, based on their solubility, aquatic humates are divided into two principal components: humic acid and fulvic acid. Humic acid is soluble in dilute alkaline media but is precipitated on acidification. Fulvic acid remains in solution at low pH values.

Destabilization of humic matter would be accomplished over a narrow pH range of 4 to 6. Alum and polymer used within this pH range can effectively remove humic substances. Both can cause formation of water-insoluble complexes or co-precipitation as aluminum humate. Aggregation can also occur due to specific chemical interaction between the humic macromolecules and the cationic polymer used.

TABLE 4-3

BENCH-SCALE EXPERIMENTAL DATA OF CHEMICAL COAGULANTS FOR LEACHATE TREATMENT

Coagulant	Dosage (mg/L)	pH	Initial COD (mg/L)	COD Removed (%)	Sludge (ml/L)	Leachate Type	Ref.
Alum	10 - 100	7.0	9100	0 - 11	3 - 130	R*	15
Alum	90 - 100	6.6	1240	0 - 13	/	R	16
Alum	75 - 200	6.7	530	8 - 13	/	R	17
Alum	75 - 200	6.0	170 - 300	5.3 - 26	/	R	17
Alum	30 - 90	5.5	33000	4 - 20	/	R	
FeCl ₃	100 - 1000	5.9	9100	4.4 - 14	10 - 67	R	15
FeCl ₃	1000 - 2500	7.2	1240	18 - 20	190 - 275	R	16
FeCl ₃	75 - 150	/	400	11 - 12	/	B**	17
Lime	1000	/	3400	0	/	R	18
Lime	1840	/	10800	3.5	/	R	15
Lime	450	/	2820	26	/	B	19

*R: Raw Leachate

**B: Effluent from biological process

Chemical coagulation is, therefore, a treatment process that should be effective in reducing colloidal and fine suspended solids in the Fresh Kills Landfill leachate. Removal of these solids will affect reduction in COD and TOC since the solids removed are primarily organic matter.

4.2.2 Air Stripping

Air stripping is a mass-transfer process in which volatile contaminants in water are transferred to gas. Generally compounds with Henry's Law constant of greater than 0.003 can be effectively removed. Typical components removed by air stripping include 1,1,1-trichloroethane, trichloroethylene, chlorobenzene, vinyl chloride, and dichloroethylene. In some cases, the stream to be treated may require pH adjustment to reduce solubility and to improve transfer to the gas phase. For example, to remove ammonia, the pH of the waste stream must be raised to 11.5 to convert ammonia from the ammonium ion (NH_4^+) to ammonia gas (NH_3) prior to air stripping.

Air stripping is usually combined with other processes to effect compliance with discharge limits. Stripping is frequently accomplished in a packed tower equipped with an air blower. The water stream flows down through the packing while the air flows upward, and is exhausted through the top. The operation of the packed tower should also be designed to comply with applicable air

emission limits. The countercurrent packed tower described is the most widely used air stripping system for the following reasons:

- Provides maximum liquid-air interfacial area;
- High air-to-water volume ratios can be achieved due to low air pressure drop through the tower; and
- Emission control systems can easily be adapted to countercurrent towers to recover stripped contaminants from the air discharge.

The major disadvantage of the packed tower may be the emission control systems. The systems that will be required for ammonia stripping may be more costly and difficult to operate than the packed tower itself.

In its potential application to leachate, air stripping may be used to remove ammonia. Volatile organics are few and in low concentrations and do not warrant separate treatment. However, ammonia removal may be feasible if ammonia can be recovered and marketed locally. Major disadvantages will be the large amount of alkali required to raise the pH to above 11.5 and disposal of the sludge that will be produced during the pH adjustment step.

4.2.3 Activated Carbon Adsorption

Activated carbon is widely used in the treatment of water and wastewater. The process of adsorption involves contacting a waste stream with the carbon, which selectively adsorbs organic

contaminants by a surface attraction phenomenon. In general, highly polar molecules cannot be effectively removed by carbon adsorption. In addition, the more hydrophobic (insoluble) a molecule is, the more readily the compound is adsorbed. Low solubility humic and fulvic acids can adsorb to the activated carbon more readily than most waste contaminants, resulting in rapid carbon exhaustion.

Activated carbon is a porous substance whose surface area is in the range of 1,000 sq meters per gram. Pore sizes within the carbon vary from macropores (an effective radius of 5,000 to 20,000 °A), to transitional pores (an effective radius of 40 to 200 °A), and finally to micropores (an effective radius of 18 to 20 °A or less). Adsorption can, therefore, take place on the external surface or the internal surface of the pores. The mechanisms of adsorption involve three distinct steps:

- The contaminant must be transferred from the bulk solution to the surface of the carbon. In so doing, it must pass through a film of water that surrounds the carbon particle. This first step is referred to as film diffusion;
- The contaminant must then travel to an adsorption site located inside the pores. This process is referred to as pore diffusion; and
- The contaminant then becomes attached to the surface of the carbon; i.e., is adsorbed.

The attachment to the carbon may be due to physical or chemical forces. Most phenomena in wastewater treatment are a combination of the two types of adsorption. Actual adsorption will depend on the strength of molecular attraction between the carbon and the contaminant, the molecular weight, the type and characteristics of the carbon, electrokinetic charge, pH, and surface area.

In designing a carbon adsorption system it is necessary to perform bench-scale or pilot tests to determine design criteria and a carbon usage rate. Bench-scale tests usually involve development of adsorption isotherms. The isotherms can be used to estimate the carbon usage rate. Three mathematical models have been used to describe the isotherms; namely, the Langmuir isotherm, the Freundlich isotherm and the Brunaur-Emmett-Teller (BET) isotherm. Of these, the Freundlich isotherm is widely used in environmental engineering since it applies well to mixed solutes. The equation used to describe the adsorption process is:

$$\frac{X}{M} = (K) C^{1/n}$$

where:

X	= amount of contaminant adsorbed
M	= weight of activated carbon used
C	= equilibrium concentration of contaminants in contact with the carbon
K,n	= constants to be evaluated for each waste stream at constant temperature

The ultimate adsorption capacity of the carbon is achieved when the

concentration, C , reaches the initial concentration, C_0 . This value is determined graphically by extrapolating a best fit line of the data or by substituting the value of C_0 for C in the above Freundlich isotherm equation.

In addition to the isotherms, a dynamic adsorption column test should be performed. The column test mimics the full-scale adsorption system that consists of wastewater flowing through a column of granular activated carbon. Granular activated carbon (GAC) is the most widely used adsorbent in packed beds for removal of organic contaminants. The test is used to determine the mass transfer zone for adsorption and gives a better estimate of carbon usage rate. Both are required to properly design an activated-carbon adsorption system.

The activated-carbon process has high operating costs. Although the process has frequently been used following biological treatment to remove the residual BOD and refractory organics that cannot be biodegraded, in its application to Fresh Kills leachate, the carbon will be exposed to high concentrations of organic contaminants not usually seen in wastewater treatment. Though the process can treat waters with TOC up to 10,000 mg/L, the leachate is expected to require a high carbon usage rate with an associated high operating cost.

4.2.4 Chemical Oxidation

In chemical oxidation, a strong oxidizing agent that is capable of reacting with one or a category of contaminants is added to the waste stream. For example, permanganate can be used to oxidize cyanide ions under alkaline conditions. Common commercially available oxidants include potassium permanganate, hydrogen peroxide, calcium or sodium hypochlorite, and chlorine gas. Ozone is another strong oxidizing reagent but it must be generated on-site.

Chemical oxidation has been used to treat dilute waste streams containing oxidizable organics. Examples of organics for which oxidative treatment has been reported include aldehyde, mercaptans, phenols, unsaturated acids and certain pesticides (20). Chemical oxidation has also been used as a pretreatment process. In some instances compounds that are refractory to biological treatment can be partially oxidized, making them more amenable to biological oxidation.

One of the major limitations of chemical oxidation is that the oxidation reactions frequently are incomplete. Organic compounds do not break down completely into carbon dioxide and water. Oxidation products could be formed that are more toxic than the original contaminants. For example, addition of chlorine can result in formation of products that can be odorous and more toxic

and, at times, have a higher resistance to biological treatment.

Chemical oxidation is also not well suited for high strength, complex wastewaters. The strong oxidants are not selective and will react with all oxidizable compounds in the waste stream. For high-strength waste streams such as landfill leachate, the chemical dosage will be high and the treatment process costly.

An equally important consideration in using chemical oxidation is that the treatment chemicals are invariably hazardous and difficult to handle. In some cases, they have to be generated onsite requiring specially trained operators. The operation of such a facility is sophisticated and the traditional wastewater treatment plant operator must be retrained in the use of such technologies.

Chemical oxidation process was not considered as a treatment alternative for the leachate. However, it was considered for pretreatment, and experiments were devised to evaluate whether it can improve biodegradation of the leachate (8).

4.3 SELECTION OF CANDIDATE TECHNOLOGIES

The processes that will be used to treat the Fresh Kills Landfill leachate will depend on the discharge limits imposed by the NYSDEC. At this time the two contaminants that may have to be controlled in an onsite treatment facility are ammonia nitrogen and TOC. In the

previous subsections, several categories of technologies were briefly described. In this subsection, the technologies are evaluated and those that warrant further consideration are identified. The evaluation process began with site visits to operating leachate treatment facilities and assessments of specific biological and chemical technologies.

4.3.1 Operating Leachate Treatment Facilities

There are few leachate treatment facilities with direct discharge of the effluent into surface waters in the country. Two facilities were located and visited as part of the evaluation process. Both locations are permitted facilities that treat the leachate to specified limits prior to discharge into surface streams. One facility, the Al Turi Landfill is in New York State and the other, the GROWS, Inc. facility, is in Pennsylvania.

4.3.1.1 The Al Turi Landfill

The Al Turi Landfill is located in Goshen, New York. Leachate from the landfill is collected and treated onsite prior to discharge into the Wallkill River, a class B surface water. The leachate flow generated has been estimated at 15,000 gpd. The strength of the waste is relatively high, with total oxygen demand (TOD), representing the oxygen demand of carbonaceous and nitrogenous compounds, approaching 8,600 mg/L. The treatment facility, ID

number NY-016-6511, is required to reduce the TOD to below 320 mg/L which is equivalent to 40 lb/day maximum. In addition to TOD a number of other action level and discharge limitations must be satisfied.

Figure 4-2 is the process schematic of the Al Turi Landfill leachate treatment plant.

The leachate is collected in an equalization basin that is lined with a dual liner system. The primary (containment) liner consists of an 80 mil high-density polyethylene (HDPE) synthetic membrane. The secondary liner, also an 80 mil HDPE membrane is set atop a two-foot thick layer of compacted clayey till/bentonite admixture. The equalization basin has a storage capacity of 1.5 million gallons, as the equivalent of retaining 100 days of flow. From the equalization basin (lagoon), the leachate is pumped through a tertiary treatment system that includes:

- Metals Removal. Metals removal is accomplished by chemical precipitation. Sodium hydroxide is used to raise the pH to effect precipitation of heavy metals. Polymer is also added to facilitate flocculation and clarification in a downstream Lamella settling tank;
- BOD Reduction. Two anaerobic filters have been provided to reduce the BOD approximately 80 percent, from an estimated influent value of 5,000 mg/L, to approximately 1,000 mg/L. The anaerobic process is effective for high strength wastewaters since it can reduce the BOD, produce methane, minimize sludge production and operate without consuming large amounts of energy;

- Further BOD Reduction and Nitrification. After the anaerobic filters, the leachate flows into a two-stage activated sludge process. The first stage is designed to remove the carbonaceous BOD remaining in the leachate and the second stage nitrifies the ammonia. It should be realized that the permit has a limit for TOD and not ammonia. From a treatment point of view, only the sum of carbonaceous and nitrogenous BOD is required to be less than the maximum specified effluent load of 40 lbs/day; and
- Removal of Suspended Solids. To remove residual suspended solids, the effluent from the clarifier flows into dual-media filters. The filtered effluent is then discharged into the Wallkill River.

All treatment operations, other than the anaerobic filters, are housed in a building of approximately 4,900 sq ft. The plant effluent is in compliance with the discharge permit. The aerobic processes operate effectively in removing the BOD and nitrifying the leachate. There are no requirements for COD or TOC removals or discharge limitations.

In terms of operation of individual processes the anaerobic filters appeared to be functioning less efficiently than anticipated, primarily because the actual BOD of the leachate was much lower than the estimated value. In their potential application to the Fresh Kills Landfill leachate, it is less likely that anaerobic filters will be feasible since the BOD tends to be low, approximately 100 mg/L.

Biological nitrification operated efficiently and did not require additional efforts other than those required to operate an

Figure 4-2. Process Schematic of the Al Turi Landfill Leachate Treatment Plant

activated sludge process. Biological nitrification warrants consideration in treating the Fresh Kills Landfill leachate.

4.3.1.2 The GROWS, Inc Facility

The GROWS, Inc. facility is located in Falls Township, Bucks County, Pennsylvania. The sanitary landfill, with a surface area of 50 acres, is underlaid by an asphaltic liner. Leachate is collected from several points within the landfill and pumped to the treatment plant via an equalization tank.

Figure 4-3 is a schematic of the process flow diagram.

The maximum leachate flow has been estimated at 150,000 gpd. The treatment facility includes the following processes:

- Chemical Precipitation. Chemical precipitation is designed to remove heavy metals and a portion of the organic matter. Lime slurry, added to cause precipitation and coagulation of the contaminants, is flash-mixed with the incoming leachate, and mixing, flocculation, and clarification occur within a single unit. The amount of lime added is sufficient to raise the pH of the leachate to approximately 11.5 so that ammonia can be air-stripped in a subsequent process;
- Air Stripping of Ammonia. Since the facility does not have to comply with air emission limits, ammonia is removed by air stripping in a packed tower. Unlike the Al Turi facility, which only removes the oxygen demand of ammonia by biological nitrification, air stripping allows for complete nitrogen removal;

- Biological Treatment. Following air stripping, the leachate's pH is re-adjusted and nutrients are added as required. The biological process is designed to remove the residual BOD and to nitrify the ammonia remaining in the leachate. The biological processes consist of two parallel aeration tanks; and
- Filtration and Disinfection. The clarified effluent from the activated sludge process passes through sand filters to remove suspended solids. The filtered effluent is then chlorinated prior to its discharge to the Delaware River. When the effluent must be recycled to the landfill, chlorination is by-passed.

The GROWS, Inc. facility uses air stripping for ammonia removal.

The GROWS, Inc. facility is apparently complying with its present permit (PA 0043818), which requires average monthly BOD of 50 mg/L, ammonia of 35 mg/L and TSS of 30 mg/L. A concern in the past was the presence of a strong color similar to that in the Fresh Kills Landfill leachate. Because the combined physical-chemical and biological treatment processes did not reduce the color sufficiently, and because the use of activated carbon adsorption, based on bench-scale evaluation studies, would have been expensive, negotiations with the State resulted in a new effluent limit of 750 colorimetric units. Compliance with this new limit has been reported in private communications. Chemical precipitation has been effective in removing the heavy metals.

While air stripping can be considered for the Fresh Kills landfill leachate, stringent air emission limits in New York State will prohibit its use without incorporation of emission control devices.

Figure 4-3. Process Schematic of the GROWS, Inc. Leachate Treatment Facility

These devices will simply recover the ammonia in a smaller volume of liquid, such as sulfuric acid. If the recaptured ammonia can be disposed of at a reasonable cost, then air stripping may be considered further.

The strong color associated with the Fresh Kills Landfill leachate may also be a significant problem. Full scale operations at the GROWS, Inc. facility showed that color is not sufficiently removed by chemical-physical and biological processes. Apparently, if color removal is required, carbon adsorption may have to be used. The high rate of carbon usage in treating the leachate makes this an expensive option. As was noted, the GROWS, Inc. facility does not use carbon adsorption. Instead, the permit was modified to allow a higher color intensity to be discharged into the Delaware River.

4.3.2 Preliminary Treatability Studies

Leachate treatment may require biological as well as chemical-physical processes. Each process was evaluated independently in a bench-scale experiment prior to bench-scale tests in combination. In order to design the bench-scale experiments more effectively, specific reactions or mechanisms inherent in the treatment processes considered, were first tested separately. For example, prior to initiating a long-term evaluation of the activated sludge process, it was considered prudent to verify that leachate was

susceptible to biological treatment (i.e. whether leachate would not inhibit biological treatment if applied to a new onsite facility or to the local Oakwood Beach WPCP).

Therefore, the primary objective of the initial studies was to determine the treatability of the Fresh Kills Landfill leachate using aerobic and anaerobic processes. Large volume respirometers were used to measure the oxygen consumption rate of the microorganisms when brought in contact with leachate. By comparing the oxygen consumption rate of leachate to that of standard nutrient solutions with different aliquots of leachate, it was possible to determine whether leachate contains bacteria-inhibiting substances. Similarly, anaerobic biological treatment were evaluated using serum bottles to measure total gas production.

After preliminary evaluation of biological treatment, several short-term experiments, including coagulation and pH adjustment, were performed to assess chemical treatment. Using jar test procedures several inorganic coagulants in association with polymers were evaluated to determine the efficiency of color and TOC removal. Lime and sodium hydroxide were tested separately to determine the dosages required to raise the pH of the leachate to 11.5. The results from these preliminary tests were used to determine chemical dosages and sludge production rates.

4.3.2.1 Aerobic Treatment of Leachate

Aerobic treatment studies were designed to address two main process concerns associated with the treatment of the Fresh Kills leachate in a conventional activated-sludge process plant. The first concern is the potential presence of toxics in the leachate at concentrations that may inhibit the activated-sludge process. Toxic can inhibit and/or slow down the growth rate of the microbial biomass and reduce the effectiveness of the activated-sludge process in treating wastes. A deterioration of the plant effluent may necessitate adjustment of process operating conditions or require pretreatment of the leachate. The second concern is the compatibility of the leachate with the treatment plant's normal influent. Although the leachate by itself may not show evidence of any toxicity, there is the possibility that the combination of leachate with the plant's normal influent may produce synergistic toxicity which, just as original toxicity, would adversely affect the activated-sludge process by reducing its effectiveness in treating wastes, thereby causing poor plant performance.

Both of these concerns were addressed using Automated Large Volume (ALV) respirometers manufactured by Tech-Line Instruments. The respirometers are designed to measure cumulative uptake of oxygen as a function of time or respiration rate. The procedure used was a slight modification of the Baltimore Inhibition Test developed at the Patapsco Wastewater Treatment Plant in Baltimore, Maryland (6).

