Development of landfill liner requirements for the New York paper industry

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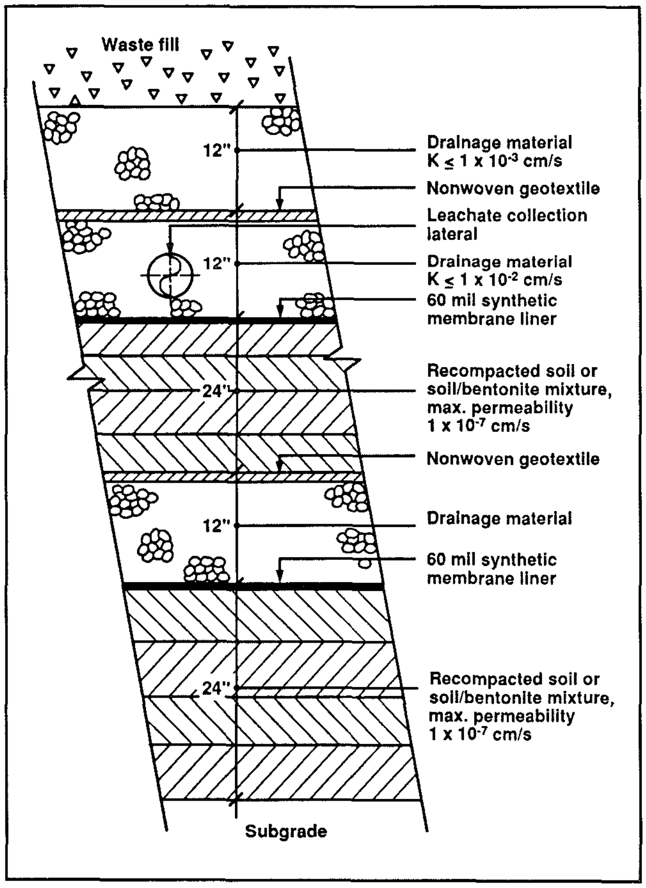
A two-part study provided justification for classifying paper industry solid wastes as a special category for landfills in New York State.

Title 6, Part 360 of the New York Code of Rules and Regulations (6NYCRR Part 360) was developed by the New York State Department of Environmental Conservation (NYSDEC) to regulate the handling and disposal of nonhazardous solid waste in New York State. These regulations govern all activities associated with the siting, design, permitting, construction, operation, closure, and postclosure of all solid-waste management facilities, including landfills. Section 360-2.13 of the regulations specifies that all landfill bases, where the slope is less than or equal to 25%, must be constructed with a double composite liner unless otherwise provided in Section 360-2.14. Such a liner is described in **Fig. 1**.

Section 360-2.14 states that the NYSDEC may impose additional or less stringent requirements on industrial/commercial landfills on a case-specific basis, based on the pollution potential of the waste. Such landfills are defined as monofills used solely for disposal of solid waste from a specific industrial or commercial operation. A consortium of 19 paper mills located in New York state, working through the National Council for Air and Stream Improvement, Inc. (NCASI), performed a study seeking this monofill status for paper industry wastes as a special solid-waste classification, with an attendant reduction in landfill liner design requirements.

This study was divided into two phases. Phase I consisted of a characterization of the solid wastes generated by the paper industry as well as ground water and leachate from existing paper industry landfill sites. Phase II involved analysis of the performance of an existing paper industry waste landfill with a single clay soil liner; laboratory testing of the compatibility of paper industry leachate on clay liner material; and an analysis of alternative liner efficiencies.

1. Double composite liner system



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Phase I: Solid-waste characterization

The 19 participating paper mills provided samples of solid and liquid waste derived from a wide spectrum of pulp and paper manufacturing processes. These samples

I. Paper industry data categories

Waste type	Number of samples
Solid sludges from integrated paper mills (groundwood and sulfite)	8
Solid sludges from nonintegrated paper mills	9
Solid sludges from secondary fiber operations	4
Miscellaneous liquid residues	6
Bark residues	4
Ash residues	5
Leachate	6
Ground water	7

II. Initial characterization of study soils

Source	Gravel, %	Sand, %	Silt, %	Clay, %	Classification[a]
No. 1	0.2	6.9	9.2	83.7	CH
No. 2	0.2	36.0	51.0	12.8	CL-ML
No. 3	5.9	51.1	34.6	8.4	SM

Source	Liquid limit, %	Plasticity index	Maximum dry density, pcf	Optimum moisture content, %	Coefficient of permeability,[b] cm/s
No. 1	72.0	43.9	100.9	20.9	1.5 E-9
No. 2	29.5	5.1	117.9	15.6	1.3 E-7
No. 3	15.0	N.P.	134.3	7.6	4.7 E-8

[a]Unified Soil Classification System
[b]Represents the hydraulic conductivity of a sample compacted to within 90% of the maximum dry density.

represented the type and concentrations of the constituents present in wastes placed in paper industry landfills. The study covered the major products and grades produced in New York state, representing over 54% of the estimated solid-waste stream produced by the industry.

In addition, several mills provided leachate and ground water samples from existing landfill sites. The majority of the mills are located in New York state; however, in order to obtain a better cross-section of solid- and liquid-waste data, mills located near the state border in Pennsylvania also participated. In addition, two Wisconsin paper mills supplied ground water and leachate samples.

A total of 49 samples were collected from 19 different mill locations. The analytical data from these samples were grouped according to the waste types presented in **Table I.** This list is based on the U.S. Environmental Protection Agency's (USEPA) categorization of paper industry processes in the effluent guidelines development document for this industrial category. While there is significant variation between the individual processes employed at different mills within the same category, this data grouping did provide a reasonable basis for comparison.

All samples were analyzed for the NYSDEC's Baseline Ground Water Quality Leachate Parameters (which include 25 water quality parameters as well as the USEPA's 126 Priority Pollutants) and the USEPA's Toxicity Characteristics Leaching Procedures (TCLP) parameters. Solid-waste samples were extracted using the TCLP and analyzed for the full list of parameters. The liquid samples (those containing less than 5% solid material) which were analyzed for the TCLP parameters were first filtered through a 0.6–0.8 μm glass fiber filter.

A quality control program was developed and reviewed by the NYSDEC for adequacy in defining the appropriate sample collection, handling, and analysis techniques to maintain the integrity of the database. This quality control program was distributed to each participating mill and was used as a guideline for the sampling program. The lab maintained standard operating procedures for sample collection and document control. These included procedures for sample kit preparation, field handling, sample tracking, transporting of samples, maintenance of custody, tracking the analysis of samples, and assembly of completed data. Appropriate sampling methods were followed at each mill site, ensuring the integrity of the sample from collection to analysis. Specifically:

1. All sampling equipment and instruments were properly cleaned and calibrated prior to sampling.
2. All sample containers were cleaned, labeled, and properly preserved while maintaining proper holding times.
3. All field data was properly recorded in a field notebook and a Chain-of-Custody Record accompanied each sample shipment.

In order to evaluate the significance of the results, the analytical data for the extracts of the sludge samples were compared to proposed TCLP limits and the sludges classified as either potentially hazardous or nonhazardous. The data were also compared to Class "GA" Ground Water Quality Standards.* The TCLP limits are set so that the National Interim Primary Drinking Water Standards will not be exceeded at downgradient drinking water wells. These limits assume that the toxicants detected by the TCLP test will be diluted or attenuated during ground water transport by a factor of 100. It should be noted that TCLP is an aggressive extraction procedure, substantially accelerating the leachability of contaminants present in the sludge. While it is not entirely appropriate to compare directly the analytical results from a sludge extract to ground water quality standards, such a comparison illustrates the potential parameters of interest in the leachate developed from landfilled paper industry waste.