The test methodology consisted of preparing a number of aliquots of equal volume in which returned activated-sludge was combined with different concentrations of the substrate being tested for toxicity or compatibility, and continuously monitoring the respiration rates of the different samples. The concentration of biomass, as measured by mixed-liquor suspended solids (MLSS), was kept constant in each preparation while a dose of synthetic nutrient broth was added to ensure a high initial respiration rate. The dose of broth is intended to saturate the biomass with nutrients. Prior to the findings at the Patapsco plant, toxicity tests were performed using organisms in the endogenous phase of respiration. A toxic sample added to the organisms during this phase would be expected to cause a decline in the respiration rate; however, in some tests, the respiration rate increased. Investigations conducted at the Patapsco Wastewater Treatment Plant while the test procedure was being developed attributed the increase in respiration to the presence of a food source in the sample being tested. The increase in respiration due to this food source masked the toxicity in the sample. Further investigations showed that prefeeding the biomass, in effect saturating it with a synthetic nutrient, eliminated this effect and increased the sensitivity of the test.

Both the toxicity and compatibility tests were conducted by first preparing an aliquot containing only biomass (MLSS) and allowing the sample to reach the endogenous phase. A blank was prepared using biomass and nutrient broth to determine a blank or baseline

respiration rate. The baseline respiration rate is the net rate for the blank sample, which is determined by subtracting the endogenous rate from the observed rate. A number of aliquots were then prepared containing different concentrations of leachate. The total volume, after adding the sludge and leachate in each preparation, was made using dilution water. In the toxicity tests the biomass used was returned sludge collected from the Ward's Island WPCP. The samples' net rates were determined and compared to the baseline rate to assess whether inhibition of the biomass had occurred. In the compatibility tests, the biomass used was returned-sludge from the Oakwood Beach WPCP, which was the plant to be used for offsite treatment of the leachate. The total volume after adding sludge and leachate was made up using primary effluent from the Oakwood Beach primary sedimentation tanks. The respiration rate for each of the test samples was determined by starting at a specific beginning rate and measuring the reduced rate after a fixed time interval. For example, in one of the tests to assess the toxicity of the leachate, the beginning rate for all the samples was approximately 44 ml/L/hr. The rates then measured 30 minutes after the beginning rate were used as the basis for comparison.

Tables 4-4 and 4-5 show the results of two sets of tests performed on the leachate. The results show no significant adverse effects of the leachate on the biomass. Most of the resulting rates are near 100 percent of the baseline rate. In the compatibility test

TABLE 4-4

RESULTS OF COMPATIBILITY TESTS

Date of test: 7/2/68

Basis for comparison: 1/2 hr reduced rate starting at
approximately 83 ml/1/hr.

Sample	Observed Rate (ml/1/hr)	Net Rate	% of Baseline
Endogenous	12	--	--
Blank	43.7	31.7	--
5% L	42.5	30.5	96.2
10% L	41	29	91.5
25% L	46.5	34.5	108.8
40% L	42.2	30.2	95.3
60% L	44	32	100.1
80% L	43.2	31.2	98.4

Date of test: 12/29/88

Basis for comparison: 1/2 hr reduced rate starting at
approximately 40 ml/1/hr.

Sample	Observed Rate ml/1/hr	Net Rate ml/1/hr	% of Baseline
Endogenous	10.3	--	--
Blank	34.5	24.2	--
10% L	30.2	19.9	82.2
25% L	35.5	25	103.3
40% L	32.8	22.5	93
60% L	33.8	23.9	97.1
80% L	30.2	19.9	82.2

TABLE 4-5**RESULTS OF TOXICITY TESTS**

Date of test: 7/29/88

Basis of comparison: 15 minute reduced rate starting at approximately 48 ml/1/hr.

Samples	Observed Rate	Net Rate	% of Baseline
Endogenous	12	--	--
Blank	31	19	--
5%	39.5	27.5	144.7
10%	33.5	21.5	113.1
25%	33	25.5	110.5
40%	37.5	25.5	134.2
60%	31	19	100

Date of test: 1/3/89

Basis of comparison: 1/2 hr reduced rate starting at approximately 44 ml/1/hr.

Samples	Observed Rate	Net Rate	% of Baseline
Endogenous	7.8	--	--
Blank	35	27.2	--
5%	38.2	30.4	111.8
10%	35.3	27.5	101.1
40%	33.3	25.5	93.8
60%	32.3	24.5	90.1

results, which are indicative of the effect that the leachate will have on the Oakwood Beach biological process, most of the rates are within 10 percent of the baseline rate. In the toxicity test results, the rates are slightly more varied, with two of the rates exceeding the baseline by more than 30 to 40 percent. These two, however, are apparently anomalous results due partly to experimental errors.

The respirometric analyses were repeated in a separate series of experiments in which a known toxic, sodium lauryl sulfate, was used for comparison with the Fresh Kills leachate. The reduction due to the known toxic, at a concentration of approximately 300 mg/L, was over 90 percent. However, the reduction observed due to the leachate was under 20 percent for a 5 to 10 percent leachate concentration. This indicates that leachate should not affect the Oakwood Beach WPCP where the dilution would be less than 2 to 3 percent.

Figures 4-4 and 4-5 show, respectively, the plotted results for the compatibility and toxicity tests. An indication of possible inhibition was noted when the leachate exceeded 10 percent of the total sample volume. However, since one of the characteristics of the leachate is a high concentration of ammonia nitrogen, its apparent inhibition may be due, not to toxicity, but to the need of the biomass to adapt to the leachate (e.g., for a population shift to nitrifying bacteria). If the leachate were to be conveyed to

Figure 4-4. Compatibility Test Results.
 (Oakwood Beach Prim. Eff. + Sludge + Leachate)

Figure 4-5. Toxicity Test Results.
(Ward's Island Sludge + Leachate)

the Oakwood Beach WPCP for treatment, it would represent between 2 and 4 percent of the total plant influent. At this low concentration the leachate is not expected to have an adverse effect on the plant's step-feed activated-sludge process.

4.3.2.2 Anaerobic Treatment of Leachate

Treatability of the leachate under anaerobic conditions was evaluated by monitoring the rate of gas production. Batch bioassays were prepared using 160-ml serum bottles following method outlined by Stuckey (21). Digested sludge from the Ward's Island WPCP was used as seed. The feed consisted of ethanol and Fresh Kills leachate. Prior to conducting the experiment, the seed and all substrates were placed in an incubator so that all solutions would be at the same temperature before intermixing. In setting up the study, all the bottles were purged with nitrogen gas. Three batch bioassays were prepared in which the quantities of sludge added to serve as seed were 20 ml, 10 ml, and 5 ml.; 0.1 ml of ethanol was added to the first batch while 0.05 ml of ethanol was added to the second and third batches. The volume of leachate added ranged from 0.1 ml to 20 ml. A buffer solution was added to each serum bottle to produce 50 ml as the final volume in each bottle. After preparation, the bottles were placed in a 35°C incubator for an hour. The serum bottles were equilibrated to atmospheric pressure and then returned to the incubator. Gas volumes were then measured periodically at predetermined incubation

periods.

The batch bioassays were divided into two groups. The first group, No.3 to No.8 as shown in Table 4-6, consisted of serum bottles to which the leachate was added as the only substrate. The second group, No.9 to No. 14, consisted of bottles to which both ethanol and leachate were added as substrates. A seed control containing seed only and a feed control containing seed and ethanol only were also prepared. The effect of the leachate was evaluated by comparing the gas production in the bottles containing leachate to that of the feed control. The data for the first batch bioassays are presented in Table 4-6. The most significant results are shown in Figures 4-6 and 4-7.

The first bioassays prepared, with 0.1 ml of ethanol added, should, if all the ethanol were fermented into gas, result in a total of 87 ml of gas produced at 35°C and 1 atmosphere (atm). The average difference between the feed control and seed control after 15 days was 72.7 ml (Table 4-6). This represents a recovery of 84 percent, which is satisfactory for this type of experiment. At 35°C and 1 atm, if all organics removed were converted to CH_4 , 0.39 ml of CH_4 would be formed per mg of COD reduction. Since the gas produced in the anaerobic process consists of approximately 66 percent CH_4 , then, theoretically, the total gas volume produced should be approximately 0.59 ml per mg of COD reduction. Accordingly, having 1,800 mg/L in the Fresh Kills leachate and using a 20-ml sample of

TABLE 4-6

CUMULATIVE GAS PRODUCTION FOR ETHANOL AND LEACHATE AS SUBSTRATE IN ANAEROBIC ASSAYS

Incubation Time (days)				0	0.87	1.83	2.83	3.67	4.67
Sample Number	Sludge (ml)	Ethanol (ml)	Leachate (ml)	Cumulative Gas Production (ml)					
Seed	20	/	/	0	8.8	13.2	17.2	20.5	23.5
Feed	20	0.1	/	0	14.9	47	81	91.3	96
3	20	/	0.1	0	10.9	15.1	19	22.3	26
4	20	/	0.5	0	10	14.4	18	21.3	24.8
5	20	/	1.0	0	8.6	13.2	17	20.2	23.8
6	20	/	5.0	0	12.7	17.4	21.4	24.5	28.3
7	20	/	10.0	0	10.9	15.1	19.6	22.7	26.4
8	20	/	20.0	0	11.7	16.1	20.4	23.3	26.9
9	20	0.1	0.1	0	14.4	42.4	68.8	78.1	82.1
10	20	0.1	0.5	0	14.2	50.2	81.8	92.2	97.1
11	20	0.1	1.0	0	17.7	54.1	83.1	93.2	97.5
12	20	0.1	5.0	0	17	52.2	82.9	94.7	99.3
13	20	0.1	10.0	0	16.1	48.8	80.6	95.6	100.2
14	20	0.1	20.0	0	17.2	48.5	79.3	94.2	99.6

Note: All gas volumes measured at 35°C and 1 atm.

TABLE 4-6 continued

CUMULATIVE GAS PRODUCTION FOR ETHANOL AND LEACHATE AS SUBSTRATE IN ANAEROBIC ASSAYS

Incubation Time (days)				5.7	7.71	9.63	12.63	14.63
Sample Number	Sludge (ml)	Ethanol (ml)	Leachate (ml)	Cumulative Gas Production (ml)				
Seed	20	/	/	25.5	28.7	31.5	36.5	39.5
Feed	20	0.1	/	98.2	102	104.7	109	112
3	20	/	0.1	28	31.7	34.2	38.2	40.9
4	20	/	0.5	27.2	29.9	32.8	36.5	39.4
5	20	/	1.0	26.2	29.3	31.4	36	38.6
6	20	/	5.0	30.3	33.8	36.5	40.1	42.7
7	20	/	10.0	28.4	31.9	34.7	38.5	41.5
8	20	/	20.0	29.8	33.6	36.6	40.5	43.1
9	20	0.1	0.1	84.1	87.6	89.7	94.6	97.2
10	20	0.1	0.5	99.6	103.1	105.5	109.5	112.3
11	20	0.1	1.0	100	103.8	106.9	111.7	114.6
12	20	0.1	5.0	101.5	105.3	107.6	111.7	114.6
13	20	0.1	10.0	102.4	105.5	108.7	113.2	116.1
14	20	0.1	20.0	101.8	104.9	107.9	111.9	114.3

Note: All gas volumes measured at 35°C and 1 atm.

Figure 4-6. Anaerobic Degradation of Leachate : 10 mL Seed Sludge.

Figure 4-7. Anaerobic Degradation of Leachate : 5 mL Seed Sludge.

leachate in sample No.8, the total gas produced should approximate 21.1 ml. ($1,800 \times 0.02 \times 0.59 = 21.1$ ml). However, only 3.8 ml of gas were produced which is the difference between the gas produced by the leachate and seed, (i.e, compared $43.1 - 39.3 = 3.8$ ml). The resulting gas recovery is 17.9 percent. This low gas production from the leachate of high COD concentration indicates that the anaerobic biodegradability of the leachate is poor.

Theoretically, gas production due solely to BOD degradation is 2.6 ml, less than the measured 3.8 ml. Therefore, it would appear that anaerobic degradation can remove up to 18 percent of the COD in contrast to aerobic processes which have a capability of COD removal up to 12 percent.

Figures 4-6 and 4-7 show that, using ethanol and leachate as substrates, the gas production of the samples was close to that of the feed control, up to 3.5 days. An explanation for this result could be that anaerobic biodegradability may be selective for simpler organics such as ethanol and that the more complex organics found in the leachate may be degraded at a later or longer detention time. Thereafter leachate biodegrades resulting in an incremental increase in gas production.

The anaerobic studies were repeated a second time to test whether anaerobic sludge adaptation to leachate would degrade a larger proportion of the COD. Figure 4-8 shows the results. During the

Figure 4-8. Gas Production During Long Term Anaerobic Decomposition of Leachate .

first phase of the experiment the bio-assay bottles were incubated for 50 days. Gas production patterns were similar to those described earlier. On the 50th day, the bottles were charged with additional ethanol and leachate of equal dosage. The gas production pattern repeated itself with gas production per unit feed being similar. The data suggested that adaptation of the seed to the leachate does not improve treatability. Apparently the leachate contained organic material that is stable and that does not significantly degrade further.

Although no inhibition of the anaerobic process was evident from this evaluation, the anaerobic biodegradability of the leachate was found to be 18 percent. Because the anaerobic process was ineffective in removing organics from the leachate significantly, and because the high content of ammonia nitrogen in the leachate requires nitrification, an aerobic process, anaerobic treatment was not considered further.

4.3.2.3 Chemical Treatment of Leachate

The refuse dumped at the Fresh Kills Landfill is essentially household wastes containing primarily paper and some wood products. The leachate produced from such waste paper products is of high intensity in both color, approximately 3,000 colorimetric units, and COD, 1,800 mg/L. Humic substances are assumed to comprise the organic contaminants in the leachate, which are

complex organic compounds having molecular weights in the range of a few hundred to tens of thousands molecular weight units (22). Humic substances are amorphous, acidic, predominantly aromatic, hydrophilic, and chemically complex polyelectrolytes that are responsible for the natural color imparted to waters. Based on the above assumption, laboratory coagulation tests with alum and polymer alone, as well as with alum combined with polymer, were conducted to measure color and TOC removal efficiencies.

Coagulation is a common treatment process used to remove humic substances from municipal and industrial water supplies. Alum is a widely used coagulant in the United States for the treatment of surface water supplies, and polymers are being used more extensively as aids in the coagulation process. Key operational parameters affecting the coagulation of humic substances with alum and polymer include the concentration of humic material, in most cases measured as TOC, coagulant dosage, and the pH at which the coagulation is carried out. A number of studies (23,24) have shown that optimum humic substance removal with alum, as defined by color and TOC reduction, occurs in a pH range from 5 to 6. At this pH, humic substances can be considered as negatively charged colloids or anionic polyelectrolytes. Limits for the optimum removal may vary slightly according to the individual study, but all fall within the same general range.

Edzwal et al. (23) found that using high-molecular-weight polymers

with alum is an effective coagulation process for removing humic substances. An optimum polymer dosage was observed, with overdosing resulting in restabilization of the humic substances when outside the pH range of 4 to 6. Combination of alum and high-molecular-weight polymers takes advantage of destabilization by both charge neutralization resulting from specific chemical interaction between positively charged aluminum species and negatively charged groups on the humic colloid. The addition of high-molecular-weight polymers can then form large floc particles via interparticle bridging. Restabilization due to overdosing can be explained in terms of unavailable sites for bridging due to coverage of colloidal humic particles with excess polymer. As the pH was raised above 6, poor removal was observed by Edzwal. With increasing pH, the humic substances become more stable due to increasing dissociation of functional groups and soluble aluminum (III) species shift from cationic to aluminate anions, that cannot provide charge neutralization.

Jar tests were conducted to determine the efficiency of color and TOC removal as a function of alum dosage, polymer dosage and alum combined with polymer dosage. The coagulants and performance criteria used for these tests follow.

1. Coagulant:

- a. Polymer: CAT-FLOC 8964, CAT-FLOC 2963, CAT-FLOC K-10, WT-2511, POL-E-Z 7763, POL-E-Z 2696 (all supplied by Calgon Corp.)
- b. Alum: Reagent grade aluminum sulfate

2. Criteria for Performance

- a. Color removal
- b. TOC removal
- c. Sludge production

The six kinds of polymers provided by Calgon Corporation were evaluated in preliminary coagulation tests. Preliminary tests were conducted to eliminate those polymers that had minimum effect on color and TOC removal. The tests were performed by simultaneously adding the various polymers to six beakers, respectively, and observing the flocculation process. Based on these preliminary tests, polymers CAT-FLOC 8964, CAT-FLOC 2963 and CAT-FLOC k-10 were selected for detailed coagulation analysis.

Since all experiments were conducted at 5.5 pH, and leachate pH was 8, 5N sulfuric acid was added to adjust the pH levels. A total volume of 500 ml of leachate was added to one-liter glass beakers. Coagulant, added during a rapid mixing period of two minutes at 100 rpm, was followed by a slow mixing period of 20 minutes at 10 rpm (flocculation period). After a 30-minute settling period, supernatant samples were taken for analysis. The samples were filtered through a glass fiber filter. After filtration, TOC and color tests were conducted for each sample. Jar test sludge was allowed to settle an additional one hour and then analyzed for solids as needed.

Jar tests using either alum or polymers alone were conducted first. The tests using alum and polymer combinations, were conducted in the following manner. First the alum was added as the solution was rapidly mixed for approximately two minutes. The polymers were then added and rapid mixing was continued for an additional one minute to ensure complete dispersal of the polymer. The remainder of the jar test procedure (flocculation period, settling period, and measurement) followed that previously described. The optimum coagulant dosages were defined as the dosages that resulted in the greatest removals of color and TOC in each jar test. Color removal was used as a major performance parameter in these initial coagulation tests.

Of the three cationic polymers selected, CAT-FLOC 8964 seemed most promising in terms of color removal and dosage required. CAT-FLOC 8964 required the lowest dosage, at 700 mg/L for the highest removal efficiency of 92 percent. For similar 92 percent removal, CAT-FLOC 2964 required a 900 mg/L sample. The best color removal for CAT-FLOC k-10 occurred at a dosage of 900 mg/L, while providing only 88 percent color removal. Based on these results, the CAT-FLOC 8964 polymer was selected for the alum-polymer combination test.

The jar test results for the polymer-alum combination tests are presented in Table 4-7. The table shows that the best dosage combination of alum with this polymer is at the alum dosage of 200

TABLE 4-7

ALUM AND POLYMER COAGULATION FOR COLOR REMOVAL

Alum Dosage (mg/L)	Polymer Dosage* (mg/L)	Color Unit
100	300	500
140	300	300
180	300	300
100	240	500
140	240	500
180	240	450
100	200	500
140	200	500
180	200	450
100	140	800
140	140	600
180	140	450
200	700	200
240	700	200
300	700	200
200	300	200
240	300	200
300	300	200
200	100	450
240	100	450
300	100	400
200	40	500
240	40	450
300	40	400

Note: *All leachate samples were initially conditioned to pH = 5.5. The polymer used was CAT-FLOC 8964. Initial Color of leachate was approximately 3000 units.

mg/L per sample and the polymer dosage of 300 mg/L, resulting in a color removal efficiency of 92 percent. Based on these results, further jar tests were conducted under an alum dosage of 200 mg/L per sample using different CAT-FLOC 8964 polymer dosages, in order to find the lowest polymer dosage with the highest removal efficiency.

Figures 4-9, 4-10, 4-11 and 4-12 show, respectively, the results for jar tests using alum alone and polymer (CAT-FLOC 8964) alone with respect to color removal and TOC removal. The optimum alum alone dosage appears to be approximately 300 mg/L per sample, with color and TOC removal efficiencies of 80 percent and 30 percent, respectively. The optimum polymer-alone dosage appears to be 700 to 800 mg/L per sample, with color and TOC removal efficiencies of 92 percent and 63 percent, respectively. The results of the alum-polymer combination test are shown in Figures 4-13 and 4-14. From Figure 4-13 it can be concluded that the optimum polymer (CAT-FLOC 8964) dosage in terms of color removal is 300 mg/L per sample. In Figure 4-14 it seems that, with an alum dosage of 200 mg/L per sample, the best TOC removal (55 percent) occurs when the polymer dosage is over 600 mg/L per sample, and at the polymer dosage of 300 mg/L per sample, the TOC removal efficiency is slightly lower (46 percent).

Applying higher polymer dosages to achieve the slightly higher TOC removal does not appear to be economically feasible nor to warrant

Figure 4-9. Removal of Color Using Chemical Coagulation : Alum.

Figure 4-10. Removal of TOC Using Chemical Coagulation : Alum.

Figure 4-11. Color Removal Using Chemical Coagulation :
Polymer CAT-FLOC 8964 .

Figure 4-12. Removal of TOC Using Chemical Coagulation:
Polymer CAT-FLOC 8964.

Figure 4-13. Removal of Color Using Chemical Coagulation:
Alum and Polymer : CAT-FLOC 8964.

Figure 4-14. Removal of TOC Using Chemical Coagulation:
Alum and Polymer : CAT-FLOC 8964.

further consideration. Therefore, using an alum dosage of 200 mg/L combined with 300 mg/L CAT-FLOC 8964 polymer is recommended in developing treatment alternatives.

In order to ensure that the CAT-FLOC 8964 polymer is the best one for leachate coagulation, a jar test using an alum dosage of 200 mg/L with all six polymers at a dose rate of 300 mg/L was conducted. The results, shown in Table 4-8, indicate that the CAT-FLOC 8964 polymer was most effective for leachate coagulation.

Ferric chloride, an alternative coagulant to alum is often used in water and wastewater treatment. Using the same jar test procedure, the leachate was coagulated using ferric chloride; effectiveness of coagulation was measured by the TOC and color removal efficiency. Figures 4-15 and 4-16 show that the maximum TOC removal achieved was 15 percent at a dosage of 600 mg/L. Color reduction was 66 percent, from an initial level of 3,000 to approximately 1,000 colorimetric units. Ferric chloride was not as effective as alum and was not further considered in this study.

TABLE 4-8
USING POLYMERS FOR COLOR REMOVAL

Polymer Types Added	Remaining Color Units
CAT- Floc 8964	300
CAT-Floc 2963	400
CAT-Floc K-10	400
WT-2511	700
Pol-E-Z-2696	800
Pol-E-Z-7736	800

Alum Dosage = 200 mg/L added to all leachate samples in addition to the polymers indicated.

Figure 4-15. Removal of TOC Using Chemical Coagulation:
Ferric Chloride.

Figure 4-16. Removal of Color Using Chemical Coagulation:
Ferric Chloride.

5.0 BENCH-SCALE EVALUATION OF SELECTED TECHNOLOGIES

The candidate technologies selected in section 4.3 were evaluated using bench-scale models. All models were constructed at City College using plexiglass as the primary material, and all were designed to simulate full-scale operation. Whenever possible, vendors of specific processes were consulted to obtain additional information that would be useful in the bench-scale evaluation study.

The leachate used in the evaluation study was obtained from the pump station of the Veterans Avenue Leachate Collection System. The leachate was transported to the College in 55-gallon plastic drums. On the average, three drums were needed twice a month for the duration of the study. Since it had already been shown that the leachate contained relatively stable organic compounds, no preservatives were used in the leachate. In addition, the data on the influent concentrations fed to the bench-scale reactors showed that the two parameters of interest, ammonia-nitrogen and TOC remained constant throughout the residence time of the drums in the laboratory. As an example, Figure 5-1 demonstrates the integrity of the leachate between the leachate collection events, by showing a stable influent concentration of ammonia to each reactor.

The bench-scale experiments of all treatment technologies were conducted concurrently. Therefore, the leachate used in the

biological processes was similar to that used to evaluate the physical processes. In both cases the experiments were conducted in the laboratory whose room temperature was not controlled, therefore, the temperature reported for each experimental run reflected the room temperature. Only the column-activated carbon adsorption experiment was performed under temperature-controlled conditions. This was done by constructing a water jacket around each column, with constant-temperature water continuously pumped through during the adsorption experiment.

All the analyses were performed in the City College Environmental Engineering Laboratory, generally soon after the samples were collected. If analyses had to be delayed, the samples were refrigerated. No chemical preservatives were used. The only analysis performed in another laboratory was the EP toxicity test. This was performed by H2M Labs, Inc. on a thickened sludge sample from the chemical coagulation, flocculation, and settling treatment of the leachate.

The results of each process evaluated by a bench-scale study are presented in this section. The first four tests were of biological nitrification of the leachate. The object of these bench-scale studies was to assess the level of nitrification that could be achieved as measured by the decrease in ammonia concentration. The last two processes studied were chemical coagulation and activated carbon adsorption. The primary objective in those studies was the

reduction of organic contamination as measured by TOC.

5.1 CONVENTIONAL ACTIVATED SLUDGE

The initial treatability studies of the leachate demonstrated that biological treatment is viable and that it would primarily remove ammonia. The process used was activated-sludge. The process includes an aeration tank to support the growth of microorganisms and a clarifier located downstream to separate the mass of microorganisms (biomass) from the water phase. In order to evaluate the effectiveness of the activated-sludge process in nitrifying the leachate, a bench-scale continuous-flow reactor was constructed and operated for more than three months.

The reactor consisted of a five-liter cylindrical flask with a conical bottom to permit sludge wasting. Internally the reactor was divided into two sections. The larger section was aerated to maintain a DO of greater than 2 to 3 mg/L. The aeration section contained the suspended biomass, which was responsible for the oxidation of ammonia nitrogen. The smaller section was designed as an upflow clarifier, which allowed continuous return of the settled solids to the aeration section of the reactor while producing a clarified effluent. The influent leachate was pumped directly into the aeration section of the reactor.

The experiment was initiated by seeding the reactor with return-

activated-sludge from the Ward's Island WPCP in New York City. The feed to the reactor during the first two days of operation was a 50-percent mixture of leachate and Ward's Island's primary tank effluent. Thereafter the feed was leachate. The reactor was operated under several loading conditions as shown in Table 5-1. The hydraulic retention time (HRT) was varied from 1.7 days at the beginning to 0.6 days toward the end of the experimental run. No wasting of solids, other than those in the effluent, was practiced. The laboratory temperature varied between 26 and 28°C. The ammonia loading rate was increased from 0.16 to 0.47 lb NH₃-N per lb of MLSS per day during the study, and reflected the corresponding decrease in HRT given above. The level of nitrification achieved in the study of activated sludge is presented in the next section.

Results. The primary purpose of this experiment was to determine the efficiency of the nitrification process using the conventional activated sludge process. The parameters monitored included ammonia-N, nitrate-N, alkalinity, and MLSS. The additional data recorded was temperature, pH, DO, and leachate flow rate. All analyses were performed according to "Standard Methods (4)." Ammonia was measured using an ammonia ion electrode in conjunction with an Orion EA920 ion analyzer. The nitrates and nitrites were reduced to ammonia using a reducing reagent provided by Orion Research, Inc. and then measured using the same ammonia ion electrode. Therefore, the difference between the initial ammonia concentration of the sample and the final concentration of the same

TABLE 5-1

**OPERATING CONDITIONS FOR THE BENCH SCALE
ACTIVATED SLUDGE PROCESS
(Started on March 9, 1989.)**

Period	HRT (days)	MLSS (mg/L)	Ammonia Loading Rate*	Temperature °C
3/9 - 4/10	1.7	3100	0.16	26
4/11 -5/11	1.0	3000	0.28	27
5/12 - 6/6	0.1	2600	0.47	28

*lbs of Ammonia-Nitrogen per lb of mixed liquor suspended solids
MLSS per day.

sample treated with the reducing reagent represented the concentration of nitrite and nitrate. Table 5-2 shows the data plotted as Figures 5-1, 5-2, and 5-3.

Figure 5-1 depicts the relationship of influent to effluent ammonia during three separate HRT operating conditions. After two weeks of operation at an HRT of 1.7 days, the effluent ammonia stabilized to approximately 210 mg/L while the influent was approximately 750 mg/L. The reactor achieved this level of nitrification for 18 days. Using ammonia as the basis, and assuming negligible ammonia uptake for biological growth, the degree of nitrification achieved was 72 percent. Figure 5-2 shows the corresponding increase of nitrate and nitrite, the two usual products of biological oxidation of ammonia, during this test period. The ratio of the nitrified end products to ammonia removed averaged 0.85, an acceptable recovery factor considering the inherent difficulties of measuring nitrates and nitrites.

After 32 days of operation, the feed rate was increased and the reactor was operated at an HRT of 1.0 day. There was an immediate deterioration of the effluent to 600 mg/L. However, after two weeks, the effluent ammonia concentration stabilized at 230 mg/L. The corresponding nitrification efficiency was 69 percent, a drop of three percent from the previously measured efficiency of 72 percent.

TABLE 5-2

CHARACTERISTICS OF THE ACTIVATED-SLUDGE PROCESS EFFLUENT

Days	NH ₃ -N (mg/L)	NO ₃ -N (mg/L)	Alkalinity (mg/L as CaCO ₃)	MLSS (mg/L)
HRT = 1.7 Days (Loading: 0.16 lb NH ₃ -N/lb MLSS, per day)				
6	490	370	4100	3216
11	300	530	3000	3357
15	250	575	2600	3251
18	210	600	2400	3042
25	200	610	2300	3052
27	170	620	2100	3300
32	200	595	2100	3117
HRT = 1.0 Day (Loading: 0.28 lb NH ₃ -N/lb MLSS, per day)				
34	610	270	4800	3052
41	320	510	3000	3089
44	270	550	2800	2985
48	240	575	2500	3019
52	210	595	2500	3151
55	230	585	2550	3104
60	220	580	2350	3100
63	210	590	2350	3200
HRT = 0.6 Days (Loading: 0.48 lb NH ₃ -N/lb MLSS, per day)				
65	670	220	5000	2625
70	550	305	4500	2589
74	500	355	3900	2550
77	480	365	3850	2579
80	480	360	3800	2346
84	485	370	3800	2456
86	480	380	3750	2504
89	480	380	3750	2500

Figure 5-1. Activated-Sludge Process, Ammonia Removal.

Figure 5-2. Activated-Sludge Process, Nitrification of Ammonia to Nitrates/Nitrites.

Figure 5-3. Activated-Sludge Process, Alkalinity Reduction During Nitrification.

Figure 5-2 shows the corresponding increase of nitrate and nitrite, which was approximately 430 mg/L. The recovery factor during this second set of operating conditions was 0.83, similar to the value calculated for an HRT of 1.7 days.

At this time the reactor was stressed further by decreasing the HRT to 0.6 days. As shown in Figure 5-1, an immediate increase in the effluent ammonia concentration was noted. Operating the activated-sludge reactor for an additional three weeks caused the ammonia in the effluent to stabilize at 480 mg/L. The corresponding ammonia removal efficiency was approximately 56 percent, a significant reduction compared to the previously tested HRTs. Figure 5-2 also shows a corresponding reduction in the amount of nitrates and nitrites formed.

Nitrification of ammonia is an acidic reaction, which will cause the pH to drop if sufficient alkalinity is not present. Stoichiometrically, as mentioned earlier, 7.1 mg/L of alkalinity as calcium carbonate will be destroyed for each mg/L of ammonia-N oxidized to nitrate. The alkalinity of the untreated leachate, in the range of 5,500 mg/L, is greater than the required value of 5,325 mg/L required to oxidize the 750 mg/L of ammonia-N present. The experimental results show the maximum level of nitrification achieved was 72 percent. Figure 5-3 shows that, as anticipated, in each of the three operating conditions, the residual alkalinity was always above 2,100 mg/L. The ratio alkalinity consumed to

ammonia-N oxidized was 6.3. Throughout the experimental run the pH remained in the range of 8. This leachate can, therefore, support biological nitrification of ammonia at a neutral or slightly basic pH without requiring any chemical conditioning.

In addition to the above parameters, both BOD and SS in the reactor effluent were measured. The periodic BOD analysis performed showed values ranging from 20 to 25 mg/L. SS in the effluent averaged 20 mg/L. Using a MLSS of 3,000 mg/L and knowing that no wasting of sludge solids other than the SS in the effluent was practiced, the solids retention time (SRT) was estimated to be 100 days. This long SRT results in a low observed biomass yield coefficient and is, thus, probably the reason why the MLSS in the reactor did not increase over a period of 89 days of continuous operation.

The experimental results of the activated-sludge process indicated that biological oxidation of ammonia (nitrification) is possible. The alkalinity present is sufficient to maintain a pH in the alkaline range. For operating temperatures of 26 to 28°C, the highest nitrification efficiency achieved was 72 percent, at an HRT of 1.7 days. However, similar removal efficiencies were achieved at an HRT of one day or a loading of 0.28 lb NH₃-N per lb of MLSS per day. The latter operating and design criteria should produce a more cost-effective nitrification facility since a smaller aeration tank would be required.

The clarified effluent always contained SS and, therefore, represented a continuous wasting of biomass from the process. The combined effect, low growth rate and constant wasting of SS in the process effluent, suggest that the inability to accumulate solids in the reactor may be the limiting factor in using conventional activated sludge. A reactor designed to allow more biomass to be retained may be more effective in carrying out nitrification of this leachate.

5.2 SEQUENCING BATCH REACTORS (SBRs)

The SBR testing procedure was designed to evaluate nitrification of the leachate. The reactor was constructed using a four inch I.D. plexiglass cylinder. The total volume provided was four liters with drainage ports at 1.5-, 2-, and 3-liter volume levels. Figure 5-4 is a flow diagram of the bench-scale SBR system used in this study.

Evaluation of the SBR began after completion of the conventional activated sludge process. The SBR reactor, in fact, was seeded with the acclimated biomass from the abandoned activated-sludge reactor. Several operating strategies were used to assess the technical feasibility of SBRs. Initially, a batch test was conducted with continuous aeration. Samples were collected at predetermined time intervals and analyzed for ammonia to determine the reaction time needed to reduce ammonia from 750 mg/L to less

Figure 5-4. Flow Diagram of the Bench-Scale Sequencing Batch-Reactor System

than 10 mg/L. After the batch test, the SBR was operated under two conditions, namely one cycle per day and two cycles per day. A cycle consisted of fill and react time, both with aeration, followed by settling and decanting of the supernatant. The SBR was evaluated over a period of 40 days. Specific operating conditions associated with each cycle are presented in Table 5-3. It should be noted that the shortest HRT used was 19.2 hours (0.8 days), approximately the time required for 70 percent nitrification using conventional activated sludge.

Results. The batch test, using an acclimated biomass and leachate, was conducted to provide a basis for selecting an appropriate cycle to use in the evaluation of the SBR process. After the biomass was transferred from the activated sludge to the SBR reactor, untreated leachate was added. Aeration began during reactor filling and continued throughout the run. Samples were collected periodically and analyzed for ammonia. The following results were obtained:

Time, hr	1	2	4	5	6	7	8	9	10	12
NH ₃ -N, mg/L	320	250	130	100	70	30	10	1.5	0.3	0.3

The data are plotted on Figure 5-5. It appears that nitrification of ammonia can be described by zero-order kinetics, and is relatively complete within 10 hours of aeration.

After completion of the batch test, the SBR study was conducted to

TABLE 5-3

OPERATING CONDITIONS FOR THE SEQUENCING BATCH-REACTOR SYSTEM

	EXPERIMENTAL RUN 1	EXPERIMENTAL RUN 2
Cycles per day	1	2
Fill time with aeration	4 hours	4 hours
Reaction time	17 hours	6 hours
Settling time	1 hour	1 hour
Decantation	0.25 hour	0.25 hour
Idle time	0.75 hour	0.75 hour
Hydraulic Retention Time (HRT)	38.4 hours	19.2 hours
F/M (BOD)	0.014 lb/lb MLSS per day	0.023 lb/lb MLSS per day
F/M (NH ₄ -N)	0.104 lb/lb MLSS per day	0.168 lb/lb MLSS per day
Length of Experiment	21 Days	19 Days

Figure 5-5. Nitrification Rate in a Sequencing Batch-Reactor.

evaluate the operating conditions required for nitrification. The test was conducted at both one and two cycles per day. One cycle per day provided 21 hours of aeration; this was reduced to 10 hours of aeration during the two-cycles-per-day phase of the study. The results of these experiments are shown in Table 5-4 and plotted in Figures 5-6 and 5-7. The ammonia concentration in the influent averaged 740 mg/L and the alkalinity was about 5,600 mg/L. Figure 5-6 shows that nitrification began immediately. This was expected because the seed to the reactor was the biomass from the abandoned activated sludge reactor, which had already demonstrated effective nitrification. With an HRT of 1.6 days, the SBR produced an effluent that was consistently below 1 mg/L. After day 21, the HRT was reduced to 0.8 days and the study entered the second phase, operation at two cycles per day. An initial deterioration was noted as the ammonia in the effluent increased to 10 mg/L. However, within a week the effluent ammonia stabilized at concentrations of less than three mg/L. The nitrification efficiency during both test runs was more than 90 percent.

During nitrification the pH remained within the range of 7.8 to 8.1 as the alkalinity in the leachate provided the necessary buffering capacity required. Figure 5-7 shows the amount of alkalinity destroyed during nitrification. The amount of residual alkalinity, after nitrification, averaged 1,000 mg/L.

Throughout the experimental run the only sludge wasting that

TABLE 5-4

CHARACTERISTICS OF THE SEQUENCING BATCH-REACTOR SYSTEM EFFLUENT

Day	NH ₃ -N (mg/L)	Alkalinity (mg/L as CaCO ₃)	MLSS (mg/L)
Operation: One Cycle per Day			
1	1.0	950	4686
3	0.35	900	4676
6	0.45	900	4785
9	0.55	950	4880
12	0.65	900	4894
15	0.45	900	4959
18	0.35	900	5045
21	0.55	900	5105
Operation: Two Cycles per Day			
22	10	1000	5214
24	8	950	5230
27	4	1000	5160
30	2	950	5178
33	2	900	5296
36	1.5	950	5345
39	2.5	950	5375
40	2	950	5396

Figure 5-6. SBR System Effluent Ammonia Concentration.