If a limit, standard, or range did not currently exist for a particular organic compound, the data were compared

*New York State Code of Rules and Regulations, Title 6 6NYCRR, Chapter X, Part 703, Classes and Quality Standards for Ground Water. Class GA waters are fresh ground waters found in the saturated zone of unconsolidated deposits and consolidated rock or bedrock with best usage as a source of potable water supply.

III. Clay content of study soils

Soil	Clay fraction minerals in approximate order of abundance	Cation exchange capacity, meq Na per 100 g soil
No. 1	Illite > Chlorite	36.9
No. 2	Mica ≈ Chlorite	10.8
No. 3	Illite > Smectite > Chlorite	5.3

to the compound's detection limits to determine whether it was present in the sample.

In general, the data provided a good representation of the wastes generated from the New York pulp and paper industry. The number of parameters and the range of concentrations illustrated the uniformity of paper industry wastes. In addition, a comparison of sludge extract data and actual leachate data indicated that the TCLP extraction procedure provides a reasonable estimate of the parameters which could be expected in leachate generated from landfilled paper industry waste. In general, there were few parameters of interest in relation to ground water quality standards associated with landfilled New York paper industry solid waste.

Specific conclusions developed from the data include:

- The actual and projected (based on TCLP extraction data) leachate characteristics indicate that the solid waste should be considered nonhazardous.
- The number of parameters and range of concentrations in the actual and projected industry leachate were consistent among the mills' samples, illustrating the uniformity of paper industry wastes.
- Iron and manganese were the only inorganic compounds present in a majority of landfill leachate (actual or projected) in excess of ground water quality limits.
- Phenol and toluene were the only organic compounds present in a majority of actual paper industry landfill leachates and in a number of sludge extracts.

Analysis of the fate and transport of the parameters of interest indicated that three out of the four (i.e., iron, manganese, and phenol) are, in fact, not established as toxic in drinking water but have water quality standards based on aesthetic quality characteristics such as taste, odor, and color. The fourth compound, toluene, currently has no ground water quality standard. Additionally, the compounds identified are not considered mobile under the conditions anticipated in a properly constructed landfill dedicated to paper industry waste.

Phase II: Development of the design guidance manual

Phase II of this project was performed to determine, via field, laboratory, and desktop evaluations, the applicability of an alternative liner system design for monofill paper industry waste landfills. The four work elements of this phase included:

1. A laboratory evaluation of the impacts of actual paper industry leachate on the permeability of compacted soil and soil/bentonite mixtures
2. An evaluation of the effectiveness of existing single clay liner systems in paper industry landfills
3. A survey of environmental characteristics at existing and potential paper industry landfill sites
4. Development of recommendations for incorporation into 6NYCRR Part 360-2.14 which outline the alternative landfill liner designs proposed for New York state paper industry landfills.

The results of each work element in this phase of the study and how they helped support reduced landfill liner requirements are presented below.

Laboratory compatibility testing

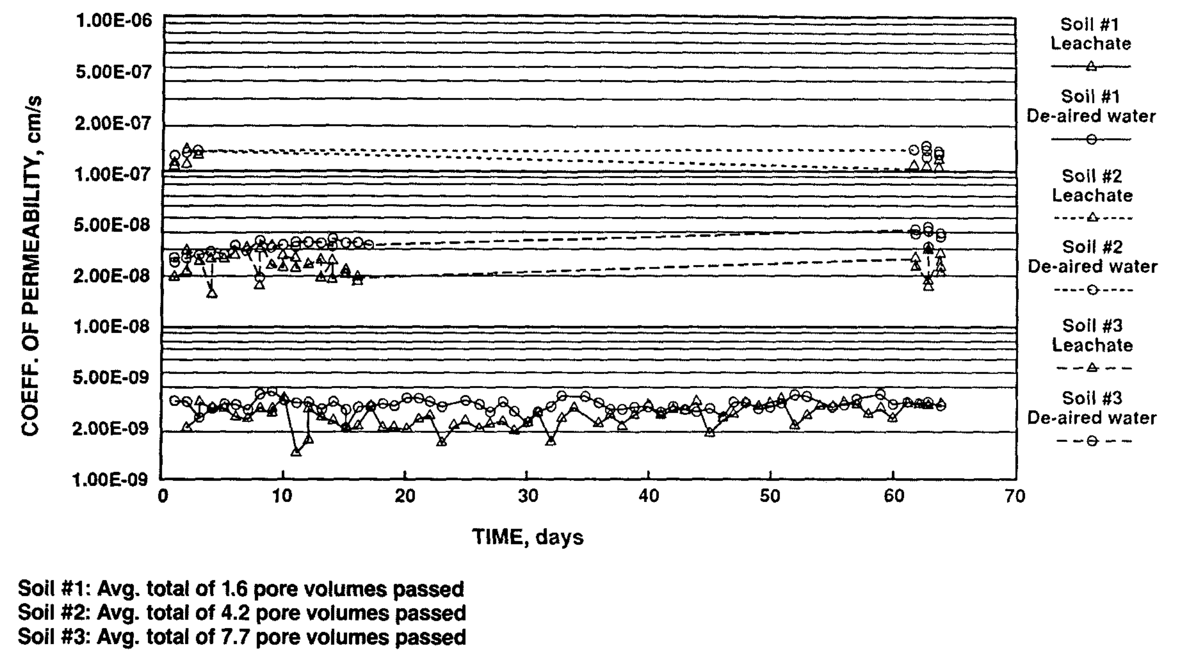
Standard laboratory permeability testing is a short-term analysis typically performed using de-aired water as the permeant. Research and actual field data at municipal solid-waste and hazardous-waste land disposal facilities have shown that the long-term performance of clay soils when subjected to mixed municipal solid-waste and hazardous-waste leachates may differ significantly from standard laboratory results. Therefore, this study was designed to observe the impact of actual paper industry landfill leachate on soils considered representative of those which could potentially be used as liner material for paper industry landfills. The leachate used for this study was selected from a paper industry monofill identified during the characterization phase of the study to have the highest concentrations of the parameters of interest to those mills studied.

An aliquot of the leachate to be used during the study was sent to an analytical laboratory for characterization prior to initiation of the study. The sample was analyzed for the NYSDEC's Baseline Ground Water Quality Parameters as well as the Toxicity Characteristics Leaching Procedures (TCLP) parameters. The leachate was determined to be of comparable quality to typical leachates characterized during Phase I. The only significant change noted in the leachate quality was in the presence of creosols, a homolog of phenol.

Three different soil materials were selected for laboratory evaluation. Two were locally available soils, and one was a mixture of on-site gravel, locally available silts, and commercially available sodium bentonite (30%, 70%, and 1% by weight, respectively). For ease of discussion, each material is referred to as a "soil."

Each soil was characterized using ASTM methods to determine if it would meet NYSDEC landfill liner material requirements as specified in 6NYCRR Part 360. The results, summarized in **Table II**, illustrate that while each of the soils meet the NYSDEC maximum permeability criterion of 1×10^{-7} cm/s in the laboratory, they have

2. New York state paper industries leachate-liner compatibility study



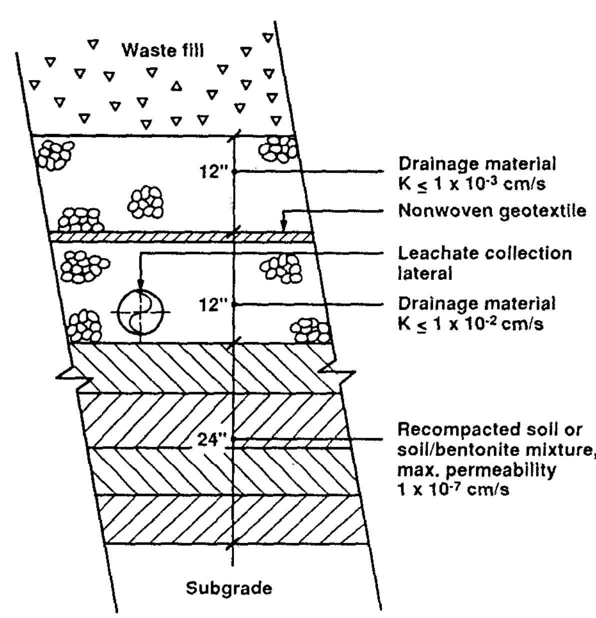
IV. Environmental matrix for landfill sites