Figure 5-7. SBR System, Alkalinity Reduction During Nitrification.

occurred was the solids removed with the decanted leachate. The SS concentration was relatively high, frequently in the range of 100 mg/L. The MLSS concentration ranged from 4,600 to 5,400 mg/L. Using an average HRT of 1.2 days, the calculated SRT was approximately 60 days. The high SRT and the warm temperature, 27°C, enabled the SBR to achieve an extremely high nitrification efficiency.

The SBR system can be used to nitrify the leachate. It has been demonstrated that nitrification rates as high as 99 percent can be achieved. The nitrification process remains effective even though the biomass is exposed to low DO during the settling, decanting, and idle times. In this experiment these times totaled two hours, during which time there was no aeration. A potential concern is the SS in the decant leachate. There apparently are problems complying with a discharge permit if there are SS limits. It is difficult to predict clarification and capture of solids based on a four-inch diameter SBR system. However, the data are a warning that concern must be addressed during the design process. The SBR will support nitrification but it may not comply with SS limits in the effluent if those limits are set at the traditional 30 mg/L monthly average. The SS limits could be met using filtration.

5.3 PACT SYSTEM

Concurrently with the conventional activated-sludge tests, another

reactor system simulating PACT was placed in operation on March 20, 1989. The PACT process reactor system consisted of two five-liter reactors identical to those used in evaluating activated sludge. The first functioned as the aeration tank and the second one, in series, as a clarifier. Between the two reactors a 0.5-liter flash-mix basin was installed on April 25, 1989, to condition the reactor effluent. Effluent from the aeration reactor flowed into the flash mix basin where the mixed liquor was conditioned with polymer. This stimulated coagulation and flocculation of the solids and greatly improved settling in the clarifier. Figure 5-8 shows the flow diagram of the bench-scale PACT system.

The PACT system was operated under two separate strategies. The first was designed to effect maximum nitrification. In the second the MLSS were increased up to 50,000 mg/L by adding powdered carbon to test whether nitrification as well as COD and/or TOC removal could be enhanced concurrently.

The reactor was seeded with activated sludge from the Ward's Island WPCP in New York City. For the first two days, the feed to the reactor was a 50 percent mixture of leachate and primary tank effluent from the Ward's Island WPCP. Afterwards, the feed was leachate only. The PACT study lasted approximately five months. The variables evaluated were HRT, carbon dosage rate and MLSS. The powdered carbon used was WPX, provided by Calgon Carbon, Inc. Table 5-5 is a summary of the operating conditions of the PACT

Figure 5-8. Flow Diagram of the Bench-Scale PACT System

TABLE 5-5

OPERATING CONDITION FOR POWDERED ACTIVATED-CARBON TECHNOLOGY (PACT) SYSTEM

Nitrification Only.						
	HRT (day)	MLSS (mg/L)	Carbon Dose (mg/L)	Polymer (mg/L)	Loading (lb/lb.day)	Temperature C
3/20-4/10	1.7	4800	140		0.09	26
4/11-4/24	1.0	5200	140		0.14	26
4/25-5/15	0.6	5000	140	150	0.25	27
5/16-6/02	0.4	4800	140	150	0.40	27
Nitrification + TOC Removal.						
Period	HRT (day)	MLSS (mg/L)	Carbon Dose (mg/L)	Polymer (mg/L)	Loading (lb/lb.day)	Temperature C
7/07-7/20	0.4	50000	3000	300	0.04	29
7/21-8/10	1.0	50000	3000	300	0.015	30

Notes:

During the Nitrification study, sludge wasting to control the MLSS in the reactor was not needed.
 In the Nitrification and TOC removal study, sludge wasting was controlled to achieve the SRT of 20 Days.

system evaluated in this study.

Results. The bench-scale PACT system was initially operated to assess the nitrification of the ammonia-N in the leachate. The powdered carbon was added to provide a site where nitrifying bacteria could grow, and at the same time, be more easily retained in the reactor. This was facilitated by adding a polymer prior to clarification. The increased solids captured by settling were returned as settled sludge to the aeration tank. The carbon addition required higher air flow rates to maintain the carbon and sludge in suspension. The MLSS in the reactor averaged 5,000 mg/L during the first phase of the experiment.

Nitrification was monitored by measuring the ammonia-N in the influent to the aeration tank and in the effluent from the clarifier using an ion selective probe. The oxidized end products, nitrate and nitrite, were measured in the same manner as before by first reducing them to ammonia and measuring the ammonia produced using an ion selective probe. Two other important parameters measured periodically were alkalinity and MLSS. The temperature, the DO in the aeration tank, and the pH were also recorded. Table 5-6 presents the results of the nitrification study. The data are also plotted in Figures 5-9, 5-10 and 5-11.

Figure 5-9 shows that it took approximately two weeks before active nitrification reduced the ammonia below 1 mg/L. During this time

TABLE 5-6

**EFFLUENT CHARACTERISTICS FROM THE POWDERED ACTIVATED CARBON
TECHNOLOGY SYSTEM (Nitrification only)**

Days	NH ₃ N (mg/l)	NO ₃ N (mg/l)	Alkalinity (mg/L as CaCO ₃)	MLSS (mg/l)
HRT = 1.7 Days (Loading: 0.09 lb NH ₃ N/lb MLSS, per day)				
4	450	420	3400	4717
10	400	440	3100	4843
14	10	815	950	5035
16	1.5	820	850	4987
18	0.32	820	900	5078
20	0.35	825	850	5013
HRT = 1.0 Day (Loading: 0.09 lb NH ₃ N/lb MLSS, per day)				
22	150	700	1870	5150
25	8	810	1000	5048
27	0.35	825	900	4989
29	0.67	820	850	5019
32	0.15	820	850	5206
34	0.45	825	900	5043
HRT = 0.6 Days (Loading: 0.25 lb NH ₃ N/lb MLSS, per day)				
36	130	715	1800	5150
39	80	750	1350	5042
41	50	780	1200	4950
46	10	800	1000	4987
50	8	805	950	5105
54	8	810	1000	5063
HRT = 0.4 Days (Loading: 0.40 lb NH ₃ N/lb MLSS, per day)				
56	450	415	3800	5012
58	180	535	2900	4956
61	230	570	2500	4758
64	250	550	2550	4731
69	230	565	2450	4785
72	230	570	2400	4803

Figure 5-9. PACT Process, Ammonia Removal.

Figure 5-10. PACT Process, Nitrification of Ammonia to Nitrates/Nitrites.

Figure 5-11. PACT Process, Alkalinity Reduction During Nitrification.

the HRT was 1.7 days and the carbon dosage was 140 mg/L. Assuming that all the ammonia removed was removed solely through biological oxidation, the nitrification efficiency was greater than 99 percent. This value is much higher than the 72 percent conversion realized by for conventional activated-sludge operating with the same HRT. During this time, nitrate and nitrite increased by approximately 680 mg/L (see Figure 5-10). The ratio of nitrates and nitrites formed, to ammonia removed, is 0.91.

The PACT system was then subjected to a number of various loading conditions by gradually decreasing the HRT to 0.4 days or a maximum load of 0.4 lb NH₃ per lb of MLSS per day. When the HRT was first decreased to one day, the effluent quality initially deteriorated (ammonia increased to 150 mg/L). However, within five days nitrification improved and the effluent ammonia concentration dropped below 1 mg/L. The HRT was further reduced to 0.6 days on day 34 of operation. The effluent ammonia concentration increased rapidly to 130 mg/L, but with time, nitrification improved. The ammonia in the effluent reached a stable value of eight mg/l, corresponding to 98.9 percent nitrification. The system was then stressed one more time, reducing the HRT to 0.4 days. This time the effluent ammonia concentration increased to 450 mg/L. After one week the ammonia concentration in the effluent had dropped to 240 mg/L, corresponding to a nitrification efficiency of 68 percent. The results suggest that complete nitrification of the ammonia in the leachate by the PACT system can be achieved with an

HRT of 0.6 days and MLSS of approximately 5,000 mg/L.

Figures 5-10 and 5-11 show the impact of ammonia nitrification on the production of nitrites, nitrates and alkalinity. Both relate well with ammonia removal as shown in Figure 5-9. The destruction of alkalinity as it relates to the removal of ammonia follows a ratio of 6.3. The pH of the reactor throughout the study was within the range of 8. The temperature recorded varied from 26 to 27°C.

The addition of powdered carbon to the aeration reactor apparently improved the nitrification of ammonia. However, the MLSS did not settle well in the clarifier. The effluent SS averaged 300 mg/L. To improve solids settling in the clarifier, polymer was added to the aeration reactor effluent in a flash-mixer installed upstream of the clarifier. The polymer proved to be an effective coagulant, resulting in improved settling of solids. The effluent SS decreased to approximately 10 mg/L soon after polymer addition was instituted.

After effective nitrification of the leachate was demonstrated, the carbon dosage and the MLSS were increased to assess removal of refractory organic substances, as measured by TOC. The carbon dosage was increased daily until the MLSS reached an average value of 50,000 mg/L. Thereafter, makeup carbon was added to maintain this concentration. The results of the second phase of the

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experiment are shown in Table 5-7 and plotted as Figures 5-12, 5-13 and 5-14.

Figure 5-12 shows that after an initial acclimation period, nitrification of ammonia was almost complete for either an HRT of 0.6 days or one day. The pH was in the range of 8 throughout the experimental run. However, the main concern in this phase of the experiment was TOC removal. Figure 5-13 shows that TOC was reduced from an influent TOC of 550 mg/L to 200 mg/L for an HRT of 0.6 days, and to 140 mg/L for an HRT of one day. The associated removals were 64 and 75 percent, respectively. Because TOC is related to color intensity, color removals were measured for the two HRTs tested and average 90 and 93 percent, respectively. The above removals were realized using a carbon dosage equivalent to 25,000 lb per million gallons (MG) of leachate.

The MLSS were controlled at 50,000 mg/L by adjusting carbon addition and sludge wasting to operate at an SRT of 20 days. Polymer was added to assist in the clarification of the treated leachate. Effluent SS were usually below 10 mg/L.

The PACT system proved to be very effective in nitrifying the leachate, with complete nitrification achievable at an HRT of 0.6 days. This low HRT indicates that smaller reactors which lower capital costs and require smaller sites could be used. Compared to activated sludge, however, the operating cost will be much higher.

TABLE 5-7

CHARACTERISTICS OF THE PACT SYSTEM EFFLUENT
(NITRIFICATION AND TOC REMOVAL)

Day	NH ₃ -N (mg/L)	TOC (mg/L)	Alkalinity (mg/L as CaCO ₃)	MLSS (mg/L)
HRT = 0.6 Day (Loading: 0.04 lb NH ₃ -N/lb MLSS, per day)				
2	120	230	1650	49,542
4	10	210	1100	50,237
5	4	200	1000	49,385
7	3	205	1000	51,382
9	1	203	950	50,847
11	2	200	950	52,295
14	2	200	1000	51,046
HRT = 1.0 Day (Loading: 0.02 lb NH ₃ -N/lb MLSS, per day)				
16	0.35	150	950	52,758
19	0.42	130	900	51,984
21	0.15	140	850	50,637
23	0.65	130	900	49,756
27	0.35	150	900	50,378
29	0.55	130	950	50,845
31	0.23	135	900	48,967
32	0.35	140	900	50,378
34	0.35	135	850	50,278

Figure 5-12. PACT Process (Nitrification and TOC Removal),
Ammonia Removal.

Figure 5-13. PACT Process (Nitrification and TOC Removal), TOC Removal.

Figure 5-14. PACT Process (Nitrification and TOC Removal), Alkalinity Reduction During Nitrification.

The energy requirements will be higher due to the additional air needed to suspend the powdered carbon and the larger volumes of sludge will cost more to dispose of. Increasing the carbon usage rate to effect TOC removal does not appear feasible. The maximum TOC removal achieved was 75 percent at an MLSS of 50,000 mg/L and a carbon dosage of 25,000 lb/MG of leachate. Other processes for TOC removal should be considered to improve efficiency.

5.4 ROTATING BIOLOGICAL CONTACTORS

Rotating biological contactors (RBCs) represented a fixed-film process evaluated in this study. A bench-scale model of an RBC system was constructed. The basin was clear plexiglass and the 8.5-inch-diameter discs, cut to size by Lyco, Inc., one of a number of RBC manufacturers, were made of the same material used in full-scale facilities. The RBC system consisted of four stages. Each stage had a width of four-inches and consisted of six discs, each spaced half an inch apart. The total surface area of the discs was 18.9 sq ft.

Startup of the RBCs began with seeding the system with activated sludge mixed liquor solids from the Ward's Island WPCP. As soon as the four stages were filled with returned sludge, rotation of the discs was initiated. The feed of the RBC system was a mixture of 50 percent leachate and 50 percent primary tank effluent from the Ward's Island WPCP. After the first day of operation, the feed was

changed to 100 percent of leachate. The evaluation of the RBC system started on March 15, 1989. The bench-scale model operated continuously through June 16, 1989.

Results. The RBCs were initially rotated at two rpm. At this speed, the level of turbulence was low and the solids began to accumulate and settle in the four stages since flow from one stage to the next was over a surface weir. Settling of solids could create potential operation problems through accumulation and subsequent anaerobiosis. Therefore, after 12 days the rotational speed was increased to 5.5 rpm. This rotation rate kept most of the solids in suspension and moving from one stage to the next, eventually flowing from the RBC system to a downstream clarifier. At this higher rpm, data began to be collected more frequently in order to assess the nitrification process. The results are shown in Figure 5-15.

The Figure 5-15 shows that between the 20th and 40th day the effluent ammonia averaged 340 mg/L compared to an influent of 690 mg/L. During this time, the discs were rotated at an average rate of 5 rpm and loaded at 0.944 lb/day/1,000 sq ft. Close examination of the disc indicated that some biological slime had developed, but it appeared uneven and almost absent in some sections. Since nitrification was not improving it was decided to decrease the loading rate and increase the rotational speed to six rpm.

Figure 5-15. Rotating Biological Contactors, Ammonia Removal.

The new loading rate, 0.37 lb/day/1,000 sq ft, was maintained for approximately 17 days. The ammonia concentration in the effluent dropped to essentially less than one mg/L. A corresponding decrease in alkalinity took place as shown in Figure 5-16. The two concurrent events indicated that nitrification was taking place. The biofilm on the discs also became more uniform at higher rpm. Having achieved nitrification, it was then decided to double the ammonia loading to 0.74 lb/day/1,000 sq ft. However, the speed of rotation was also increased to maintain a high DO. The degree of nitrification remained essentially the same. The DO in the RBC effluent was above six mg/L.

The ammonia loading was further increased to 1.21 lb/day/1,000 sq ft and the disc speed was increased to 18 rpm. An initial deterioration was observed on the 70th day. Though effective nitrification appeared to resume and the ammonia dropped below five mg/L, this proved to be an unstable operating level and nitrification began to deteriorate. It was observed that the DO in the RBC effluent had decreased to less than 2.5 mg/L. Attempts to increase the DO by increasing the speed of rotation up to 24 rpm did not correct the situation. It appears that oxygen transfer may have become the limiting factor for nitrification. Throughout the experimental run the pH was always above 7.5.

The bench-scale RBC demonstrated that nitrification can occur at higher ammonia loadings, greater than the approximately 0.3

Figure 5-16. Rotating Biological Contactors, Alkalinity Reduction During Nitrification.

1b/day/1,000 sq ft used for municipal wastewaters. The data also suggested that DO may become a limiting factor. However, since the RBC is a low energy use system, further evaluation at pilot-plant scale is warranted. A disadvantage of the process was the relatively long time required to establish a biofilm on the discs. This may be due to the fact the disc surfaces were flat and smooth. It is recommended that, for a pilot-plant study, the media configuration used should resemble that used in full-scale operations.

5.5 CHEMICAL COAGULATION

Chemical coagulation was not specifically evaluated during the bench-scale studies. However, chemical coagulation using alum and a polymer was used to pretreat the leachate prior to the dynamic carbon adsorption tests. Using a batch system, 20 gallons of leachate were treated at one time. The coagulants used were alumn at 200 mg/L and polymer CAT-FLOC 8964 at 300 mg/L. This combination of coagulants was effective in reducing both TOC and color from the Fresh Kills Landfill leachate. The sludge volume produced during chemical coagulation was 62 ml/L of leachate at a dry solids concentration of 1.4 percent.

The flocculated solids settled well. Figure 5-17 shows the relationship of supernatant turbidity as a function of overflow rate. The data indicates that an overflow rate of 500 to 600 gpd

Figure 5-17. Turbidity Removal Related to Overflow Rate.

TABLE 5-8

EP TOXICITY: SLUDGE SAMPLE FROM CHEMICAL COAGULATION OF LEACHATE

Parameter	Concentration (mg/L)
Arsenic	<0.294
Barium	<0.20
Cadmium	<0.005
Chromium	0.03
Lead	<0.124
Mercury	<0.0002
Selenium	<0.386
Silver	<0.01
Cyanide	<0.01
Herbicides:	
2,4-D	<0.002
2,4,5-Tp (Silvex)	<0.0005
Pesticides:	
Lindane	<0.00025
Endrin	<0.0005
Methoxychlor	<0.0025
Toxaphene	<0.005

Note:

The coagulants used were alum at 200 mg/L and CAT-FLOC polymer at 300 mg/L.

per sq ft should reduce the turbidity by 60 to 70 percent.

The sludge produced during the coagulation of the leachate was sampled and analyzed by H2M Labs, Inc. for EP toxicity. The results, shown in Table 5-8, indicated that the concentrations are below the standards established by EPA.

Chemical coagulation is thus a viable process that can reduce both TOC and color. The sludge produced does not require special handling and disposal.

5.6 ACTIVATED CARBON ADSORPTION

The design of activated carbon adsorption began with a series of bench-scale tests to determine proper design criteria. The tests were used to confirm level of treatment, to estimate the carbon usage rate and to evaluate pretreatment operations that may be used to optimize the adsorption process. In this study the tests performed were a series of isotherm tests followed by a dynamic column test. The isotherm tests were used to screen the different pretreatment processes as they affect adsorption. The optimum pretreatment process was selected and used to treat the leachate. The pretreated leachate was then pumped through a series of columns containing granular carbon. The breakthrough curves from the granular carbon columns were analyzed to develop the design criteria for a full-scale carbon adsorption facility.

5.6.1 Isotherm Tests

Adsorption isotherms were developed for raw and pretreated leachate. Isotherms for raw leachate were used to estimate a baseline carbon usage rate, which was then used to compare the savings in carbon usage with the different pretreatment alternatives. The cost of pretreatment compared to the savings in carbon was used as a criterion for adopting the particular treatment sequence.