Sitting and construction criteria	*Percent of landfill sites[a] that appear to meet criterion given existing condition*		
	Existing	*Potential*	*Total*
A) Not located over a principal/ primary aquifer	33.3%	100.0%[b]	63.6%
B) Five-foot separation from base of liner to seasonal high ground water table	83.3	40.0	72.7
C) Not within close proximity to NYSDEC classified surface water or state designated wetlands	66.7	60.0	63.6
D) Ten-foot separation from base of liner to bedrock	66.7	80.0	72.7
E) A through D above	16.6	0.0	16.6

[a]Based on the six industries that responded to the survey; information was submitted for six existing and five potential sites.

[b]One site may recharge a primary aquifer.

3. Basic liner system



widely varying physical characteristics which could have an impact on performance in the field.

Each soil was also characterized via X-ray diffraction, and its cation exchange capacity, shown in **Table III**, was determined to establish the nature of the clay minerals present. In general, most clays in central New York state are primarily illite and chlorite, as is the case with these samples. Therefore, one would expect the study soils to have moderate reactivity to chemicals and a moderate capacity for cation exchange.

A standard six-inch compaction permeameter mold was used to contain the soil samples. The permeameter was modified with a transparent acrylic barrel to allow observation of the sample. Viton gaskets and Teflon® tubing were used for compatibility with leachate. A stainless steel high-pressure permeameter was used to contain the permeant without loss of volatiles and in the absence of light.

Two permeameter setups were operated simultaneously during the study with duplicate molds for each study soil; hence six molds were connected to each permeameter. One permeameter utilized de-aired water as the permeant (as in standard laboratory hydraulic conductivity determinations) to constitute a "control test"; the other operated with the waste leachate as the permeant. Each sample was compacted in the soil chamber of the mold to greater than 90% of the modified Proctor maximum density on the wet side of the optimum moisture content.

Hydraulic conductivity readings were collected at a minimum of three times daily throughout the testing period. Testing was conducted over a two-month time period. Since it was necessary to place all three soils at the same test pressure, and the samples covered a wide range of permeabilities, each sample passed the permeant at different flow rates. Soil Nos. 2 and 3 passed three pore volumes of permeant in an average of three days and nine days, respectively. Soil No. 1 passed an average of 1.7 pore volumes over the two-month study period. Once three pore volumes had passed through the samples, flow to those individual molds was shut off.

The flow passed more quickly through Soil Nos. 2 and 3 (relative to No. 1), providing shorter soil-leachate contact time; however, the soils were maintained in contact with the leachate in the mold, even though flow (i.e., pressure) was discontinued. Prior to the end of the study, the molds containing Soil Nos. 2 and 3 were repressurized and an additional pore volume of permeant was passed in order to observe any impact of the leachate-soil contact on permeability over time.

A plot of the averaged hydraulic conductivity for the duplicate molds versus pore volumes of permeant passed for each soil is presented in **Fig. 2.** The results illustrate that the permeability of each of the study soils appears unaffected by the landfill leachate in comparison to the permeability as determined with de-aired water (i.e., the control samples). The permeabilities do show slight variations with time; however, this variability is mirrored in the control samples and is probably representative of the variability inherent in laboratory permeability testing.

The results of this study indicate that paper industry landfill leachate should not increase the permeability of a properly compacted soil landfill liner over time.

Historical single soil liner performance evaluation

Evaluation of the historical performance of lined landfills dedicated to paper industry wastes, in terms of their impact on ground water quality, is difficult due to a general lack of data. In fact, no historical data are available for lined, monofill paper industry landfills in New York state. Consequently, this performance evaluation of single soil liners is based on a limited ground water quality evaluation of two paper mill landfills located in Wisconsin, described here as Landfills A and B. Each landfill has been in operation for approximately 5–7 years. Each was constructed with a gradient control system (namely, a ground water withdrawal system) and 2-ft-thick soil liners compacted in 4- to 6-in. lifts (to within 95% of standard proctor density with the moisture content within 3% of optimum) to a specified maximum permeability of 1×10^{-7} cm/s. The clay liners are underneath a 1-ft-thick sand leachate collection layer. Each landfill receives primarily a 50:50 mixture of primary/secondary sludge dewatered on a belt filter press to approximately 20% solids, plus some bark and ash.

As part of this study, two rounds of ground water quality sampling and analysis were performed at both these sites approximately six months apart. All of the samples were analyzed for the NYSDEC's Baseline Ground Water Quality Parameters and the TCLP parameters. Due to the configuration of the gradient control systems for these landfills, all downgradient samples were collected in gradient control sumps, reflecting overall ground water quality beneath the sites.

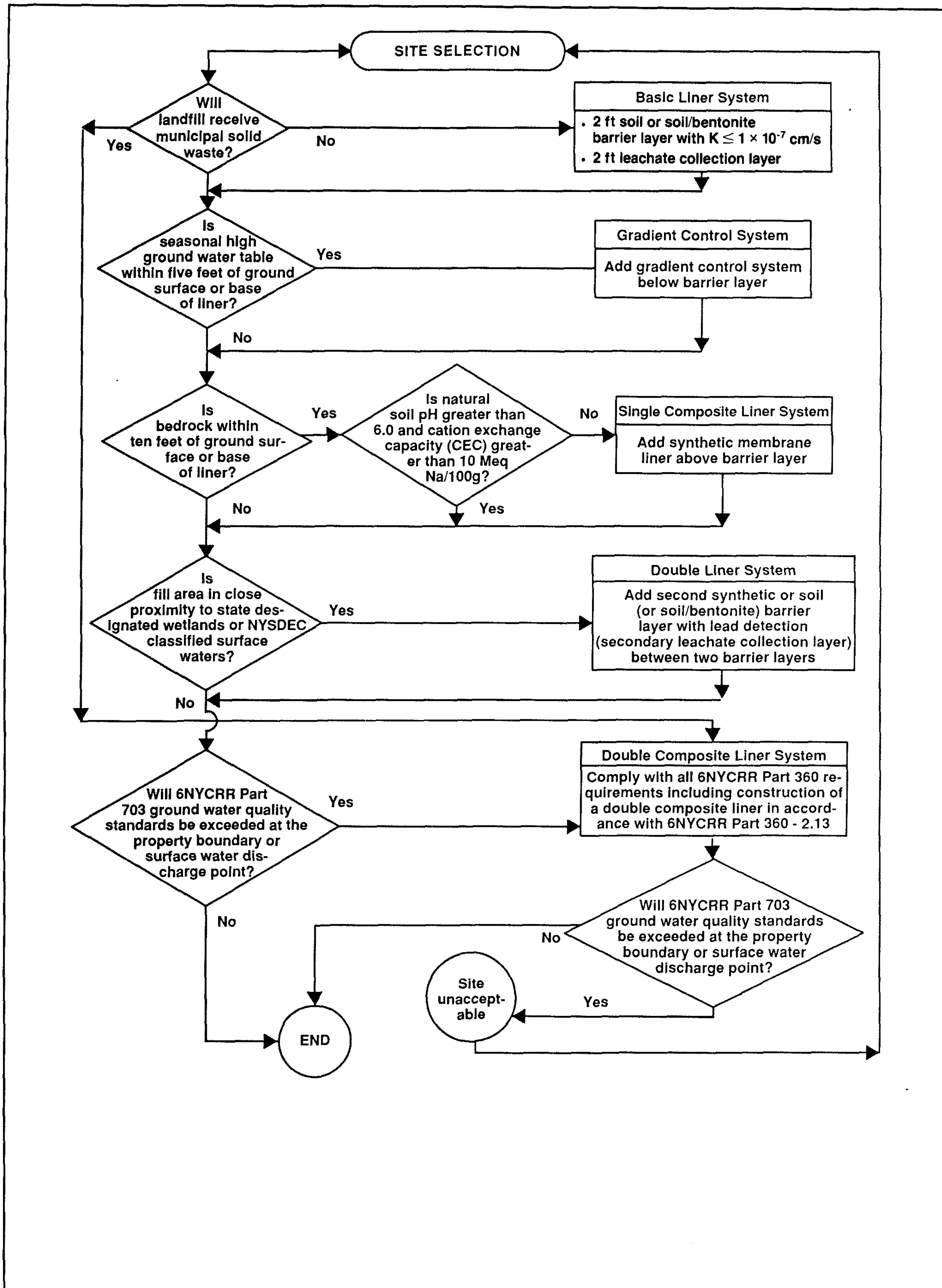
The data correlate well with the TCLP sludge extract and leachate characterization data collected in Phase I of this study. Only two organic compounds, toluene and phenol, were present in the leachate above their detection limits, and at concentrations similar to those found during the Phase I characterization. Soluble iron and manganese were the only metals which appeared elevated relative to Part 703 Ground Water Quality Standards and Guidelines.