All isotherm experiments were performed on a mechanical shaker at a speed sufficient to maintain the powdered carbon in suspension. Leachate was mixed with predetermined amounts of carbon in 200 ml Erlenmeyer glass flasks that were covered with parafilm to prevent splashing during shaking. The isotherm experiments were performed in the laboratory where the temperature varied from 22 to 26°C.

An important variable for developing isotherms is the contact time required to reach equilibrium. Sometimes this value is set high, at 0.5 to one day, in order to assure adsorption equilibrium. Since many tests were to be performed, it was decided to conduct an initial test to determine the minimum time required to reach equilibrium. Using powdered carbon and raw leachate an experiment was performed to measure TOC in solution as a function of contact time. Figure 5-18 shows the decreasing percent TOC remaining in the liquid phase with time. The TOC in the liquid phase dropped to

Figure 5--18. Contact Time to Adsorption Equilibrium.

55 percent after 10 minutes, but the curve becomes relatively flat, decreasing to 45 percent after 1.5 hours. A contact time of two hours is apparently sufficient to reach equilibrium and therefore, two hours was used as the contact time for all further isotherm experiments.

The procedures used to develop all isotherms in this study were as follows:

- Set up eight to ten flasks and add a selected amount of powdered carbon to each flask (0.1 to 7.0 g). Include a control flask with no carbon;
- Add an equal amount (50 to 100 ml) of the leachate to each flask and place the flasks on a shaker table;
- Shake the flasks for two hours, the time determined in the initial experiment to attain equilibrium;
- Filter the samples to remove the powdered carbon and analyze the filtrate. Determine the TOC remaining in solution in each flask, the value C , and the TOC in the control sample, the value C_0 . The mass of TOC adsorbed by the carbon is calculated as the difference between the initial and remaining concentration ($C_0 - C$) multiplied by the volume of leachate, namely:
$$X = (C_0 - C) \times (\text{Volume of leachate in liter.});$$
- Tabulate the data. Divide the value of X obtained, by the weight (M) of carbon used to obtain the quantity (X/M), which is the amount of TOC adsorbed per unit weight of carbon; and
- On Cartesian coordinate paper, plot the values of $\log C$ on the abscissa and $\log (X/M)$ on the ordinate. Draw a least-squares fitted curve. Alternately, use log-log paper to plot curves of X/M versus C .

Isotherms characterizing a large matrix of conditions had been obtained in the course of this study to elucidate the effects of the activated carbon type, molecular weight of the organics in the

leachate, pretreatment and pH on the adsorption. The data generated are presented in the following sub-sections.

5.6.1.1 Effect of Carbon Type on Adsorption

The adsorption characteristics of activated carbon depend on the source material and the process of activation. To assess the feasibility of using carbon to treat the Fresh Kills Landfill leachate, it was first necessary to select an appropriate commercially available carbon. In discussions with Calgon Carbon, Inc., a major vendor in the country, two carbons were recommended, F300 and WPX. Samples of both carbons were made available and tested by developing corresponding isotherms following the procedures described. The isotherms for the two carbons are presented in Figure 5-19.

The isotherms show that both carbons can be used to reduce the TOC in the leachate. However, the isotherm of carbon WPX lies above the isotherm of carbon F300 over the entire range of concentrations investigated. This indicated that, for the equilibrium TOC concentration, the amount of TOC adsorbed per unit weight of carbon will be greater for carbon WPX than for carbon F300. In Table 5-9, the adsorption capacity of WPX ($(X/M)_o = 80.1$ mg TOC/g carbon) is about two times that of F300 ($(X/M)_o = 41.1$ mg TOC/g carbon). Therefore, the estimated carbon dosage of WPX would be half of the dosage of F300 to treat the same volume of leachate. Furthermore,

Figure 5-19. Adsorption Isotherms for Two Different Carbons.

TABLE 5-9

EFFECT OF CARBON TYPES ON ADSORPTION ISOTHERMS

Type of Activated Carbon	Freundlich constants		Influent TOC, C_o . (mg/L)	Adsorption Capacity (X,M), (mg TOC/gm Carbon)
	1/n	K		
WPX	0.62	1.75	480.1	80.10
F300	0.47	2.24	480.1	41.10

Notes:

Freundlich isotherm equation: $X/M = K \cdot C^{1/n}$

pH = 8.3; Temperature = 25 °C

Adsorption Capacity X/M at $C = C_o$

TABLE 5-10

EFFECTS OF MOLECULAR WEIGHT ON ADSORPTION ISOTHERMS

Molecular Weight	Freundlich constants		Influent TOC (mg/L)	Adsorption Capacity (X,M), (mg TOC/gm Carbon)
	1/n	K		
Raw Leachate	0.47	2.24	488.2	41.20
Leachate with Adsorbates:				
Less than 30K ^a	0.52	1.78	444.5	42.35
Less than 5K	0.64	1.55	350.4	63.59
Less than 1K	0.72	1.44	270.3	62.43

Notes:

Freundlich isotherm equation: $X/M = K \cdot C^{1/n}$

pH = 8.3; Temperature = 25 °C; Type of PAC: F300

^a30K => Molecular weight of 30,000.

=> K = 1000 Atomic Mass Units

the isotherm for carbon WPX has a steeper slope ($1/n = 0.62$). In general, carbons that exhibit steep isotherms are more efficient for column application than are carbons with flat isotherms.

Because carbon WPX offers the above and is less expensive than F300, carbon WPX was recommended for future adsorption studies.

5.6.1.2 Effect of Molecular Weight of Organic Contaminants on Adsorption

The molecular weight distribution of the organic contaminants in the leachate, as measured by TOC, was determined using ultrafiltration membranes manufactured by Amicon, Inc. Several molecular weight fractions were obtained and each fraction was then subjected to an isotherm test.

Isotherms for different molecular weight fractions of leachate (raw leachate, less than 30,000 mol wt, less than 5,000 mol wt, less than 1,000 mol wt) are given in Figure 5-20 and Table 5-10.

For the same carbon type (F300), adsorption capacities varied with the change of molecular weight remaining in the leachate. The adsorption capacity of the lower-molecular-weight fraction was higher than that for the untreated leachate. Significant differences in the ultimate adsorption capacity between the raw leachate and the filtrate appeared when the fraction of MW 5,000 to

Figure 5-20. Effect of Molecular Size on Carbon Adsorption.

30,000 was removed. Any process, such as chemical coagulation, that can remove the high MW fraction will favorably affect adsorption by decreasing the carbon usage rate. In contrast, biological processes, which generally remove lower MW fractions, would not improve adsorption. Biological pretreatment, therefore, may not be beneficial as a pretreatment process for removal of organic contaminants by activated carbon adsorption.

5.6.1.3 Effect of pH on carbon Adsorption

The pH is an important factor that influences adsorption. This is partly because the hydrogen ions are strongly adsorbed and partly because pH influences the ionization and the adsorption of many compounds. The relative ease of adsorption can vary with different functional group compounds, and the pH of the solution. Table 5-11 outlines the factors affecting adsorption. Due to the large number of factors affecting adsorption on activated carbon, the optimum pH for any wastewater should be determined experimentally.

In this study, different pH conditions using two types of PAC were tested. The pH ranges evaluated varied from 4 to 11. The results of this study are plotted as isotherms in Figures 5-21 and 5-22 and summarized in Tables 5-12 and 5-13. Five families of curves of roughly equal slopes but different vertical distributions were obtained for each type of carbon. This is indicative of different adsorptive affinities. The displacements between curves indicate

TABLE 5-11

FACTORS AFFECTING EQUILIBRIUM ADSORBABILITY

Compound Adsorbability Favored by:	
1.	Increasing carbon chain length ^a
2.	Increasing aromaticity
3.	Decreasing polarity
4.	Decreasing branching
5.	Decreasing solubility
6.	Decreasing degree of dissociation
Functionality:	
Relative adsorbability: acids > aldehydes > esters > ketones > alcohols > glycols > when number of carbon atoms is < 4	
pH Effects:	
Undissociated species are more easily adsorbed	
- Low pH favors the adsorption of acids (e.g., volatile acids, phenols) ^b	
- High pH favors the adsorption of bases (e.g., amines)	
Other compounds: Adsorption can be favored by higher pH	
- Postulated general effect: Partial neutralization of surface activity reduces hydrogen-bonding of surface groups eliminating steric blockages of micropores	
Temperature:	
1.	Increased temperatures can increase rate of adsorption due to viscosity and diffusivity effects
2.	Exothermic adsorption reactions are favored by decreasing temperatures usually, a minor effect on equilibrium level.

Notes:

^a When this rate is controlled by intraparticle transport, decreasing molecular size would result in faster rate, all being equal.

^b This is often the most significant pH effect so adsorption generally is generally increased decreasing pH.

Adapted from Handbook Remedial Action at Wastes Disposal Sites (Revised)
Environmental Protection Agency (EPA) EPA/625/6-85/006.

Figure 5-21. Effect of pH on Carbon Adsorption : WPX.

Figure 5-22. Effect of pH on Carbon Adsorption : F300.

TABLE 5-12

EFFECTS OF pH ON ADSORPTION ISOTHERMS (CARBON: WPX)

pH	Freundlich constants		Influent TOC (mg/L)	Adsorption Capacity (X,M), (mg TOC/gm Carbon)
	1/n	K		
4.1	0.57	3.98	468.6	132.5
6.8	0.59	2.57	468.6	96.7
8.3	0.62	1.74	481.4	80.1
9.5	0.68	1.35	473.7	89.05
10.9	0.76	0.72	473.7	77.75

Notes:

Type of PAC: WPX Temperature: 25 °C

Freundlich Isotherm Equation: $X/M = K \cdot C^{1/n}$

TABLE 5-13

EFFECTS OF pH ON ADSORPTION ISOTHERMS (CARBON F300)

pH	Freundlich constants		Influent TOC (mg/L)	Adsorption Capacity (X,M), (mg TOC/gm Carbon)
	1/n	K		
4.1	0.47	3.72	468.6	67.1
6.8	0.48	2.63	468.6	50.3
8.3	0.47	2.24	488.2	41.1
9.5	0.49	1.95	473.7	39.9
10.9	0.57	1.12	473.7	37.5

Notes:

Type of PAC: F300 Temperature: 25 °C

Freundlich Isotherm Equation: $X/M = K \cdot C^{1/n}$

the impact of the pH on adsorptive behavior. The results indicated that, for the same type of carbon, the adsorptive capacity at low pH is higher than at high pH. For example, the adsorption capacity of PAC can be increased by 21 percent and 65 percent for WPX, when the pH of leachate is reduced to 6.8 and 4.1, respectively.

The influence of pH on the removal of TOC from the leachate was similar for both carbons. Adsorption capacity increased with decreasing pH of the leachate.

The influence of pH is complex, as both the surface charge of the carbon and the degree of dissociation of the organic contaminants are affected. The adsorption behavior of a complex mixture such as the leachate as a function of pH is difficult to explain. However, if the organic materials in the leachate are classified as humic substances, an analysis of the physical and chemical characteristics of humic substances may help explain the observed behavior of leachate as pH changes. The humic substances are usually grouped into two broad categories of organic acids: fulvic acids and humic acids. The predominant chemical compositions of humic substances are aromatic somewhat aliphatic and hydrophilic compounds with the functional groups of carboxyl, phenolic, alcoholic, ketonic, carbonyl, methoxyl, and quiconoid groups. The influence of pH on the adsorption behavior of PAC may stem from the acidic character of a fraction of the organics being removed, since the ionic form of carboxylic acid is more poorly adsorbed than the

un-dissociated acid molecules. Lowering the pH of the leachate results in the predominance of the un-dissociated forms that exhibit more effective adsorption. In other studies the adsorption of several aromatic acids showed a very strong dependence on pH. As pH was increased from 5 to 9, the adsorption capacity of phenoxyacetic acid decreased by a factor four to five (24).

As the pH is increased, the carbon surface becomes more negatively charged (because weakly acidic functional groups on the carbon surface dissociate) and weakly acidic groups (such as phenolic groups) in the organics found in leachate dissociate, rendering the organics more negative. This will tend to bring a reduction in adsorption capacity as the pH is increased. At the higher pH values, it is possible that hydroxyl (OH) adsorption could also occur, further reducing the adsorption capacity.

5.6.1.4 Effect of Leachate Pretreatment on Carbon Adsorption

Although carbon adsorption is an efficient process in removing various organic contaminants, it is expensive. Pretreatment prior to adsorption is often undertaken to reduce the organic load on the carbon. Unfortunately, characteristics of the organic compounds may be changed altering their adsorptive properties. If pretreatment of the leachate reduces the load to the activated carbon columns, thereby extending the life of the columns, it may reduce the overall treatment costs. However, if the organic matter

removed by pretreatment is more adsorbable than that remaining after pretreatment, or if the organic matter remaining after pretreatment is chemically or physically altered so that it is not as strongly adsorbed as it would have been prior to pretreatment, it is quite possible that bed life will decrease rather than increase, resulting in increased regeneration frequency and higher overall treatment cost.

In order to predict the effect of pretreatment on a subsequent adsorption process, it is first necessary to compare the adsorptive capacity of the carbon in both the untreated and pretreated leachate. Two pretreatment technologies commonly used in leachate treatment are chemical and biological treatment.

Since the adsorption of leachate by two types of carbon had previously been evaluated, and since this discussion focuses only on the variables associated with the pretreatment processes, only the better of the two carbons (WPX) was used. Adsorptive capacity, rather than the rate of adsorption, was used as the primary measure of the effect of pretreatment on adsorption.

Biological pretreatment for adsorption. Biological pretreatment was provided by rotating biological contactors. The effectiveness of RBC pretreatment in terms of nitrification and TOC removal is indicated in Table 5-14. The isotherm results of the biologically pretreated leachate are shown in Figure 5-23 and Table 5-15. Its

TABLE 5-14

PRETREATMENT BY ROTATIONAL BIOLOGICAL CONTACTORS (RBCs)

Reactor Data	Rev. per minute	18
	Flowrate, Q	10 ml/min
	Temperature	23 °C
Parameter	RBC Influent	RBC Effluent
Alkalinity (mg/L as CaCO ₃)	5450	1700
NH ₃ -N (mg/L)	720	50
pH	8.0	8.0
TOC (mg/L)	503	410.5

TABLE 5-15

EFFECTS OF PRETREATMENT FOR ADSORPTION ISOTHERMS

pH	Freundlich constants		Influent TOC, C ₀ . (mg/L)	Adsorption Capacity (X, M), (mg TOC/gm Carbon)
	1/n	K		
8.3 (Raw Leachate)	0.62	1.74	481.4	80.1
Adjust pH to 5.9 prior to Coagulation	0.97 1.04	0.62 0.31	293.7 350.6	153.5* 137.2**
7.81 (After RBC)	0.77	0.664	410.5	68.3
5.6 After RBC and Coagulation	1.17	0.25	250.5	159.8*

Notes:

*Alum (200 mg/L) and polymer (300 mg/L) as coagulants

**Alum (300 mg/L) the only coagulant

Type of PAC: WPX Temperature: 25 °C

Freundlich Isotherm Equation: $X/M = K \cdot C^{1/n}$

Figure 5-23. Effect of Biological Pretreatment on Carbon Adsorption.

adsorption capacity was as low as the one for raw leachate. Cook and Foree (25) and Pohland and Kang (26) found that activated carbon resulted in higher COD removals from biologically pretreated leachate than that from the raw leachate. The present results are contrary to those of Cook et al., because of different leachate characteristics. In the research of Cook et al., leachate from young landfills contained high concentrations of low molecular weight (MW) volatile fatty acids, which are highly degradable but of low adsorptive capacity. Biological processes can remove this fraction of organics, and thus, result in higher adsorption capacities. However, for the leachate landfills of intermediate age such as the Fresh Kills Landfill, the organic matter composition is comparable to the effluent from biological units treating leachate from young landfills. The organic matter in the stabilized, aged leachate cannot be reduced further by biological processes. The organic composition of the raw leachate from the Fresh Kills Landfill was not significantly affected using the RBC system as measured by TOC, although the RBC system was effective in removing ammonia nitrogen. Therefore, the adsorption capacity of the RBC effluent appeared to remain similar to that of the raw leachate.

Chemical Pretreatment for Adsorption. Prior to coagulant addition, sulfuric acid was used to lower the pH of the leachate to within a range of five to six. Alum and alum-polymer were separately used as coagulants for chemical pretreatment. The conditions and

results of chemical pretreatment were given in section 4.1. Chemical coagulation reduces both the TOC and color from the leachate. The process is more effective in removing macromolecules from the leachate, resulting in a higher adsorption capacity on activated carbon.

Adsorption isotherms before and after coagulation are shown in Figure 5-24, and Freundlich isotherm parameters under various conditions are listed in Table 5-15. The capacity of the carbon WPX to adsorb TOC after the leachate was pretreated with alum or alum-polymer was markedly increased. In the alum-polymer combination, the carbon adsorption capacity, it could be increased if the effluent were chemically pretreated with alum and polymer. Since nitrification destroys alkalinity, biological pretreatment offers a positive side benefit because it reduces the amount of acid required for pH reduction. If both TOC and ammonia must be removed, nitrification should precede chemical coagulation to take advantage of the alkalinity in the untreated leachate. Nitrification will destroy a significant amount of alkalinity, which in turn reduces the amount of acid required to lower the pH during chemical coagulation.

5.6.2 Dynamic Column Tests

The carbon adsorption isotherms were analyzed and chemical coagulation of the leachate was determined to be the best

Figure 5-24. Effect of Chemical Pretreatment on Carbon Adsorption.

pretreatment alternative. In order to determine the feasibility of chemical-physical treatment, a continuous flow bench-scale evaluation of a "complete system" was conducted. The process flow diagram used is shown schematically in Figure 5-25.

The treatment began with batch coagulation and settling in the same reactor. Alum and polymer were added to the raw leachate at the optimum dosages of 200 mg/L alum and 300 mg/L CAT-FLOC 8964. After a two-minute flash mixing, the mixture was flocculated and allowed to settle, producing a clear supernatant. The supernatant was then filtered through sand media to remove the residual SS and the filtered water was then pumped through four columns containing granular activated carbon. The objective of this experimental run was to exhaust one of the columns while collecting data from the remaining three to plot breakthrough curves.

The four columns were each three-feet tall and one inch I.D., surrounded by a water jacket, filled with "carbon react-C" as manufactured by Calgon, Inc., and connected in series. The flow rate through the columns was controlled by a peristaltic pump at a rate of 30 ml per minute. The empty volume contact time in each column was approximately 15 minutes.

The granular carbon was soaked in distilled water for 24 hours prior to charging the columns. Periodically the carbon slurry was mixed to degas the carbon and remove the fines. The columns were

**Figure 5-25. Flow Diagram of Bench-Scale
Physical-Chemical Treatment of Leachate**

charged with the carbon slurry in small increments, always keeping a thin layer of supernatant liquid above the carbon during charging. During this process and throughout the experimental run the temperature was maintained at 22 °C by circulating water from a temperature controlled water bath through the water jackets around the columns. Water samples collected between each column were analyzed for TOC and intermittently for color and pH.