The ground water quality data indicated that no organic compounds were detected. Soluble iron and manganese concentrations were moderately elevated relative to the standards in both upgradient and downgradient ground water samples with no apparent trends. All other parameters were either present below their corresponding standard/guideline or were not evaluated because 6NYCRR Part 703 Standards/Guidelines do not exist. This evaluation of existing ground water quality (with emphasis on the parameters of interest and parameters with 6NYCRR Part 703 Standards or Guidelines) indicated no significant impact from the landfill leachate. Consequently, the single soil liners have, to date, prevented the release of contaminants to the ground water.

Environmental matrix of New York paper industry landfill sites

The paper companies participating in this study were surveyed via questionnaire to establish a database of geologic, hydrogeologic, and hydrologic characteristics of their existing and potential landfill sites. In addition, a literature review was completed to supplement the information submitted with the completed questionnaires. This environmental setting characterization was designed to obtain information for use in development of a decision

4. Decision tree for selection of landfill liner configuration



V. Liner efficiency calculations

Liner configuration	Leachate capture efficiency, %
Basic liner system	99.77
Single composite liner system	99.999
Double liner system	
w/soil secondary liner	99.9995-99.9999
w/synthetic secondary liner	99.999
Double composite liner system	99.99999

VI. Summary of unit cost estimates (per acre)

Liner configuration	Construction without gradient control	Construction with gradient control
Basic liner system	$220,000	$265,000
Single composite liner system	290,000	335,000
Double liner system		
w/soil secondary liner	470,000	515,000
w/synthetic secondary liner	420,000	465,000
Double composite liner system	510,000	555,000

Cost estimates include construction and quality assurance monitoring of liner and leachate collection/detection systems within landfill boundary.

Cost estimates do not include the following:
- Design and permitting
- Site clearing and subgrade preparation
- Leachate storage or transfer facilities
- Closure costs
- Miscellaneous facilities (i.e., access road, maintenance and/or equipment storage facilities)

Costs are presented in 1989 dollars.

tree for selection of landfill liner configurations.

Questionnaires were sent to 11 of the paper companies participating in this study; six responded, representing each major type of product grade produced in the state. These six companies submitted information on a total of 11 existing and potential sites.