Using the TOC data, breakthrough curves were plotted for each column separately. The run continued until fully developed breakthrough curves were obtained, that is, until the first column effluent TOC concentration approached the influent concentration. At this time, the run was terminated. The carbon from each column was removed, dried and weighed. The amount of carbon in each column was:

Column 1:	261 g
Column 2:	258 g
Column 3:	241 g
Column 4:	260 g

All data collected during this phase of the study was based on a chemically pretreated leachate. Table 5-16 shows that the leachate initially had a TOC of 548 mg/L and a pH of 8.3. Sulfuric acid was used to lower the pH to 5.8. The acidified leachate was then chemically coagulated with alum and polymer. After flocculation, gravity settling and sand filtration, the TOC was reduced to 345

TABLE 5-16

LEACHATE TREATMENT USING CHEMICAL COAGULATION AND CARBON ADSORPTION

Unit	Dosage	Operating Conditions	Result		
			Characteristic	Influent	Effluent
pH Adjustment	96% H_2SO_4 2.3 mg/L		pH	8.3	5.8
Coagulation	Alum, 200 mg/L Polymer 8964 300 mg/L	HRT 30 minutes	TOC, mg/l	548 mg/L	
Sedimentation		HRT 60 minutes	pH TOC, mg/L Color Units Sludge, ml/L	5.8 3000	5.8 347 300 62
Filtration		Flowrate 100 ml/min	pH TOC, mg/L Color Units	5.8 347 300	5.9 345 300
Adsorption	Carbon React-C	HRT 60 minutes Hydraulic Flowrate 1.45 gpm/ft ²	pH TOC, MG/L Color Units	5.9 345 300	6.0 50 30

mg/L, a reduction of 37 percent. The color was reduced to 300 colorimetric units, a reduction of 90 percent. The pretreated leachate was then pumped through the carbon columns to develop the breakthrough curves for use in developing full-scale design criteria.

5.6.2.1 Column Adsorption Results

Figure 5-26 shows the breakthrough curves developed from the carbon column data by plotting the effluent concentration compared to the volume processed for each column. To calculate the number and size of the carbon columns required, the mass transfer zone, contact time and carbon usage rate were determined.

Empty-Bed Contact Time (EBCT). The rate of adsorption is a function of residence time. For the purpose of developing a preliminary design, it was assumed that the effluent would show 85 percent TOC removed by the adsorption step. A horizontal line that intersects the breakthrough curves at the desired concentration, TOC = 50 mg/L, was drawn to determine the breakthrough volume for each column. The EBCT was determined from the following equation:

$$EBCT = \frac{(\text{bed depth (ft)}) \times 7.48}{(\text{hydraulic surface loading [gpm/sq ft]})}$$

Figure 5-26. Activated Carbon Adsorption Breakthrough Curves.

Carbon Usage Rate. Carbon usage is determined from the equation :

$$\text{Usage rate (lb/1,000 gal)} = \frac{(\text{weight of carbon column (lb)})}{(\text{Volume throughput at breakthrough (gal)}) \times 1,000}$$

Data from Figure 5-26 was used to construct an EBCT/carbon usage curve. The plot of the carbon usage rate in lb of carbon per 1,000 gal of leachate treated versus EBCT is shown in Figure 5-27.

The carbon usage rate decreases rapidly with increasing EBCT, as depicted in Figure 5-27, and it approaches a constant value at high EBCT. The lower carbon usage rate is obtained at a 60 minute contact time. It can also be seen from Figure 5-27 that increasing the EBCT beyond this value results in a minor reduction in usage rate. Therefore, an EBCT of 60 minutes was selected for design purposes.

The Mass Transfer Zone (MTZ). The mass transfer zone (MTZ) is another important factor in determining carbon column configuration. The MTZ is the critical bed depth required to prevent the effluent solute concentration from exceeding the desired breakthrough concentration. For an 85 percent TOC removal using the adsorption process, the MTZ is determined as follows: in Figure 5-26 when the first column was exhausted at 245 liters, all adsorption was taking place in the remaining three columns. Thus the MTZ is approximately nine feet (12 feet total minus three feet of the exhausted first column). This is the minimum design carbon

Figure 5-27. Carbon Usage Rate Versus Residence Time.

bed depth that would facilitate a lower carbon usage rate.

Carbon Capacity in Dynamic Columns. The usage rate curve in Figure 5-27 is based on a system that uses a single carbon column. The purpose of obtaining breakthrough curve is to obtain data that allows one to design an adsorption system to approach complete carbon exhaustion prior to replacement. It may be advantageous to use two or more smaller columns operated in series rather than one large column containing the same amount of carbon. In the series system, once the MTZ had passed from the first column to the second column, the carbon in column one is exhausted and should be replaced. Thus, the carbon required per 1,000 gal treated will be less than if a single, large column was used and replacement of all the carbon was determined by column breakthrough. In Figure 5-26, when column four reached breakthrough (EBCT = 60 min), the carbon in column one was almost exhausted and the TOC in the effluent approached 90 percent of the influent TOC. The carbon dosage in column one was determined from the breakthrough curves. The dosage rate equals the area between the influent and effluent concentration profiles up to the point representing exhaustion of column one, which represents the mass of TOC removed divided by the weight of carbon in column one as shown in Figure 5-27. The carbon dosage or capacity, (X/M) , equaled 118.6 mg TOC/g carbon. Therefore, this usage rate will be used to determine the columns in series for preliminary design of full-scale operation.

From the above data analysis, a summary of carbon adsorption for dynamic system can be given.

Contact time	=	60 min.
MTZ	>	9 ft
Carbon usage (for 85 percent TOC removal)	=	118.6 mg TOC/g

All the bench-scale studies can now be reviewed and evaluated prior to developing a treatment train for the Fresh Kills Landfill leachate.

5.7 RECOMMENDED TREATMENT TECHNOLOGIES

The technologies evaluated in the bench-scale study fall into two categories. The first category consisted of biological processes designed to effect nitrification of the leachate. These processes were monitored primarily by measuring ammonia in the influent and effluent from each reactor. The second category consisted of physical/chemical processes designed to reduce the concentration of refractory organic contaminants as measured by TOC. The results of the bench-scale studies have been presented in the previous sections. In this section the recommended treatment technologies for each category are identified.

5.7.1 Biological Nitrification

Biological nitrification of the leachate was demonstrated using several types of reactors that supported suspended growth as well

as fixed films. Some important general conclusions include:

- Biological nitrification can reduce the ammonia concentration from the initial level of 750 to 800 mg/L to less than 10 mg/L;
- The leachate contains sufficient alkalinity to maintain the pH above 7.5 throughout the nitrification process;
- No inhibition of nitrification was evident in any of the studies;
- Biological nitrification has a minimal impact on organic contaminants. The reduction in COD was in the range of 20 to 30 percent;
- Nitrification is sensitive to the concentration of DO in the reactor. It appears that the DO should be maintained at higher than 3 mg/L;
- The ability to maintain a high DO may limit the ammonia loading in some of the reactors. For example, in the activated sludge process, increasing the aeration rate to maintain a high DO produces severe turbulence that breaks down the size of the floc. A pin-point floc has poor settling characteristics, which can ultimately result in a solids washout from the reactor. In the RBC system, the oxygen transfer rate limits the ammonia loading rate that can be used;
- Ammonia loadings higher than those available in the literature were demonstrated for all the treatment technologies. This is very significant since it affects the size of the facility, which directly affects the capital costs of the treatment plant;
- All experiments were performed indoors where the temperature varied from 22°C to 28°C;
- Biological nitrification produces less sludge compared to conventional activated sludge. In the bench-scale experiment no intentional sludge wasting was necessary because the low SS carry over in the effluent water were sufficient to maintain a stable concentration in the reactor; and
- Prior to full-scale design, a pilot study of the selected technology is recommended.

The preceding conclusions are based on the bench-scale evaluation of the conventional activated sludge process, the SBR, PACT, and RBC systems. However, each technology may contain inherent benefits that warrant further consideration.

The SBR system demonstrated that ammonia can be reduced to less than 10 mg/L. The process appears to have additional benefits in combining aeration and settling in one tank. It can potentially result in a higher recovery of solids and smaller site requirements. The aeration period can also be varied to achieve different treatment objectives. The loss of suspended solids is a major concern with SBRs in treating the leachate because frequent excursions of high SS in the decant water were observed in the bench-scale studies mentioned earlier. In addition, nitrifying biomass may periodically exhibit poor settling, which in a full-scale facility could mean loss of solids and violation of discharge permit limits for SS. Nevertheless, SBR systems have been adopted for leachate treatment at other sites, but not necessarily for nitrification. Because of the process's inherent benefits of lower cost and reduced site requirements, the SBR system was retained for further consideration.

The PACT system was evaluated for both nitrification only and nitrification and TOC removal. Powdered carbon serves as a site for nitrifying bacteria to grow. The carbon can also adsorb chemicals that may inhibit nitrification when the chemicals are

present in the leachate. The PACT process proved quite reliable for nitrification of the leachate. The drawbacks include the cost of the carbon, which must be replaced continuously, and the production of more sludge, which results from the continuous addition of fresh powdered carbon. Additionally, the powdered carbon had to be conditioned with a polymer to achieve clarification in the downstream secondary tank. When carbon dosage was increased to effect TOC removal in addition to nitrification, several concerns were evident. The MLSS had to be increased to approximately 50,000 mg/L to effect TOC removal. Considerable energy had to be expended to sustain the solids in suspension. The high MLSS also caused clogging of the diffuser which had to be replaced periodically. The maximum TOC removal achieved was 75 percent. Based on these results, and considering the high cost of energy and carbon, it is recommended that PACT be retained for further consideration for nitrification only. Other technologies should be considered for TOC removal.

RBC systems have been used for BOD removal and ammonia nitrification. The bench-scale experiment has demonstrated good results with high ammonia loadings, which can potentially exceed 1.21 lb ammonia per day per 1,000 sq ft of disc area. DO appears to be a limiting factor. The process was retained for further consideration primarily because of the low energy usage. However, it is recommended that, during any pilot study, aeration of the leachate in each of the cells be evaluated by using either full-

size discs or by preaerating the leachate to DO saturation prior to input to the RBC system. In a full-scale treatment facility, aerated discs could be used to increase the DO availability.

The treatment trains considered in the next section include SBR, PACT, and RBC systems for nitrification of the ammonia in the leachate.

5.7.2 Physical-Chemical Treatment

The physical-chemical technologies evaluated were designed to remove TOC. The polishing operation, the last process in the treatment train, is activated carbon adsorption designed to remove TOC. The treatment train should, therefore, include those processes that minimize both the size of the carbon adsorption reactors and the carbon usage rate. Of the pretreatment processes evaluated only pH adjustment and chemical coagulation significantly impacted the carbon usage rate. A preliminary cost analysis is performed to select the pretreatment operations in a full-scale treatment facility.

Chemical coagulation with alum, or alum and polymer, was more efficient at low pH. Since chemical coagulation tends to remove high-molecular-weight organic compounds, it produces a process water that has high adsorption capacity. The selection of pretreatment must consider operating and maintenance costs. Table

5-17 is a summary of several treatment alternatives using activated carbon adsorption.

The first alternative considered was to treat the leachate only with carbon. In this case, no pretreatment is used and the cost of treatment would be \$37.50 per 1,000 gallons. In the second alternative, the leachate would be pretreated using alum coagulation. Considering the cost of sulfuric acid to lower the pH, the alum, the sludge produced, and savings in carbon usage, the overall treatment cost is \$17.12 per 1,000 gallons. The third alternative is similar to alternative two, but it uses alum and polymer as the coagulants. The overall treatment cost is reduced to \$13.80 per 1,000 gallons.

The most feasible method to remove TOC from the leachate is to first lower the pH to $5.5\pm$, use alum and polymer as the coagulants and polish by carbon adsorption. This treatment sequence is retained for further consideration in developing treatment alternatives in the next section.

TABLE 5-17

TREATMENT COST ESTIMATES FOR VARIOUS CHEMICAL PRETREATMENT PROCESSES AND CARBON ADSORPTION*

Treatment Alternative	Chemical Cost \$/1000 gal	Carbon Cost \$/1000 gal	Sediment Disposal Cost \$/1000 gal	Total Cost \$/1000 gal
GAC only	-	37.50	-	37.50
Alum and GAC	0.94	15.98	0.20	17.12
Alum, GAC and Polymer	1.47	11.98	0.40	13.85

*Assumed Unit Costs (1000 USG):

Liquid alum = \$0.055/lb; Polymer = \$0.23/lb; Sulfuric Acid = \$60.00/lb; GAC = \$0.75/lb.

From Table 5-17: For GAC only:

Carbon Dosage = $(461/100.1) \times 0.34 = 50 \text{ lb/1000 gal}$; Carbon Cost = $50 \times \$0.75 = \$37.50/1000 \text{ gal}$

For Alum and GAC:

Alum = $300 \text{ mg/L} = 2.51 \text{ lb/1000 gal}$; Sulfuric Acid = $2.1 \text{ ml/L} = 0.0016 \text{ ton/1000 gal}$ Chemical Cost: $2.5 \times \$0.055 + 0.016 \times 50 = \$0.94/1000 \text{ gal}$ Carbon Dosage: $(200.6/137.2) \times 0.34 = 21.31 \text{ lb/1000 gal}$ Carbon Cost: $21.31 \times \$0.75 = \$15.98/1000 \text{ gal}$ Sediment Disposal: Sediment vol. = 30 ml/L at 1.45% solids; Sediment Disposed at $\$20.00/\text{cubic yard} = \0.20

For Alum, Polymer and GAC:

Chemical Dosage per 1000 gal: Alum = $200 \text{ mg/L} = 1.67 \text{ lb}$; Polymer = $300 \text{ mg/L} = 2.5 \text{ lb}$; $\text{H}_2\text{SO}_4 = 2.1 \text{ ml/L} = 0.016 \text{ ton}$ Chemical Cost: $1.67 \times \$0.055 + 2.5 \times \$0.23 + 0.016 \times 50 = \$1.47/1000 \text{ gal}$ Carbon Cost: $(203.7/153.9) \times 0.34 = \$0.75 = \$11.98/1000 \text{ gal}$ Sediment Volume: 62 ml/L at 1.45% SolidsSediment Disposed at $\$20.00/\text{cubic yard} = \0.40

6.0 TREATMENT TRAIN ALTERNATIVES

Treatment train alternatives for the Fresh Kills Landfill leachate depend on the discharge limits that will be imposed by the NYSDEC. During the study, NYSDEC, on a preliminary basis, indicated that reduction of COD may be one requirement. As indicated in Table 2-18, there was also concern about organic and heavy metal contaminants.

The treated leachate may be discharged into Fresh Kills or the Arthur Kill. Both streams are classified as SD waters. A water quality criteria concern is the potential oxygen demand of the ammonia present in the leachate. Therefore nitrification technology may have to be incorporated into the treatment train.

The treatment trains recommended at this time involve removal of COD and TOC, nitrification of ammonia, and COD and TOC removal in conjunction with nitrification. The treatment trains are being developed in steps. First each process train will be developed for a design flow of 1.1 MGD of leachate. The leachate characteristics used were those from the pump station of the Veterans Avenue Leachate Collection System. These conditions represent the most conservative design. Second, the process trains will be combined to form facility treatment trains to address TOC and/or ammonia nitrification.

6.1 PROCESS TRAINS

Each process train is developed in this section. The costs presented include the items associated with the individual process. Site preparation costs or special foundation design, which may be required, for example, are not included.

6.1.1 Design of an SBR System

From the bench-scale experimental results, it was demonstrated that SBR is effective in nitrifying the Fresh Kills Landfill leachate. Based on the experimental results, a preliminary design was prepared:

Influent:

Maximum flow	=	2.2 MGD
Design flow	=	1.1 MGD
Minimum flow	=	0.5 MGD
NH ₃ -N	=	750 mg/L
	=	6,881 lb/day
BOD ₅	=	100 mg/L
	=	826 lb/day
COD	=	1,800 mg/L
TOC	=	530 mg/L
Alkalinity	=	5,600 mg/L as CaCO ₃
Color	=	3,000 units
pH	=	8

Effluent:

NH ₃ -N	=	1 - 10 mg/L
BOD ₅	=	10 mg/L
pH	=	6 - 8

Note: TOC and COD removal in SBRs are negligible, usually ranging from 10 to 20 percent.

Design Criteria

Flow	=	1.1 MGD
HRT	=	23.8 hr
F/M	=	0.023 lb BOD ₅ /lb MLSS/day
F/M	=	0.168 lb NH ₃ -N/lb MLSS/day

Theoretical oxygen demand:

lb O ₂ /lb BOD ₅ removed	=	1.25
lb O ₂ /lb NH ₃ -N removed	=	4.6
Minimum DO residual	=	2 mg/L

Note: To facilitate nitrification and subsequent clarification in a full-scale operation, an HRT of 23.8 hours is used instead of the 19.2 hours demonstrated in the bench-scale operation.

SBR Tank Design

Type of tank	=	circular
Number of tanks	=	2
Total volume	=	1.09 MG (for two tanks)
Maximum SWD	=	22 ft
Minimum SWD	=	14 ft
Free board	=	3 ft
Total height	=	25 ft
Diameter	=	65 ft

Note: SWD is the side water depth in the tank.

Oxygen Requirement

Actual oxygen required (AOR)	=	32,640 lb/day
(based on BOD and ammonia removal)		
Standard oxygen required (SOR)	=	59,622 lbs/day
(at 20°C, 1 atm, alpha=0.8, beta=0.95)		

Note: AOR is the amount of the oxygen required by the biological reaction and SOR is the amount of the oxygen required by the system to provide the required amount of AOR for the biomass.

Operation of SBR

Number of cycles per day per tank	=	3
Time for each cycle	=	8.0 hours
Fill time (aerated)	=	4.0 hours
React time	=	2.0 hours
Settle time	=	1.0 hours
Decant time	=	0.48 hours
Idle time (aerated)	=	0.52 hours
Total aeration time	=	6.52 hours/cycle
SOR for aeration design	=	1,656 lbs/hr

Note: To provide a well settled effluent, a three-cycle operation was recommended by the vendor rather than the two cycles used in the bench-scale experiments.

Aeration System Design per tank

SOR	=	1,656 lbs/hr
Transfer efficiency	=	24%
Air flow	=	6,667 SCFM
Aerators per tank	=	3
Jets per aerator	=	26
Air flow per jet	=	85 SCFM
Submergence	=	16.8 ft

Blower Calculation

Operating blower	=	1 per tank
Air flow per blower	=	6,667 CFM
Design ambient temperature	=	100°F
Blower efficiency	=	70%
Total blower BHp	=	344 per tank

Pump Design

Pumps per tank	=	1
Flow per pump	=	28,560 GPM
Total pump head	=	20 ft
Pump efficiency	=	79%
Bhp per pump	=	182.6

Note: The large flow per pump is due to its use for liquid as well as for air flow.