New York paper companies and their potential landfill sites are located in geologic/hydrogeologic settings which make siting, designing, and constructing a landfill in compliance with 6NYCRR Part 360-2.12 and 360-2.13 criteria extremely difficult. Four criteria which have been identified as critical to the siting/design of paper industry landfill sites are:

1. That the landfill not be located over a principal/primary aquifer (6NYCRR, Part 360-2.12(c)(1))
2. Five-foot separation distance from liner to seasonal high ground water table (6NYCRR, Part 360-2.13(d))
3. That the landfill not be in close proximity to surface waters (6NYCRR, Part 360-2.13(a)(2))
4. Ten-foot separation distance from base of liner to bedrock (6NYCRR, Part 360-2.13(e)).

Table IV, the Environmental Matrix, is a summary of the information collected as it relates to the number of existing and proposed sites which appear to meet the siting criteria listed above. The survey results indicate that the majority of the proposed sites, as described in response to the questionnaire (greater than 50%), appear to meet each of the individual siting criteria, while only 20% (one existing and one potential site) appear to meet all four criteria.

Further examination indicates that location over a principal/primary aquifer is not a critical site selection/design criterion, since all of the proposed sites were reported as not being over a principal/primary aquifer. Consequently, this criterion was not considered further when designing the selection process for landfill liner configurations. The three remaining criteria were factored into the design of the liner selection process.

Summary

Liner selection process

Based on the results of the Phase I and Phase II studies, paper industry solid wastes were shown to have a significantly reduced pollution potential from that of municipal solid wastes, and a single soil liner was shown to have the potential to mitigate the pollution associated with monofill paper industry landfills. Consequently, it was recommended to the NYSDEC that paper industry landfills be incorporated into 6NYCRR Part 360--2.13 as a new monofill category with the following basic liner system:

- A two-foot-thick soil or soil/bentonite barrier layer ($k \leq 1 \times 10^{-7}$ cm/s)
- A two-foot-thick leachate collection layer.

This liner system is illustrated in **Fig. 3.**

This basic liner system would apply to all paper industry landfill sites, provided that the site/design complies with all other Part 360 siting/design criteria. Liner system upgrades were recommended when the site/design does not comply with specific siting criteria.

In order to facilitate selection of an appropriate liner system and to provide a consistent approach to the liner system selection process, a decision tree approach was developed. The decision tree is presented as **Fig. 4.** The decision tree consists of a series of questions which are linked to upgrades of the basic liner system.

Liner efficiency calculations were performed for the three paper industry monofill liner systems proposed, as well as the 6NYCRR Part 360 double composite liner system. **Table V** indicates that all of the liners will provide greater than 99% leachate capture efficiency with appropriate construction quality assurance. As expected, Table V also indicates that the liner efficiency increases as the liner system is upgraded.

Construction cost estimates

Construction costs were estimated on a per-acre basis for the three paper industry monofill liner systems and the 6NYCRR Part 360 double composite liner system in order to illustrate the economic impact of increased landfill liner design requirements. These cost estimates, summarized in **Table VI**, assume that soil liner material is available within 10 miles of the site, that the construction is to be contracted, and that the volume of soil to be purchased and handled is 25% greater than the final compacted volume. The cost estimates are very sensitive to the unit price for the soil material. The unit price for delivery to the site was assumed to be US$ 20/cubic yard; however each US$ 1/cubic yard increase or decrease in the unit price will increase or decrease the cost per acre lift of soil liner by approximately US$ 3300. The costs per acre of each liner system both with and without a gradient control system are summarized. This cost summary illustrates that reducing liner requirements from a double composite to a single liner will produce an associated cost reduction of over 55% or approximately US$ 250,000 per acre of construction.

Conclusion

The results of the Phase I and II studies were presented to the NYSDEC as documentation of the reduced pollution potential of paper industry solid wastes as compared to municipal landfill leachate. The state has drafted a Technical Assistance Guidance Memorandum establishing paper industry solid wastes as a special monofill category of solid waste under 6NYCRR Part 360 with reduced (from double composite) liner design and long-term ground water monitoring requirements.□

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