Decanter Design

Cycle per tank per day	=	3
Decant flow	=	6,364 GPM
Mechanism	=	Gravity flow

Sludge pump

Sludge production	=	1,706 lbs/day
(based on yield factor of 0.2 on NH ₃ -N removal and 0.4 on BOD ₅ removal)		
Total sludge flowrate	=	20,456 GPD
(Assume: 1% solids concentration)		
Sludge flowrate per tank	=	10,228 GPD
Sludge volume per cycle	=	3,049 gallons
Design sludge volume per cycle	=	3,100 gallons
Waste sludge flowrate	=	345 GPM
Pump head	=	15 ft
Efficiency	=	60%
Bhp per pump	=	2.2

Total Power Required

Avg. BHp for 24 hrs	=	790
	=	592 KW
	=	12.92 Kwh/1,000 gallons treated

Figure 6-1 shows the flow diagram of the proposed SBR system.

For the purpose of calculating preliminary costs, a potential vendor, JetTech, Inc., was contacted.

Preliminary capital and O&M costs for the SBR system to treat 1.1 MGD of leachate are estimated in Tables 6-1 and 6-2. Information from CECOS, Inc., an existing SBR system treating leachate was also used to estimate the O&M cost.

6.1.2 Design of the PACT System

Based on the bench-scale experimental results, a preliminary design and cost estimation for a PACT process was prepared with the cooperation of Zimpro Passavant, Inc. The preliminary design is presented below.

Influent leachate:

Maximum flow	=	2.2 MGD
Design flow	=	1.1 MGD
Minimum flow	=	0.5 MGD
NH ₃ -N	=	750 mg/L
BOD ₅	=	100 mg/L
COD	=	1800 mg/L
Color	=	3,000 units
TOC	=	530 mg/L

Figure 6-1. Flow Diagram of a Sequencing Batch-Reactor
Leachate Treatment System.

TABLE 6-1
CAPITAL COST FOR THE DESIGNED SBR SYSTEM

Item	US Dollars
Equipment (Two Covered Tanks)	1,020,000
Installation	1,000,000
Yard Piping	72,000
Control Building	300,000
Sludge Dewatering	100,000
Sub-Total	2,502,000
Engineering and Contingencies (at 40% of Sub-total)	1,000,000
Total	3,502,000

TABLE 6-2
OPERATING AND MAINTENANCE COST FOR THE SBR SYSTEM

Item	US Dollars/Year
Power @ \$0.15/KWH	800,000
Labor: 5 Operators @ \$40,000/year	200,000
Cake Disposal: \$20.00/cubic yard	31,000
Total	1,031,000

Effluent leachate:

NH ₃ -N	=	10 mg/L
BOD ₅	=	30 mg/L
COD	=	400 mg/L
TOC	=	150 mg/L
Color	=	200 units

Two preliminary designs and cost estimates were evaluated, one without a Wet Air Regeneration (WAR) system and the other with a WAR system. The costs of the two systems were estimated using either a filter press for sludge dewatering before disposal offsite, or a packaged WAR system to recover 94 percent of the powdered activated carbon and to oxidize the biomass and adsorbed organics. Table 6-3 summarizes the design of the two PACT systems.

The designed PACT system is a packaged plant with an overall diameter of 150 ft. The package plant contains an aeration tank, sludge storage/digester, and a clarifier.

The capital costs for the two PACT systems are shown in Table 6-4. The equipment cost for a package PACT system was provided by Zimpro Passavant, Inc. The additional costs of a control building, installation, and yard piping were estimated based on onsite needs to handle the leachate.

Table 6-5 presents the O&M costs in operating the PACT process. The vendor estimated that power usage represents the major cost in the operation of the PACT system for nitrification of the leachate. This was partly due to the assumption they made in calculating the

TABLE 6-3

PACT SYSTEM DESIGN

	PACT	PACT WITH WAR
Aeration Basin Volume	263,000 ft ³	265,000 ft ³
Make-up Carbon (lb/day)	4,100	350
Oxygen Required (lb/day)	42,800	43,200
Clarifier (Area/Diameter)	2,200 ft ³ /55 ft	2,200 ft ³ /55 ft
Sludge Thickening and Storage		
Digester Volume	30,000 ft ³	3,500 ft ³
Solids Wasted (lb/day)	7,600	600
Operating Power	55,000 KWH/day	57,300 KWH/day

TABLE 6-4**CAPITAL COST FOR THE DESIGNED PACT SYSTEMS**

Item	Cost (US Dollars)	
	PACT	PACT WITH WAR
Equipment	2,220,000	5,100,000
Installation	200,000	300,000
Yard Piping	22,000	51,000
Control Building	300,000	300,000
Sub-Total	2,722,000	5,751,000
Engineering and Contingencies (at 40% of Sub-total)	1,088,000	2,300,000
Total	3,810,800	8,051,400

TABLE 6-5**OPERATING AND MAINTENANCE COST FOR THE PACT SYSTEMS**

Item	US Dollars/Year	
	PACT	PACT WITH WAR
Power @ \$0.15/KWH	3,040,000	3,140,000
Labor: Operators @ \$40,000/year	280,000	320,000
Total	3,457,000	3,471,000

oxygen demand in terms of COD and not in terms of BOD. The vendor felt that this was a prudent assumption since the additional air will be needed anyway to sustain the powdered carbon in suspension.

As was noted previously, the PACT process was not considered for TOC removal.

6.1.3 Design of an RBC System

The preliminary design of the RBC system is based on the data collected during the bench-scale study. As noted in the previous section, the ammonia loading to be used is much higher than traditionally used in nitrification facilities. These loadings should be confirmed in pilot studies prior to design a full-scale facility. In this context full-scale discs could be used with variable rpm operation. It may be necessary to operate the RBCs at speeds higher than the usual 1.5 to 1.7 rpm. Higher rpms, of 2 to 2.5 may be necessary to increase the DO in the leachate, which appears to be limiting the efficiency of the nitrification process.

Based on information currently available the following criteria and design were developed.

Influent Leachate:

Design Flow	=	1.1 MGD
Maximum Flow	=	2.2 MGD
Ammonia - N	=	750 mg/L
SS	=	30 mg/L
ROD	=	100 mg/L

Alkalinity = 5600 mg/L
pH Range = 7.5 to 8.5

Effluent Leachate:

Ammonia - N = less than 10 mg/L
BOD₅ = 10 mg/L
pH = 6 to 8

The RBC treatment system would consist of the contactors followed by final settling tanks. Based on ammonia loading criteria, the minimum number of shafts is 24, each providing 175,000 sq ft of high-density media. The cells that contain the shafts are all made of concrete. Rotation of the shafts is set at 1.7 rpm, requiring three kilowatts per shaft. The effluent from the RBCs would flow into two 40-foot-diameter clarifiers. The sludge produced is estimated at 1,100 lb/day of dry solids.

The estimated capital and operation and maintenance costs are shown in Tables 6-6 and 6-7. It should be noted that the capital cost of an RBC system is relatively high. However, the operating costs are low. Of particular interest is the low power requirement, which is lower than any of the other biological nitrification processes.

6.1.4 Design of a Physical-Chemical System

The bench-scale studies indicated that a combination of chemical coagulation and carbon adsorption were needed to remove the TOC from the leachate. Each operation was designed using loading factors determined in the study. Where appropriate, information

TABLE 6-6
CAPITAL COST FOR THE DESIGNED RBC SYSTEM

Item	US Dollars
RBCs - 24 Shafts	2,065,000
2 Clarifiers @ \$260,000.00 each	520,000
Installation of Shafts	375,000
Yard Piping	100,000
Sub-Total	3,260,000
Engineering and Contigencies	1,200,000
Total	4,260,000

TABLE 6-7
OPERATING AND MAINTENANCE COST FOR THE RBC SYSTEM

Item	US Dollars/Year
Power @ \$0.15/KWH	115,000
Labor: 5 Operators @ \$40,000/year	200,000
Cake Disposal: \$20.00/cubic yard	31,000
Total	346,000

was obtained from vendors of chemicals and equipment.

6.1.4.1 Chemical Pretreatment

Influent:

Design flow	=	1.1 MGD
TOC	=	500 mg/L
pH	=	8
Color	=	3,000 units

Effluent:

TOC	=	300 mg/L (40 percent removed)
pH	=	6.0
Color	=	300 units (90 percent removed)

Chemical dosages:

H₂SO₄: H₂SO₄ dosage required to bring pH down from 8.0 to 6.0 was 2.1 ml 96 percent H₂SO₄/L leachate.

For 1.1 MGD leachate:

H₂SO₄: $2.1 \times 1.1 \times 10^6 \times 3.78 \times 10^{-3}$
= 8,731 L/day
= 2,307 gal/day
= 35,787 lb/day
= 17.9 tons/day
(specific gravity of H₂SO₄ = 1.86)

Alum & Polymer: Alum needed was 200 mg/L.
Cat-floc 8964 needed was 300 mg/L.

For 1.1 MGD leachate:

Alum: $200 \times 1.1 \times 8.34$
= 1,834 lb/day
= 334 lb/day

Polymer: $300 \times 1.1 \times 8.34$
= 2,752 lb/day
= 502 tons/yr

Sludge production: Sludge production was approximately 62 ml sludge/L leachate
(sludge solids = 1.4 percent)

For 1.1 MGD leachate:

Sludge production: $14000 \times 1.1 \times 8.34 \times 0.062$
= 7963 lb dry solids/day
= 1451 tons/yr

6.1.4.2 Carbon Adsorption

Influent:

TOC = 300 mg/L
pH = 6.0
Color = 300 units

Effluent required:

TOC = 50 mg/L
pH = 6.0
Color < 30 units

Carbon dosage: According to dynamic tests, at an empty bed contact time (EBCT) of 60 min., carbon adsorption capacity in the column in series is 118.6 mg TOC/g carbon as given in Section 5.6.2.1. For TOC = 300 mg/L and 85 percent removal in the adsorption system, carbon usage rate equals $(300 - 50) \times 8.34 / 118.6 = 18$ lb carbon/1,000 gal leachate.

For 1.1 MGD leachate:

carbon required: $18 \times 1,100$
= 19,800 lb/day
= 7,227,000 lb/yr

6.1.4.3 System Design for TOC Removal

The recommended physical-chemical treatment plant consists of coagulation, filtration, and carbon adsorption. Figure 6-2 illustrates a schematic flow diagram of the plant.

Figure 6-2. Schematic of a Physical-Chemical Leachate Treatment Facility.

Chemical Coagulation Units: Lamella Gravity Settler Thickener.

Lamella Gravity Settler/Thickener (LGST) is selected for the coagulation process. The LGST is a high-rate gravity settler, combined with a circular picket-fence sludge thickener/scrapper, all in one tank. The high-rate settler section uses the same counter-current flow principles and inclined-plate design that is currently used in Parkson's packaged Lamella Gravity Settlers. LGST has these benefits: (a) space requirements are reduced by 90 percent or more, resulting in lower installed costs; (b) underflow sludge concentration are up to five times higher; (c) significant cost reductions for dewatering equipment and conditioning chemicals when hydroxides are being settled out, savings can be up to 50 percent or higher compared to conventional gravity clarifiers.

Filtration Unit: Dynasand Filter. Dynasand Filter is selected to remove the remaining SS. The filter is a continuous backwash, upflow, deep-bed granular media filter. The filter can readily be used as a polishing filter following the LGST. It is designed as a gravity-feed system. The filtrate passes to the carbon adsorption columns. The backwash returns to the holding sump upstream of the LGST. Thus, the entire flash-mixing, flocculation, clarification and filtration process can be accomplished in an uninterrupted, minimum-operator-attention basis using only one feed pump.

Calgon Chemical Feed System. Chemical feed and storage equipment

recommendations were supplied by the Calgon Corporation. The flow of the leachate is continuously measured. A signal generated from the flowmeter controls the rate at which the chemicals are added.

Carbon Columns. Based on a flow of 1.1 MGD, a three train, three-stage system is recommended. The following loading rates and reactor sizes are based in part on the laboratory experiments and on recommendations by Calgon Carbon, Inc.

Flow rate per train	= 254 gpm
Total contact time per train	= 60 min.
Effective adsorption depth (MTZ) per absorber	= 9 ft.
Bulk density of the carbon	= 28 lb/cu ft

Absorber Size: A circular absorber is used with a 50 percent freeboard for bed expansion.

Diameter of each absorber	= 10 ft.
Sidewall height	= 1.5x9
	= 13.5 ft. (14 ft)
Carbon weight of absorber	= 20,000 lb per absorber

6.1.4.4 Preliminary Capital and O&M Cost Estimate

Preliminary capital and O&M costs for physical-chemical treatment are estimated in Table 6-8 and 6-9. The tables show that the major cost is associated with carbon adsorption. The cost of granular-activated carbon represents more than 80 percent of the annual operation and maintenance cost required to remove TOC. Carbon adsorption is expensive because of the quantities required, but removes refractory organic substance. The process could be implemented if adverse impacts associated with TOC and color on the

TABLE 6-8

CAPITAL COSTS FOR PHYSICAL-CHEMICAL TREATMENT

Item	US Dollars
Lamella Gravity Settler/Thickeners (2 Units @ \$188,500 each)*	377,000
DynaSand Filters (2 Units @ \$123,500 each)*	247,000
Carbon Columns (3 Trains @ \$400,000 each)	1,200,000
Dewatering	110,000
Chemical Feed System	48,000
Control Building	300,000
Sub-Total	2,282,000
Design and Contigencies (40% of Sub-Total)	912,400
Total	3,194,400

Including 30% delivery and start-up.

TABLE 6-9

OPERATION AND MAINTENANCE COST
FOR PHYSICAL-CHEMICAL TREATMENT

Item	Dosage	Cost	US Dollars per year
Liquid Alum	1834 lb/day	\$0.055/lb	36,500
Cat-Floc	2752 lb/day	\$0.23/lb	227,395
Sulfuric Acid	17.9 tons/day	\$50.00/ton	326,695
Activated Carbon	19,800 lb/day	\$0.75/lb	5,420,250
Labor	5 Operators	\$40,000 each/yr	200,000
Power	100 HP	\$0.15/KWH	98,024
Total			6,308,844

receiving waters are documented.

6.2 TREATMENT ALTERNATIVES

The process trains developed previously were combined to form different treatment alternatives for an onsite leachate facility. Lacking specific discharge limits, treatment alternatives were developed to remove organic contaminants, as measured by TOC, alone or in combination with ammonia nitrification. Table 6-10 shows five alternatives, their relative capital, operation and maintenance costs, and the levels of removal expected for TOC, ammonia, and color.

Alternative one is a combination of physical-chemical processes designed to remove TOC and color. Each process was evaluated in laboratory-scale studies using leachate from the Veterans Avenue Leachate Collection System pumping station. Based on the results of these studies, design criteria were developed for sizing a full-scale facility to handle 1.1 MGD of leachate.

The first step in leachate treatment is lowering the pH to a range of five to six using sulfuric acid. The acidified leachate is then chemically coagulated using alum and CAT-FLOC 8964 polymer in a flash-mixing reactor. The coagulated leachate flows into a flocculator followed by gravity settling to remove the settleable solids. The settled leachate is then filtered for complete removal

TABLE 6-10

SUMMARY OF ON-SITE TREATMENT ALTERNATIVES

Alternative	Capital Costs (\$)	O&M Costs (\$)	Energy Use (HP)	Percent Removal		
				TOC	NH ₃ -N*	Color
Chemical Coagulation + Filtration + Adsorption	3,193,400	6,468,484	100	90	0	>95
SBR + Chemical Coagulation + Adsorption	6,182,000	7,247,350	685	90	>95	>95
RBC + Chemical Coagulation + Adsorption	7,634,200	6,588,350	206	90	>95	>95
PACT + Adsorption	6,740,000	9,740,100	3200*	90	>95	>95
Lime Coagulation + Air Stripping + Adsorption	6,436,000	11,047,000	120	90	>95	>95

* Based on ammonia nitrification and COD removal

of suspended solids prior to removal of the remaining dissolved TOC on granular activated carbon (GAC) columns. The removals expected in alternative one are 90 percent for TOC and 95 percent for color. Ammonia removal will be negligible. Table 6-10 shows the capital cost of this alternative to be relatively low. The apparent high O&M cost is associated primarily with the cost of carbon.

Alternative two combines alternative one with additional process to nitrify the ammonia in the leachate. The process is rotating biological contactors. In RBCs nitrifying bacteria grow as a slime on the surface of rotating discs which are partially submerged in the leachate. As the slime comes into contact with the leachate, the nitrifying bacteria oxidize the ammonia into nitrate. The RBCs were sized in accordance with loading rates determined in the laboratory-scale studies.

In alternative two the leachate will first be treated in the RBCs to reduce the ammonia to less than 10 mg/L. The nitrification process will destroy most of the alkalinity present and thus reduce the amount of sulfuric acid needed to lower the pH prior to chemical coagulation. The nitrified leachate would then flow through the same physical-chemical processes described for alternative one. Table 6-10 shows a significant increase to the capital cost of alternative one. This increase reflects the costs of the RBC media. However, the O&M cost increase is relatively small due to the low energy consumption of RBCs.

Alternative three is similar to alternative two. The main difference is the use of sequencing batch reactors in lieu of RBCs. SBRs represent suspended growth systems where nitrifying organisms in the form of suspended flocs come in contact with the leachate and oxidize the ammonia. The nitrified leachate flows through the physical-chemical processes described for alternative one. Based on laboratory SBRs, full-scale reactors were designed to handle the leachate flow. Table 6-10 shows that the capital cost of SBRs is much lower than that of RBCs. However, the O&M costs are much higher. The increase cost is associated with the cost of power needed to aerate the leachate and satisfy the oxygen demand of nitrification.

Alternative four is designed to remove TOC, color, and ammonia. The first process incorporates biological nitrification with some TOC and color removal. This is done by adding powdered carbon to an activated sludge process. The process was evaluated in laboratory studies and found to be effective. The effluent is polished using granular activated carbon columns. The overall removal is expected to be 90 percent for TOC, and greater than 95 percent for both color and ammonia. Table 6-10 shows a capital cost almost midway between alternatives two and three. However, the O&M cost is much higher. This is due primarily to the high consumption of power that would be required to operate the PACT reactor.

Alternative five uses purely physical-chemical processes to remove TOC, color, and ammonia. Ammonia removal by air-stripping was not evaluated in the present study. However, the lime requirement to increase the pH to 11.5 and the volume of sludge production were measured in jar tests. Alternative five is the only one that achieves ammonia removal rather than nitrification. Ammonia stripping and recovery in sulfuric acid costs were based on operating data at a similar facility located at the Tahoe-Truckee Sanitation Agency Water Reclamation Plant, Truckee, California. TOC and color removal would be achieved in granular activated carbon columns as in the other alternatives. Table 6-10 shows a capital cost within the range of alternatives two through four. However, the O&M cost is highest among the alternatives evaluated. This increase in cost is associated primarily with the added cost of lime and the cost of disposing the resulting sludge. It has been assumed that the sludges in all alternatives will be dewatered and disposed of at the Fresh Kills Landfill.

The five alternatives developed address two concerns associated with disposal of the leachate. One concern is the oxygen demand that will be imposed by the BOD and high ammonia concentration. The second concern is the high concentration of refractory organics in the leachate and the strong tea-like color. In developing the costs for these five alternatives, a preliminary design of each was made. A summary of the calculations and a process flow diagram for each alternative are given in Appendix A.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The leachate from two Fresh Kills Landfill sections, 1/9 and 6/7, was sampled and analyzed for both conventional and priority pollutants. The analyses indicated that the organic contaminants present are biologically stable and their release would have a relatively small impact on the receiving waters. The BOD in most leachate samples was approximately 100 mg/L or less while the COD was greater than 1,400 mg/L in section 1/9 and 600 mg/L in section 6/7.

The ammonia concentration in the leachate was high and would thus have the greatest impact on the oxygen balance in the receiving waters. In section 1/9 ammonia tends to range from 700 to 900 mg/L while in section 6/7, 150 to 350 mg/L. The oxygen demand of ammonia is associated with its biological oxidation to nitrate. The leachate has a pH of seven to eight and an alkalinity concentration sufficient to support complete nitrification of the ammonia. Biological treatment to remove both BOD and ammonia to eliminate the oxygen demand of the leachate is possible and implementable.

The leachate from several samples in both landfill sections had a strong tea-like color. The samples over a period of two years showed a color intensity of 3,000 units at the Veterans Avenue Leachate Collection System. The color is associated primarily with the presence of the refractory organic compounds in the leachate.

These compounds behave like humic substances. They can be removed by coagulation with alum and or polymer at a pH of five to six.

Heavy metals analyses performed on leachate from both sections showed concentrations in the range of municipal wastewaters. The average concentration of all metals of concern are below the levels required for industrial discharges into the sewage collection system by the New York City Sewer Use Regulations. The two metals that showed high concentrations were iron, 13 and 35 mg/L, and lead, 0.135 and 1.45 mg/L, in sections 1/9 and 6/7, respectively.

Organic priority pollutant analyses of the leachate showed a few compounds present and at very low concentrations. The method of analyses for organic compounds groups them into two categories, purgeable and semivolatile organics. The leachate from section 6/7 was free from any volatile organics while leachate from section 1/9 showed the presence, in some samples, of vinyl chloride, benzene, toluene, ethylbenzene, xylene, carbon disulfide, 1,4-dichloroethene, and acetone. The four semivolatile organic compounds found in some of the leachate samples were 2-methylphenol, 2,4-dimethylphenol, naphthalene, and bis (2-ethylhexyl) phthalate. The presence of priority pollutants in the leachate apparently would not be a major concern in developing leachate management alternatives.

The leachate characteristics as previously presented indicate that

the primary concern on the receiving surface waters is the impact on the oxygen balance. Treatment offsite at an existing water pollution control plant was impossible due to the lack of available hydraulic capacity to handle the 1.1 MGD leachate flow estimated to be produced from sections 1/9 and 6/7. As a result, after evaluation of the leachate characteristics, New York State DEC issued preliminary discharge limits which would apply to an onsite treatment facility. Essentially, the limits required reduction of BOD, nitrification of ammonia and monitoring of a number of other contaminants present in the leachate. Based on discussions with the New York City DOS and the New York State ERDA, the following treatment alternatives were developed to address nitrification of ammonia and the removal of organic matter as measured by BOD, COD, and TOC.

Alternative 1. This alternative is designed to remove color and organic matter. The recommended process to be included are pH adjustment of the leachate to within the range of five to six followed by chemical coagulation using alum and a polymer. The coagulated solids will then be flocculated, settled, and filtered prior to final treatment granular activated carbon (GAC) columns. This treatment alternative can reduce TOC by 90 percent and color by more than 95 percent. However, alternative one will not reduce the ammonia concentration.

Alternative 2. Alternative two is designed to remove color,

organic matter as well as ammonia. It is recommended to remove ammonia first since nitrification requires alkalinity which is already present in the leachate. Nitrification will destroy alkalinity which will facilitate pH adjustment of the leachate needed for chemical coagulation. Alternative two is composed of rotating biological contactors followed by all the operations defined under alternative one.

Alternative 3. Alternative three is similar to alternative two. The difference is that in alternative three sequencing batch reactors are used to nitrify the leachate rather than RBCs.

Alternative 4. Removal of organic matter and nitrification can take place simultaneously in the same reactor. In alternative three, powdered activated carbon is added to activated sludge to effect nitrification of ammonia and partial removal of organic matter. Additional removal would take place in downstream GAC columns. The alternative can thus effect color and organic removal as well as ammonia nitrification.

Alternative 5. Alternative five represents a series of physical chemical processes designed to remove color, organic matter, and ammonia. The leachate is initially treated to raise the pH above 11.5. Air stripping removes the ammonia from the leachate and recaptures it in a much smaller volume of sulfuric acid as ammonium sulfate. Afterwards, GAC columns are used to remove the organic

matter and color.

All the treatment processes used to develop the five treatment alternatives have been evaluated in batch- and continuous-flow laboratory-scale studies. The only operation not evaluated was stripping. The results from the laboratory studies were the basis for developing process design criteria. In some cases, vendors of treatment processes were consulted prior to developing the treatment alternatives.

The selection of the treatment alternative for the Fresh Kills Landfill leachate depends on the discharge limits imposed by the New York State DEC. The treatability studies performed represent a spectrum of operations and treatment capabilities from which alternatives can be developed to address whatever discharge limits are imposed. However, it may be prudent to reevaluate some processes at a pilot-scale level before final implementation.

In addition to pilot studies, it was recommended to classify compounds other than those on the priority pollutant list. Testing the stability of refractory organics to assess whether hydrolytic reactions can increase the biodegradability of the organics in the leachate was also recommended. These later studies have been performed and are reported in Volume III (8).

REFERENCES

1. Wehran Engineering, Fresh Kills Hydrogeologic Investigation, Volume 1- Hydrologic Report, August 1983.
2. New York Department of Environmental Conservation, Division of Water, "Proposed Revisions of Water Quality Regulations for Surface Waters and Groundwaters", GNYCRR Parts 700-705, April 1990.
3. Parsons Brinkerhoff, Fresh Kills Water Quality Data Report, Appendix B, December 1985.
4. "Standard Methods for the Examination of Water and Wastewater". 16th Ed. Am. Public Health Assoc., Washington, D.C. (1985).
5. New York State Energy Research and Development Authority. "Fresh Kills Leachate Treatment and Minimization Study". Volume II: Modelling, Monitoring, and Evaluation of Leachate at the Fresh Kills Landfill.
6. "The Baltimore Inhibition Test", Patapsco Wastewater Treatment Plant, Private Communication, (1988).
7. Camp Dresser McKee, Inc., "Guidelines for Water Reuse" March 1980.
8. New York State Energy Research and Development Authority. "Fresh Kills Leachate Treatment and Minimization Study". Volume III: Biodegradability, Nitrification and Denitrification of the Leachate from the Fresh Kills Landfill.
9. Kiff, R.J., "The Ecology of Nitrification and Denitrification in Activated Sludge", Journal of Inst. of Water Pollution Control, Vol. 71, 475 (1972).
10. Harkness, N., "Bacteria in Sewage Treatment Process", Journal of Inst. for Sewage Purification, Vol 36, 640 (1966).
11. Zanoni, A.E., "Secondary Effluent Nitrification Kinetics", Journal Water Pollut. Control Fed. Vol 41, 640 (1969).
12. U.S. Environmental Protection Agency, "Process Design Manual For Nitrogen Control", Technology Transfer, Washington D.C. (October 1975).
13. Alleman, J.E.; Irvine, R.L. "Nitrification in the Sequencing Batch Biological Reactor", Journal Water Pollut. Control Fed. Vol 52, 2747 (1980).

14. O'Shaughnessy, J.C., "Fixed Film Nitrification Kinetics", Second Intern. Conf. on Fixed-Film Biol. Process, Arlington, Va., July 1984.
15. Ho, S.; Boyle, W.C. and R.K. Ham, "Chemical Treatment of Leachates from Sanitary Landfills", Journal Water Pollut. Control Fed., Vol 46, 1776 (1974).
16. Shasler, K.A., "Leachate Damage Assessment: Case Study of the Peoples Avenue Solid Waste Disposal Site in Aurora, Illinois", US EPA, 1976.
17. Johansen, O.J., "Treatment of Leachate from Sanitary Landfills", O-26/74 PRA 29, Norwegian. Institute of Water Research and Department of Civil Engineering, Univ. of Washington, Seattle, Washington, 1975.
18. Reynold, T.D., "Unit Operations and Processes in Environmental Engineering", PWS-KENT Publishing Company, 1977.
19. Chian, E.S.K. and F.B. Dewall, "Evaluation of Leachate Treatment", Vol II, Biological and Physical-Chemical Treatment Processes. US EPA, September 1977.
20. U.S. Environ. Protect. Agency, "Handbook: Remedial Action at Waste Disposal Sites", Office of Research and Development, EPA/625/6-85/006, October 1985.
21. Stuckey, D.C., et al., "Anaerobic Toxicity Evaluation by Batch and Semi-Continuous Assays", Journal Water Pollut. Control Fed., Vol 52, 720 (1980).
22. Montgomery, J.M., "Water Treatment Principles and Design", John Wiley & Sons, New York, 1985.
23. Edzwald, J.K. and J.D. Haff, "Polymer Coagulation of Humic Acids in Waters", Journal of Env. Eng. Div. ASCE, 103, EE6, 989 (1977).
24. Michael, C.L., et al., "Activated Carbon Adsorption of Humic Substances", Journal American Water Works association Vol 73, 442 (1981).
25. Cook, E.N. and E.G. Foree, "Aerobic Biostabilization of Sanitary Landfill Leachate", Journal Water Pollut. Control Fed., Vol 46, 380 (1974).
26. Pohland, F.G. and S.J. Kang, "Sanitary Landfill Stabilization with Leachate Recycle and Residual Treatment", Amer. Inst. of Chem. Engrs., Symposium Series No 45, 71, 308 (1975).

APPENDIX A

**Preliminary Design Calculations
for
Five Leachate Treatment Alternatives**

CHEMICAL COAGULATION - FILTRATION - ADSORPTION

1. Preliminary Design

Design Flow Rate = 1.1 million gallons per day (MGD)

Chemical coagulation in lamella gravity settler thickeners
(LGST): Model No. LGS-2480/55 (Two Units)
Height = 22 feet
Length = 20 feet
Width = 13 feet

Filtration
Sand Filter: Dynasand Filter: Model no.: DSF-100 (Two Units)
Diameter = 10 feet
Height = 15.5 feet

Activated Carbon Adsorption
Carbon Columns: Three trains each with three carbon columns
Flow Rate per train = 254 gpm/train
Hydraulic Retention Time = 60 mins per train
Column Diameter = 10 feet
Sidewall Height = 14 feet

2. Preliminary Costs

<u>Capital Cost</u>	<u>US\$</u>
LGST	377,000
Dynasand Filter	247,000
Carbon Column	1,200,000
Sludge Dewatering	110,000
Control Building	300,000
Chemical Feed System	48,000
Design and Contingencies	<u>911,400</u>
Total	3,193,400

<u>Operation and Maintenance Cost</u>	<u>US\$/Year</u>
Liquid Alum 1.7 lb/1000 gal	36,500
CAT-FLOC 8964 2.5 lb/1000 gal	277,400
Sulphuric Acid 32.5 lb/1000 gal	326,310
Carbon Dosage 18 lb/1000 gal	5,420,250
Cake Disposal @ \$20.00/cubic yard	110,000
Power(100 HP) @ \$0.15/KWH	98,024
Labor(5 Operators) @ \$40,000 each	<u>200,000</u>
Total	6,468,484

Figure A-1. Schematic of a Physical-Chemical Leachate Treatment Facility

RBC - CHEMICAL COAGULTION - ADSORPTION

1. Preliminary Design

Design Flow Rate = 1.1 million gallons per day (MGD)

Nitrification

RBC: Length = 200 feet
 Width = 58 feet
 Diameter = 5.3 feet

Chemical Coagulation

(LGST) Model no. LGS-2480/55 (Two Units)
 Height = 22 feet
 Length = 20 feet
 Width = 13 feet

Filtration

Sand Filter: Dynasand Filter: Model no.: DSF-100 (Two Units)
 Diameter = 10 feet
 Height = 15.5 feet

Activated Carbon Adsorption

Carbon Columns: Three trains with three carbon columns
 Flow Rate per train = 254 gpm/train
 Hydraulic Retention Time = 60 mins per train
 Column Diameter = 10 feet
 Sidewall Height = 14 feet

2. Preliminary Costs

Capital Cost

US\$

RBC	3,171,000
LGST	377,000
Dynasand Filter	247,000
Carbon Column	1,200,000
Sludge Dewatering	110,000
Control Building	300,000
Chemical Feed System	48,000
Design and Contingencies	<u>2,181,200</u>
Total	7,634,200

Operation and Maintenance Cost

US\$/Year

Liquid Alum	1.7 lb/1000 gal	36,500
CAT-FLOC 8964	2.5 lb/1000 gal	277,400
Sulphuric Acid	22.1 lb/1000 gal	222,200
Carbon Dosage	18 lb/1000 gal	5,420,250
Cake Disposal @ \$20.00/cubic yard		150,000
Power(206 HP) @ \$0.15/KWH		202,000
Labor(7 Operators) @ \$40,000 each		<u>280,000</u>
Total		6,588,350

Figure A-2. Flow Diagram for an RBC - Chemical Coagulation -
Filtration - Adsorption Treatment Facility

SBR - CHEMICAL COAGULATION - ADSORPTION

1. Preliminary Design

Design Flow Rate = 1.1 million gallons per day (MGD)

Nitrification

SBR: Number of Tanks = 2
 Total Volume = 1.09 gallons
 Diameter = 65 feet
 MLSS = 5,000 mg/L

Chemical Coagulation

(LGST) Model no.: LGS-2480/55 (Two Units)
 Height = 22 feet
 Length = 20 feet
 Width = 13 feet

Filtration

Sand Filter: Dynasand Filter: Model no.: DSF-100 (Two Units)
 Diameter = 10 feet
 Height = 15.5 feet

Activated Carbon Adsorption

Carbon Columns: Three train with three carbon columns
 Flow Rate per train = 254 gpm/train
 Hydraulic Retention Time = 60 mins per train
 Column Diameter = 10 feet
 Sidewall Height = 14 feet

2. Preliminary Costs

Capital Cost

	US\$
SBR	2,100,000
LGST	377,000
Dynasand Filter	247,000
Carbon Column	1,200,000
Sludge Dewatering	110,000
Control Building	300,000
Chemical Feed System	48,000
Design and Contingencies	<u>1,800,000</u>
Total	6,182,000

Operation and Maintenance Cost

	US\$/Year
Liquid Alum 1.7 lb/1000 gal	36,500
CAT-FLOC 8964 2.5 lb/1000 gal	277,400
Sulphuric Acid 22.1 lb/1000 gal	222,200
Carbon Dosage 18 lb/1000 gal	5,420,000
Cake Disposal @ \$20/cubic yard	110,000
Power @ \$0.15/KWH	901,000
Labor (7 Operators) @ \$40,000 each	<u>280,000</u>
Total	7,247,100

Figure A-3. Flow Diagram of a Sequencing Batch Reactor
Leachate Treatment System

PACT - ADSORPTION

1. Preliminary Design

Design Flow Rate = 1.1 million gallons per day (MGD)

Nitrification without WAR
Overall Diameter = 150 feet

Chemical Coagulation
(LGST) Model no. LGS-2480/55 Two Units)
 Height = 22 feet
 Length = 20 feet
 Width = 13 feet

Filtration
Sand Filter: Dynasand Filter: Model no.: DSF-100 (Two Units)
 Diameter = 10 feet
 Height = 15.5 feet

Activated Carbon Adsorption
Carbon Columns: Three trains with three carbon columns
 Flow Rate per train = 254 gpm/train
 Hydraulic Retention Time = 60 mins per train
 Column Diameter = 10 feet
 Sidewall Height = 14 feet

2. Preliminary Costs

<u>Capital Cost</u>	<u>US\$/Year</u>
PACT	2,422,000
LGST	377,000
Dynasand Filter	247,000
Carbon Column	1,200,000
Sludge Dewatering	220,000
Control Building	300,000
Chemical Feed System	48,000
Design and Contingencies	<u>1,926,000</u>
Total	6,740,000

<u>Operation and Maintenance Cost</u>	<u>US\$/Year</u>
Liquid Alum 1.7 lb/1000 gal	36,500
CAT-FLOC 8964 2.5 lb/1000 gal	277,400
Sulphuric Acid 22.1 lb/1000 gal	222,200
Carbon Dosage 18 lb/1000 gal	5,496,000
Cake Disposal @ \$20.00/cubic yard	250,000
Power @ \$0.15/KWH	3,138,000
Labor(8 Operators) @ \$40,000 each	<u>320,000</u>
Total	9,741,000

Figure A-4. Flow Diagram for a PACT System - Filtration
Adsorption Treatment Facility

LIME - AIR STRIPPING - ADSORPTION

1. Preliminary Design

Design Flow Rate = 1.1 million gallons per day (MGD)

Lime: pH Adjustment to 11.5
 (LGST) Model no. LGS-2480/55 (Two Units)
 Height = 22 feet
 Length = 20 feet
 Width = 13 feet

Air Stripping: 8 Towers 12 inches in diameter

Activated Carbon Adsorption

Carbon Columns: Three trains with three carbon columns
Flow Rate per train = 254 gpm/train
Hydraulic Retention Time = 60 mins per train
Column Diameter = 10 feet
Sidewall Height = 14 feet

2. Preliminary Costs

Capital Cost

US\$

Tanks and Settlers	800,000
Lime Feed System	400,000
Air Stripper	1,760,000
Carbon Column	1,200,000
Sludge Dewatering	110,000
Control Building	300,000
Chemical Feed System	48,000
Design and Contingencies	<u>1,828,000</u>
Total	6,436,00

Operation and Maintenance Cost

US\$/Year

Lime	67 lb/1000 gal	3,228,000
Carbon Dosage	18 lb/1000 gal	5,420,000
Cake Disposal		1,350,500
Power @ \$0.15/KWH		768,500
Labor (7 Operators) @ \$40,000 each		<u>280,000</u>
Total		11,047,000

**Figure A-6. Flow Diagram for a Chemical Coagulation -
Air stripping - Adsorption Treatment System**

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